Survey of heavy metals in the sediments of the Swartkops River Estuary, Port Elizabeth South Africa

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Abstract

Elevated levels of heavy metals in the sediment can be a good indication of man-induced pollution. Concentrations of chrome, lead, zinc, titanium, manganese, strontium, copper and tin were measured in the sediments taken along a section of the Swartkops River and its estuary. These results showed that the highest heavy metal concentrations in both the estuary and river were recorded at points where runoff from informal settlements and industry entered the system. Comparison of the results for the estuary with those obtained in a similar survey made about 20 years ago revealed some remarkable increases. This raises concern over the long-term health of the Swartkops River ecosystem.

Introduction

The Swartkops River flows through a highly urbanised and industrialised region of the Eastern Cape and forms an integral part of Port Elizabeth and the surrounding areas. It is a valuable recreational and ecological asset, but owing to the rapidly expanding urban areas, it is subject to the effects and influences of these developments.

The Swartkops River catchment contains almost the entire municipal area of Uitenhage and Kwanobuhle, Despatch and Ibhayi and also half of the Port Elizabeth municipal area. It is estimated that approximately one million people live and work presently in the Swartkops River catchment. The Swartkops catchment not only contains the greatest part of the metropolitan population, but it is also the area where the greatest diversity of urban users is found and where urban growth is most rapid. High-density, low-income housing is developing in the catchment with a concomitant increase in industry, and in the quality and quantity of stormwater runoff. These developments will also necessitate the building of further road and rail crossings over the river as well as developing more telecommunication links and power supply lines (Horenz, 1988).

The occurrence of elevated levels of trace metals especially in the sediments can be a good indication of man-induced pollution and high levels of heavy metals can often be attributed to anthropogenic influences, rather than natural enrichment of the sediment by geological weathering (Davies et al., 1991; Lord and Thompson, 1988). There can be significant temporal and spatial variability in water column concentrations of heavy metal contaminants, which leads to problems in obtaining representative samples. Sediments, on the other hand, integrate contaminants over time and are in constant flux with the overlying water column. The analysis of heavy metals in the sediments permits detection of pollutants that may be either absent or in low concentrations in the water column (Davies et al., 1991), and their distribution in coastal sediments provides a record of the spatial and temporal history of pollution in a particular region or ecosystem. Heavy metal concentrations in the water column can be relatively low, but the concentrations in the sediment may be elevated. Low level discharges of a contaminant may meet the water quality criteria, but long-term partitioning to the sediments could result in the accumulation of high loads of pollutants. It has been estimated that about 90% of particulate matter carried by rivers settles in estuaries and coastal areas (Martin and Whitfield, 1983).

Once heavy metals are discharged into estuarine and coastal waters, they rapidly become associated with particulates and are incorporated in bottom sediments (Hanson et al., 1993). The accumulation of metals from the overlying water to the sediment is dependent on a number of external environmental factors such as pH, Eh, ionic strength, anthropogenic input, the type and concentration of organic and inorganic ligands and the available surface area for adsorption caused by the variation in grain size distribution (Davies et al., 1991). Diagenetic processes in the sediments can change and redistribute these contaminants between the solid and the dissolved phases, but most of the elemental contaminants are immobilised through sedimentation (Hanson et al., 1993).

The effect of heavy metal contaminants in the sediment may be either acute or chronic (cumulative) on benthic organisms (Griggs et al., 1977). The bioaccumulation of metals in various fish and shellfish organisms is well studied (Canli and Furness, 1993; Wolfe et al., 1996), whilst the bioavailability of trace metal concentrations is controlled by many chemical, physical and biological factors (Morse et al., 1993, Morse and Rowe, 1999). Gyedu-Ababio et al. (1999) have also demonstrated that the density and diversity of nematode communities in the Swartkops River estuary are influenced by the degree of heavy metal contamination in the sediments. Many of these metals serve no known biological function in the marine environment, but can act synergistically with other chemical species to increase toxicity. Increased heavy metal concentrations and organic carbon will tend to be associated with finer-grained sediments because of their high surface to volume ratios and absorption abilities.

The objectives of this paper are to illustrate the distribution and levels of sediment contamination by heavy metals in the Swartkops River and estuary, and to compare recent data with those collected during the early 1980s.

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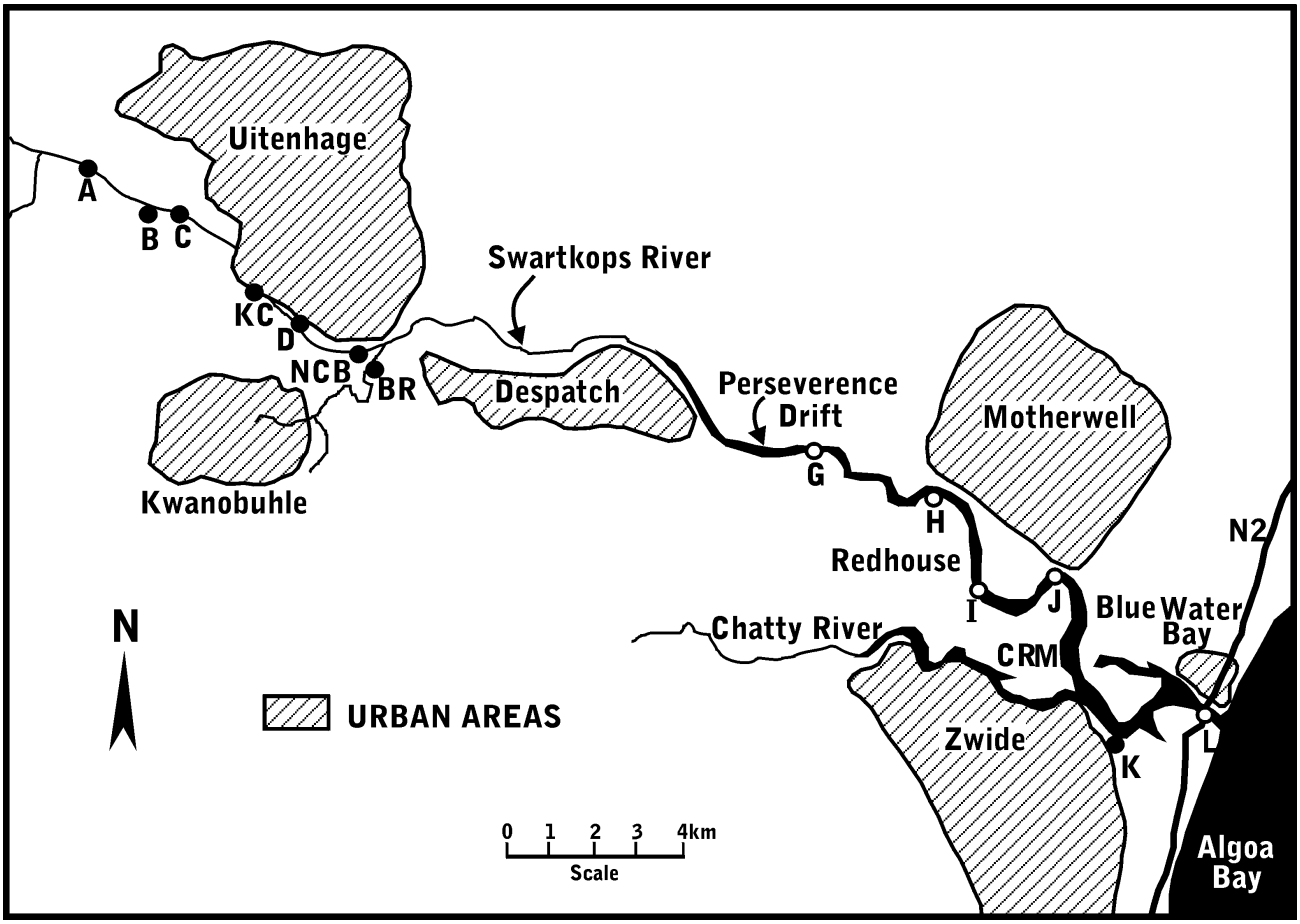

Figure 1
Map of the Swartkops River and estuary showing the major urban areas and sampling sites

Materials and methods

Sampling sites

Fourteen sampling sites in the Swartkops River ecosystem were selected. Seven of these sites were located in the estuarine region of the river and the other seven were located above the tidal head in the freshwater reaches of the river (Fig. 1).

Heavy metal and sediment particle size analysis

Samples for heavy metal and particle size analyses were collected in August 1995, December 1995 and March 1996. Sediment samples were collected with a 6.5 cm diameter corer to a depth of 10 cm and stored in clean plastic bottles in a cold room until the analysis was carried out.

The sediment was dried in petri-dishes at 80°C for 48 h and then ground into a powder. Approximately 2 g of each sample was placed in a beaker with 20 mℓ Aqua Regia (1:3 $cHNO_3$: cHCl) and allowed to stand overnight. The mixture was heated to near dryness and allowed to cool before 20 mℓ of a 5 M HNO_3 solution was added. The samples were allowed to stand overnight and were then filtered through Whatman No 41 filter paper. The filtrates were transferred to a 100 mℓ volumetric flask and made up to the mark with 0.5 M HNO_3.

The metal determinations of the solutions were performed on a Shimadzu sequential plasma spectrometer (ICPS - 1000II) using the calibration curve method. Concentrations of the following metals were determined using the above method: Mn, Ti, Sr, Cu, Cr, Pb, Sn and Zn.

The sediment particle analysis was done according to the method described by Parker (1983). The samples were oven-dried at 60°C for 48 h, and a 30 g portion of sediment from each site was washed and re-weighed after drying. The dry samples were put on the topmost of a nest of sieves and sieved by machine for 8 min. The fraction of each sieve was weighed, and the median grain size, sorting values, mud composition, and all other sand fractions were determined using the computer program SANDX (SANDSTA.BAJ).

Results and discussion

Results of an ANOVA showed that there was no significant difference ($p > 0.05$) between the three sampling months for each of the heavy metals sampled. The results of the heavy metal analysis are shown in Tables 1 and 2.

The Motherwell Canal (J) and the Chatty River Mouth (CRM) showed the highest concentrations of all the heavy metals with the exception of Sr. These two sites are located where stormwater runoff from informal settlements enters the estuary. The remaining estuarine sites had much lower metal concentrations.

The highest concentration for each metal was recorded in the Kat Canal (KC), which was 2 to 4 times higher than at any of the other non-estuarine sites. The highest concentration of Cu was

TABLE 1
Mean heavy metal concentrations (µg/g) in the sediment of the Swartkops estuary
(Estuarine sampling site locations are shown in Fig. 1)

Sites	Heavy metal concentrations (µg/g)							
	Cr	Pb	Zn	Ti	Mn	Sr	Cu	Sn
Settlers Bridge (L)	7.8	9.6	7.0	58.7	33.4	615.2	1.0	591.3
Motherwell Canal (J)	34.7	34.5	69.6	116.4	158.3	104.5	10.3	6891.7
Swartkops Yacht Club (K)	19.8	90.7	27.9	136.7	51.4	359.6	7.8	1 361.8
Chatty River Mouth (CRM)	38.8	30.2	42.3	144.6	150.0	63.5	6.1	4 284.6
Redhouse Yacht Club (I)	12.7	19.6	22.6	114.8	63.0	25.0	5.0	1 307.3
Bar-None (H)	8.0	10.4	9.7	86.4	51.8	9.4	2.5	932.0
Perseverance Drift (G)	20.0	35.6	72.2	37.7	296.1	39.5	15.2	3 044.8
Mean	20.3	32.9	35.9	99.3	114.9	173.8	6.8	2 630.5
(SE_x)	(4.7)	(10.5)	(10.1)	(15.1)	(35.6)	(86.4)	(1.8)	(865.6)

TABLE 2
Mean heavy metal concentrations(µg/g) in the sediment of the fresh water reaches of the Swartkops River
(Freshwater sampling sites are shown in Fig. 1)

Sites	Heavy metal concentrations (µg/g)							
	Cr	Pb	Zn	Ti	Mn	Sr	Cu	Sn
Nic Claasen Bridge (NCB)	8.7	4.1	12.4	9	78.7	30.1	5.1	615.8
Brak River (BR)	11	13.3	21.5	50	134.4	9.6	5.1	1 196.9
Kat Canal (KC)	20.1	62	173.9	100.4	252.6	134.9	16.8	4 210.9
Niven Bridge (D)	10.3	27.9	44.2	22.6	61.6	13.3	8.1	1 021.3
Bullmer Drift (A)	5.6	25.2	9	21.9	36.8	8	4.3	859.6
Gubb & Inggs Ponds (B)	7.9	23.8	19.8	26.6	184.3	41.4	21.1	1 091.9
Gubb & Inggs Factory (C)	16.4	16.9	34.3	42.9	87.7	18.7	6.1	2 108.7
Mean	11.9	24.7	45.0	39.1	119.4	36.6	9.5	1 586.4
(SE_x)	(1.9)	(6.9)	(21.9)	(11.5)	(28.9)	(17)	(2.5)	(471.7)

measured at the Gubb and Inggs Ponds (B) (see Table 1). Although these two sites are not part of the river system, they are considered to be important sources of freshwater contamination during periods of increased rainfall and runoff. The Kat Canal (KC) receives runoff from an informal township as well as industry in the Uitenhage area, while the Gubb and Inggs Ponds Site (B), is located next to the evaporation ponds of a tannery plant. High loads of Pb have been found to enter False Bay from stormwater runoff from low-income, high-density settlements in the Western Cape (MacKay, 1994).

The role of organic matter and sediment grain size in relation to the accumulation of heavy metal to the sediment has often been emphasised (Davies et al., 1991). Increases in heavy metal concentrations tend to be associated with finer grained sediments and this can be seen in that the higher heavy metal concentrations in the estuary are found at the sites where finer sediments occur, namely the Motherwell Canal (J) and the Chatty River Mouth (CRM). Both these sites are located at point-source discharges of the Motherwell Canal and the Chatty River, both of which drain urban areas.

The heavy metal concentrations in the freshwater reaches are generally lower than in the estuary, with the exception of Zn and Cu, which have higher values in the freshwater reaches. These higher levels are possibly due to inputs from industry in the Uitenhage area.

Some 20 years ago Watling and Watling (1979) conducted a survey of heavy metal concentrations in the water column and in the sediments of the Swartkops Estuary. They selected 18 sites in the estuary, and some of these correspond to those sampled in this study, thus allowing for direct comparison between sites over the intervening time period. Sediment cores were taken and then divided at 20 mm intervals to access the vertical distribution of the heavy metals in the sediment. A mean value for the top 100 mm of each core was calculated and these results from the surveys of Watling and Watling (1979, 1982) are given in Table 3. Their results also show higher concentrations at their Sites 8, 10 and 11 (corresponding to Sites J, K and CRM of this study) where finer sediments occur.

Of great interest, however, is the dramatic increase in heavy metal concentrations in the sediments of the Swartkops Estuary since the measurements of Watling and Watling (1979). All the metals measured by Watling and Watling (1979) namely Cr, Pb,

TABLE 3
Mean heavy metal concentrations in the sediment (µg/g) at sampling sites of Watling & Watling (1979) in the Swartkops estuary (Their sampling sites are given in brackets). Site locations are shown in Fig. 1.

Sites	Heavy metal concentrations (µg/g)					
	Cr	Pb	Zn	Mn	Sr	Cu
L (14)	3.3	2.9	4.6	12	883	1.2
J (8)	25.6	12.4	30.2	57	15	6.3
K (11)	14.1	12	22.9	26	44	3.7
CRM (10)	8.2	10.6	12.8	19	648	3
I (16)	6.2	5.1	9	77	8	2.1
H (3)	7.5	5.6	10.7	46	5	2.5
Mean (SE_x)	10.8 (3.29)	8.10 (1.66)	15 (3.92)	39.5 (10.19)	333.17 (155.73)	**3.1** (0.72)

TABLE 4
Per cent change in heavy metal concentration in the sediment of the Swartkops Estuary (numbers in bold indicate a decrease) between the studies of Watling and Watling (1979) and the present study at corresponding sites. Site locations are shown in Fig. 1.

	Per cent change					
Sites	**Cr**	**Pb**	**Zn**	**Mn**	**Sr**	**Cu**
L	136.4	231	52.2	178.3	**30.3**	**16.7**
J	35.6	178.2	129.1	177.7	596.7	63.5
K	40.4	655.8	21.8	97.7	**18.3**	110.8
CRM	373.2	184.9	230.5	689.5	**90.2**	103.3
I	104.8	284.3	151.1	**18.2**	212.5	138.1
H	6.7	85.7	**9.4**	12.6	88	0
Mean (SE_x)	116.2 (55.02)	270 (81.69)	95.9 (36.85)	189.61 (105.37)	126.4 (103.67)	72.1 (22.49)

Zn, Mn, Sr, and Cu have increased substantially in recent years at most of the sites. Only at a few sites were decreases in concentrations observed: Zn at site H, Mn at site I, and Sr at Sites L, K, and CRM.

The percent change in concentration of metals between the studies of Watling and Watling (1979) and the present study at corresponding sites are shown in Table 4. The range of mean concentrations over the entire estuary of all the metals increased by between 6.7% (Cr at Site H) and 689% (Mn at site CRM). The increase in Cr can probably be ascribed to tannery wastes (Papathanassiou and Zenetos, 1993) discharged into the river, while the increase in the other metals discussed in Tables 1 and 3 is clearly related to inputs from industrial activities and urban developments in the catchment of the river and floodplain of the estuary. Table 4 shows that all metals increased throughout the estuary over the past 20 years ranging in percentage increases from 72% for Cu to about 190% for Mn. All metals measured during this study increased on average by more than 100%, with the exception of Zn and Cu. Unfortunately, no comparative data exist for the freshwater reaches of the Swartkops River.

The concentrations of heavy metals measured in the Swartkops River and estuary during this study are, by comparison, generally lower than those of other highly urbanised and industrialised estuaries as shown in Table 5. Long et al. (1995) proposed guideline concentrations for a range of heavy metals to assess their possible adverse effects on a wide variety of aquatic biota. They suggested two guideline values namely the ERL (effects range-low) and ERM (effects range-medium) which delineate three concentration ranges for a particular chemical. If a metal occurs in concentrations below the ERL value, effects on the biota would rarely be observed. At concentrations equal to the ERL but below the ERM, biota could occasionally be affected by the pollutant, whereas at concentrations equal to or above the ERM, effects would be expected to occur frequently. Mean concentration values for Cr, Cu, Pb, and Zn (given in Tables 1 and 2) occur in concentrations well below the ERL as given by Long et al. (1995). Only Cu concentrations at the Swartkops Yacht Club (Site K) and Pb at the Kat Canal (Site KC) exceed the ERL values according to Long et al. (1995). It would

TABLE 5
Mean concentrations and ranges of selected heavy metals in Galveston Bay Estuary, Texas, the Hudson-Raritan Estuary, New York, and the Swartkops Estuary, South Africa [concentrations in ppm][adapted from Morse et al., 1993; Wolfe et al., 1996]

Estuary	Metal	Average concentration	Range in concentration
Galveston Bay	Cr	37	4-102
Hudson-Raritan*	Cr	122	67-420
Swartkops**	Cr	20.3	SD=12.35
Galveston Bay	Cu	8	2-15
Hudson-Raritan*	Cu	142	112-520
Swartkops**	Cu	6.8	SD=4.83
Galveston Bay	Pb	25	12-46
Hudson-Raritan*	Pb	160	103-510
Swartkops**	Pb	33	SD=27.64
Galveston Bay	Zn	55	6-116
Hudson-Raritan*	Zn	299	217-1400
Swartkops**	Zn	36	SD=26.63
Galveston Bay	Mn	605	165-2365
Swartkops**	Mn	115	SD=94.25
Hudson-Raritan*	Ti	21.7	17.4-100
Swartkops**	Ti	99	SD=40.00

*Most contaminated sites
**n = 21

appear that despite the large increase in metal concentrations in the sediments of the Swartkops Estuary, they are still below the guideline concentrations where possible adverse effects on the benthic biota can be expected. In a wide variety of chemical compounds examined for potential biological contamination in the Hudson-Raritan estuary, Wolfe et al. (1996) suggested that heavy metals were generally not the cause of the observed toxicity, but rather polynuclear aromatic hydrocarbons.

The continuous increase in heavy metal contamination of estuaries and coastal waters is a cause for concern as these metals have the ability to bioaccumulate in the tissues of various biota, and may also affect the distribution and density of benthic organisms, as well as the composition and diversity of infaunal communities (Geydu-Ababio et al., 1999). The estuarine sediments and adjoining marshes serve as reservoirs for the heavy metals and their concentrations are controlled by a variety of physical and chemical factors. It is important to determine the source of these heavy metals and to manage their input into the Swartkops River ecosystem so that their concentrations in the sediment do not reach toxic levels. The heavy metal concentrations in estuarine and coastal sediments also need to be monitored on a more regular basis. It has been pointed out, however, by Papathanassiou and Zenetos (1993) that the effects of pollution on benthic communities can only be assessed if large data sets throughout time are available.

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