

Heavy Metal Abundances in the Kandy Lake—An Environmental Case Study from Sri Lanka

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ABSTRACT / The Kandy lake, situated in the heart of Sri Lanka's second largest city with a population of nearly 120,000, has been monitored to probe the extent of heavy metal pollution. Although the lake is a source of drinking water to the city, a large number of effluent canals drain into

the lake carrying a continuous flow of industrial and domestic waste matter. A total of 66 surface water samples were analyzed for their Fe^{2+} , total Fe, total V, SO_4^{2-} , Cd^{2+} , and Pb^{2+} contents. Pb and Cd were found in high concentrations averaging 150 $\mu\text{g/l}$ and 77 $\mu\text{g/l}$, respectively, and exhibit a marked positive correlation with each other ($r = +0.94$). Vehicular emissions and industrial waste matter contribute largely to the Pb and Cd contents of the lake, the anthropogenic influence outweighing the contributions made by geological materials. All field observations and laboratory experiments indicate a tendency of the Kandy Lake towards eutrophication.

Introduction

Studies concerning environmental pollution and heavy metal distribution in the aquatic systems are rare in Sri Lanka. However, work carried out by the Environmental Geochemistry Research Group of the Department of Geology, University of Peradeniya, has shown that pollution of aquatic systems in Sri Lanka by heavy metals is increasing rapidly. Rivers and lakes around Colombo, the capital city of Sri Lanka, do in fact contain heavy metal concentrations as high as those found in rivers in some industrialized areas of Europe (Dissanayake and others 1985, Weerasooriya and others 1984).

The lake under study (Fig. 1) is located in the heart of Kandy, the second largest city in Sri Lanka, best known for its natural beauty and tourist attraction. The lake itself is circumscribed by a highway with a heavy inflow of traffic from the suburbs. Moreover, building activities around the environs of the lake are intense and these add further pollutants to the lake. Being situated at a low elevation amidst hills, the lake acts as a sink for surface runoff and domestic and industrial waste matter carried by effluent canals. In a preliminary study, Dissanayake and others (1982) studied the NO_3^- , PO_4^{3-} , Cu^{2+} , F^- , and coliform levels of the lake water and identified several sources of pollution. In the second phase of the research program, Weerasooriya and others (1982) studied the environmental impact of the effluent canal which carries the spill water of the Kandy lake and which runs a distance of 8 km through a densely populated area.

In view of its critical location with respect to domestic dwellings, business centers, hospitals and

nursing homes, schools, and public conveniences, and also because of its use as an additional reservoir for the town water supply, Kandy lake provides an excellent case study of environmental pollution in a city in Sri Lanka. This study covers the third phase of the research program and deals with the abundances of some heavy metals and their modes of distribution in the lake water.

Materials and Methods

Figure 2 illustrates the sampling locations of the lake water. All samples were collected in 500-ml pre-cleaned polythene bottles, acidified with double distilled reagent grade conc. HCl to prevent any bacterial action and also to prevent metal adsorption on the walls of the container. All samples were collected during the dry season of May.

Chemical Analyses

All chemical analyses were carried out using the standard methods for the examination of water and wastewater as prescribed by the American Public Health Association (Rand and others 1976). The accuracy of all analyses was checked by interlaboratory comparisons. In general, reasonable accuracy was achieved, with a range of 5–25% error.

Lead and Cadmium

Standard solutions were prepared to cover the expected range of metal concentrations. One hundred ml of each filtered water sample along with 100 ml of deionized water as blank were brought to a pH of 2.20–2.80 by the addition of 1N HNO_3 . Each solution

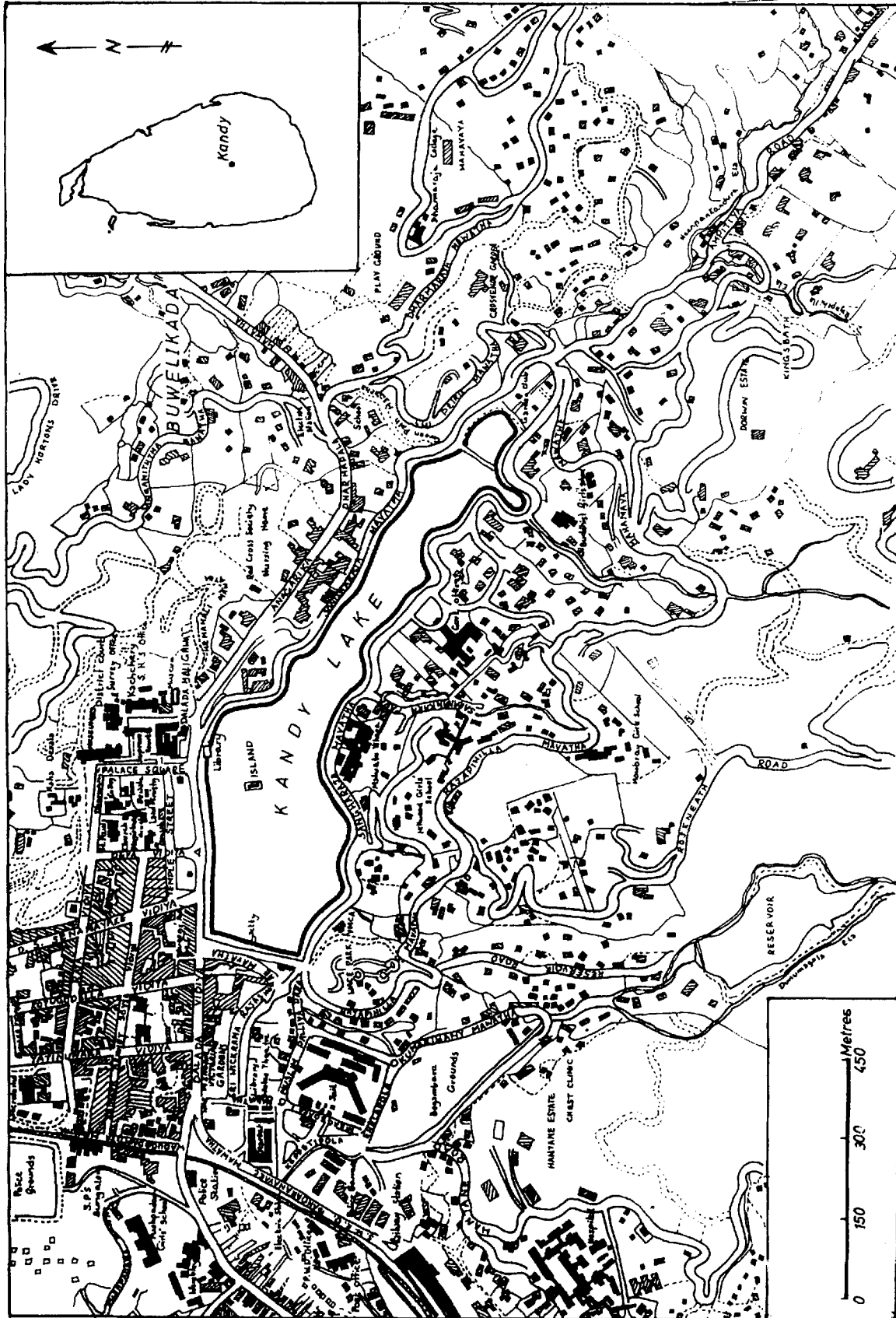


Figure 1. Map showing Kandy lake, Sri Lanka.

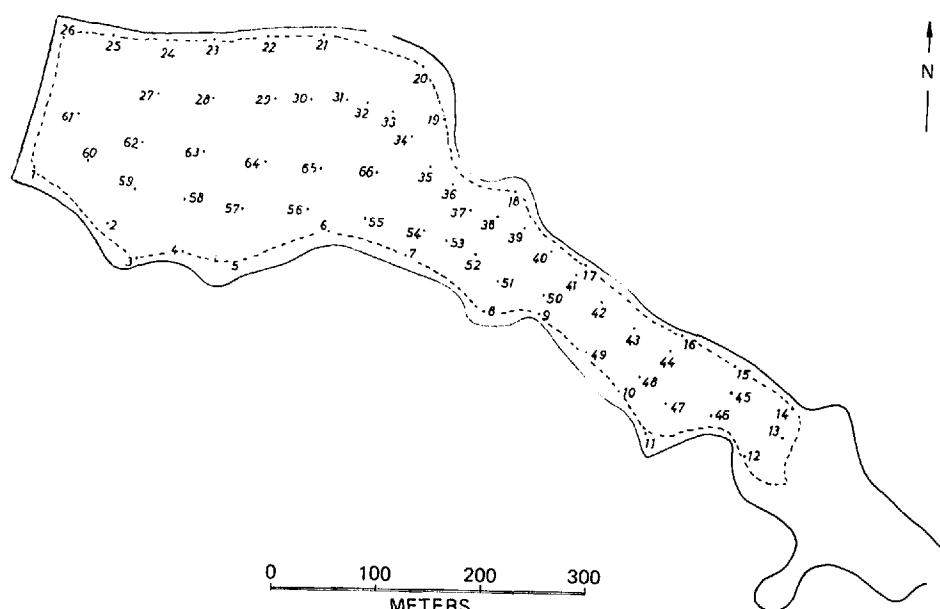


Figure 2. Map showing sampling locations.

was transferred to a 250-ml separating funnel and shaken with 1 ml of ammonium pyrrolidine dithiocarbamate (APDC). Ten ml of methyl iso-butyl ketone (MIBK) were then added and shaken vigorously. The organic layer was then separated and aspirated into the flame of a Varian-6 atomic absorption spectrophotometer with zero adjustment using the MIBK blank. Replicate analyses were carried out and a relative standard deviation of 20% for Cd and 23% for Pb were recorded.

Total Fe and Fe^{2+}

The total Fe determination was carried out by the direct aspiration of the filtered water samples into the flame of the atomic absorption spectrophotometer. A relative standard deviation of 16% was recorded. The Fe^{2+} determination was carried out spectrophotometrically using the 22' bipyridyl complex at $\lambda = 552 \text{ nm}$, the lower detection limit of the method being $10 \mu\text{g/l}$. A relative standard deviation of 10% was recorded.

Vanadium

The total vanadium content was measured by the catalytic oxidation method (Jarabin and Szarves 1961). The oxidation of gallic acid by acid persulphate is catalyzed by the presence of vanadium in the sample. Depending on the vanadium content, a red-yellow color is produced, which is proportional to the vanadium content in the samples, the intensity of the colored complex depending mainly on time and temperature.

Fourteen test tubes including ten lake water samples and four references were used for one set of analyses. Vanadium solutions containing 0.01, 2.5, 5, and 10 ml were analyzed. Five ml of lake water samples were added to the test tubes. The final volume of each tube was adjusted to 10 ml with deionized water and equilibrated at 25°C in a water bath for 10 min, and 1 ml of 0.66 M $\text{K}_2\text{S}_2\text{O}_8$ and 1:1 H_3PO_4 were then added, mixed, and the tubes placed in the water bath. After the addition of 1.96% gallic acid, the test tubes were well equilibrated at 25°C for exactly 1 h and the absorbance measured at 415 nm wavelength, using deionized water as a reference. In addition 0.00013 M $\text{Hg}(\text{NO}_3)_2$ was added to prevent interference by excess halogens in the samples. A relative standard deviation of 15% was recorded.

Sulphate

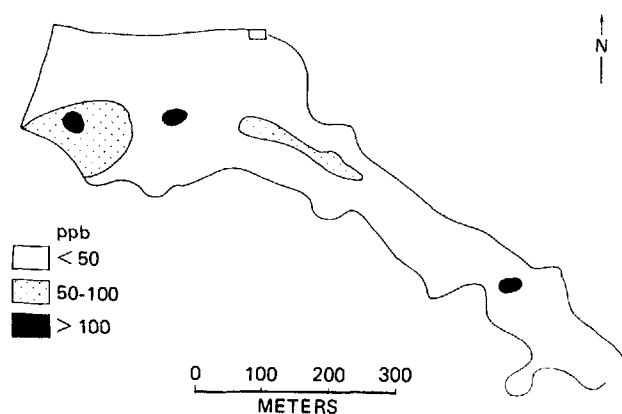
The sulphate contents of the samples were measured using the turbidimetric method on the unacidified filtered water samples (Rand and others 1976). The SO_4^{2-} ion is precipitated in HCl medium, with barium chloride to form BaSO_4 , crystals of uniform size. Ten ml, 5 ml, 2.5 ml, and 200 ppm Na_2SO_4 solution and 50 ml of each sample were added to separate 100 ml plastic beakers. In addition, 2.5 ml of a conditioning reagent (5 ml glycerol + 30 ml conc. HCl + 300 ml distilled water + 100 ml 95% $\text{C}_2\text{H}_5\text{OH}$ + 75 g NaCl) and approximately 0.5 g of BaCl_2 crystals were added to each sample and stirred for 60 sec. The ab-

Table 1. The total iron, Fe²⁺, lead, cadmium, vanadium, and SO₄²⁻ contents in the surface water samples of the Kandy lake. See Figure 2 for the locations of samples.

Loc.	Total Fe ppm	Fe ²⁺ ppm	Cd ppm	Pb ppm	V ppm	SO ₄ ²⁻ ppm
1	0.32	0.06	0.11	0.24	18.0	5.5
2	0.10	0.05	0.11	0.21	19.1	6.5
3	0.11	0.09	0.08	0.15	11.0	—
4	0.08	0.05	0.13	0.27	24.4	5.8
5	0.27	0.18	0.16	0.33	16.8	6.3
6	0.12	<0.01	0.19	0.25	13.2	16.8
7	0.06	<0.01	0.16	0.31	21.4	16.6
8	0.04	0.03	0.16	0.30	9.0	23.6
9	0.03	<0.01	0.16	0.31	6.0	18.2
10	0.01	0.01	0.16	0.29	6.0	25.0
11	0.03	<0.01	0.16	0.34	11.8	23.0
12	0.06	0.01	0.11	0.31	6.2	28.0
13	0.12	0.11	0.11	0.30	12.0	26.0
14	0.07	0.02	0.18	0.28	8.8	19.2
15	0.22	<0.01	0.19	0.37	8.8	25.0
16	0.18	<0.01	0.19	0.16	12.0	17.0
17	0.35	<0.01	0.19	0.39	8.6	32.0
18	0.19	<0.01	0.19	0.38	7.2	21.0
19	0.15	<0.01	0.19	0.39	7.6	19.0
20	0.28	<0.01	0.19	0.36	9.2	9.0
21	0.12	<0.01	0.19	0.34	9.6	10.0
22	0.11	<0.01	0.19	0.36	9.2	20.0
23	0.25	<0.01	0.19	0.37	8.4	17.0
24	0.09	<0.01	0.19	0.38	8.0	19.0
25	0.16	<0.01	0.18	0.24	7.6	20.0
26	0.14	<0.01	0.16	0.33	7.8	21.0
27	0.10	0.03	0.02	0.09	15.6	19.0
28	0.20	0.06	0.02	0.08	16.0	7.0
29	0.08	<0.01	0.03	0.10	12.4	8.0
30	0.08	0.04	0.05	0.15	14.0	7.0
31	0.08	<0.01	—	0.12	8.0	7.0
32	0.09	0.01	0.01	0.03	19.2	11.0
33	0.08	0.01	0.01	0.03	12.8	10.0
34	0.06	<0.01	0.01	0.07	14.0	6.0
35	0.08	<0.01	0.03	0.08	17.6	5.0
36	0.30	0.08	0.02	0.04	15.8	5.0
37	0.05	0.01	0.02	0.02	16.8	6.0
38	0.16	0.11	0.01	0.03	14.0	5.0
39	0.14	0.02	0.01	0.03	14.8	5.0
40	0.22	0.11	0.01	0.07	14.4	5.0
41	0.34	0.01	0.02	0.03	20.2	6.0
42	0.28	0.02	—	0.08	24.0	6.0
43	0.19	0.01	0.01	0.12	39.2	7.0
44	0.13	0.02	0.01	0.13	36.0	6.0
45	0.23	<0.01	0.02	0.08	32.0	10.0
46	0.17	<0.01	0.10	0.22	18.4	12.0
47	0.09	0.01	0.01	0.04	14.0	6.0
48	0.09	<0.01	0.01	0.03	13.8	8.0
49	0.08	0.01	0.01	0.08	13.6	5.0
50	0.08	<0.01	0.01	0.03	17.2	3.0
51	0.09	<0.01	0.02	0.02	15.0	4.0
52	0.08	<0.01	0.04	0.04	14.8	5.0
53	0.08	0.01	0.01	0.10	16.0	4.0
54	0.09	<0.01	0.01	0.03	16.4	4.0
55	0.08	<0.01	0.01	0.03	17.2	3.0
56	0.31	0.01	0.01	0.01	18.8	5.0
57	0.04	<0.01	0.02	0.07	18.8	5.0

Table 1. Continued.

Loc.	Total Fe ppm	Fe ²⁺ ppm	Cd ppm	Pb ppm	V ppm	SO ₄ ²⁻ ppm
58	0.10	0.09	0.17	0.07	26.0	5.0
59	0.07	0.06	0.01	0.03	18.8	4.0
60	0.35	0.25	—	0.03	26.0	—
61	0.19	0.02	0.01	0.02	18.8	—
62	0.42	0.14	0.01	0.03	23.2	—
63	0.16	0.02	0.02	0.02	20.2	—
64	0.21	0.19	0.03	0.05	18.0	—
65	0.22	0.04	0.03	0.10	18.0	—
66	0.11	0.07	—	0.07	18.4	—

Figure 3. Distribution of Fe²⁺ ions in Kandy lake.

sorbance was measured at 30-sec intervals for 4 min at a wavelength of 420 nm using a Cecil spectrophotometer. Calibration curves were obtained by the use of known concentrations.

Results and Discussion

Table 1 shows the analytical data obtained for the water samples from Kandy Lake. The total Fe content of the lake water samples averages 130 µg/l, a value which does not exceed the WHO recommendation for drinking water. Work carried out by the authors in other parts of the Kandy district has also shown that the Fe content of the groundwater in the Kandy district is of this order and reflects the geology of the area, the Fe²⁺ and Fe³⁺ being mobilized in the aquatic environment as a result of weathering and leaching of ferromagnesian mineral rocks. Higher concentrations of Fe²⁺ (>50 µg/l) occurred in the offshore areas of the lake, and higher total Fe contents (>100 µg/l) were found closer to the onshore areas (Figs. 3 and 4), particularly close to the inlets of drains bringing effluent materials from the Kandy town into the lake. Figure 5 illustrates the Fe²⁺, total Fe, and

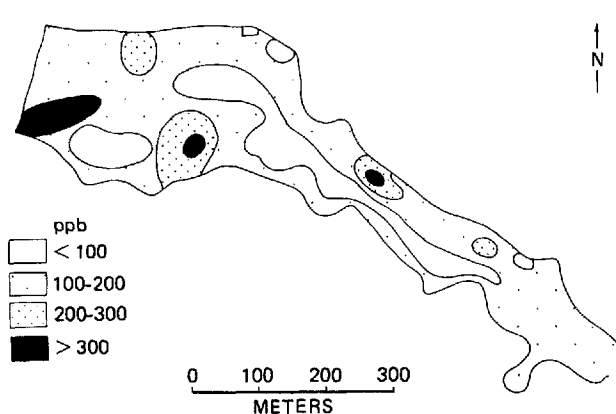


Figure 4. Distribution of total iron in Kandy lake.

other elemental and ionic distributions within the Kandy lake. It is of interest to note that the sulphates occur in markedly lesser concentrations in the offshore area of the lake, indicating relatively more reducing conditions prevailing in offshore regions.

Vanadium ranges in concentrations from 6 to 32 µg/l. As shown in Figure 6, the vanadium concentration increases towards the offshore regions. Among the ions that can possibly exist in natural water are H₄VO₄⁺, H₂VO₄⁻, HVO₄²⁺ and VO₄³⁻ ions. Turekian (1977) reported an average of 2 µg/l vanadium in natural fresh water. In plants and soils, the vanadium averages 22 and 100 µg/l, respectively (Hawkes and Webb 1962). The geochemical mobility of vanadium is probably very low and is limited by reaction and precipitation with organic matter. In the Kandy lake, apart from the contribution by geological materials, it is expected that vanadium-bearing pollutants also contribute to the total vanadium content of the lake. Goren (1966) coupled the activity of iron oxidizing bacteria such as *thiobacillus ferrooxidans* and *ferrobacillus* sp. with the oxidation of vanadium in acidic solutions. The Fe³⁺ ion acts as an oxidant for vanadium, and the ferrous ion so formed is oxidized by the other oxi-

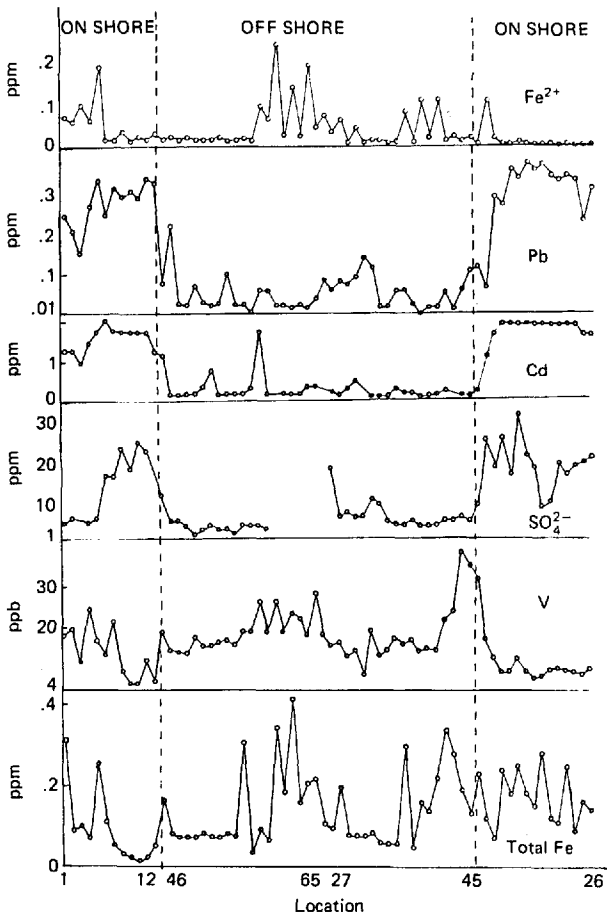


Figure 5. Variation of Fe^{2+} , lead, cadmium, SO_4^{2-} , vanadium, and total Fe in the onshore and offshore regions of Kandy lake.

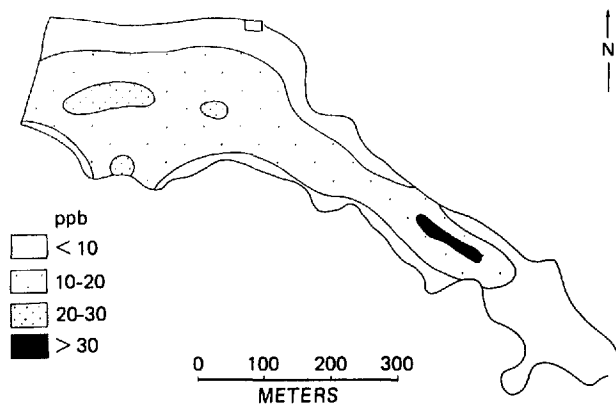


Figure 6. Distribution of total vanadium in Kandy lake.

dizing bacteria. Figure 7 illustrates the variation of Fe^{2+} with total V and SO_4^{2-} , respectively, for the onshore and offshore samples. In both cases, there is an apparent negative correlation between the ionic species.

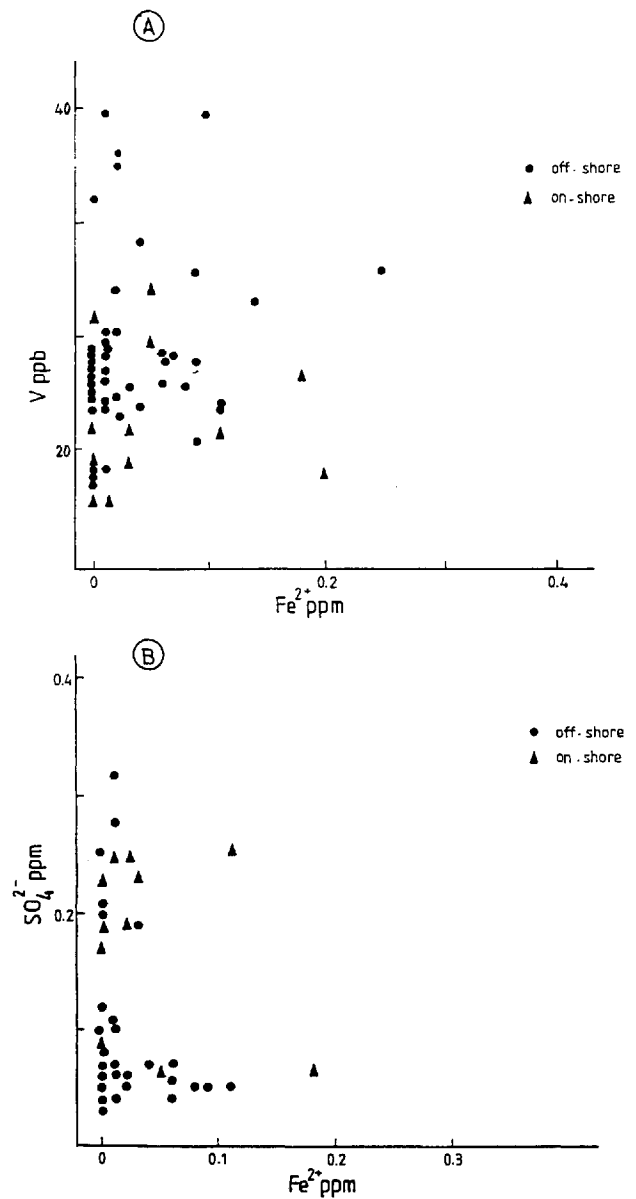


Figure 7. A: Variation of vanadium with Fe^{2+} in the onshore and offshore water samples. B: Variation of SO_4^{2-} with Fe^{2+} in the onshore and offshore water samples.

The average Pb and Cd contents of the lake water are $150 \mu\text{g/l}$ and $77 \mu\text{g/l}$, respectively. When compared to the WHO recommended values of $100 \mu\text{g/l}$ for Pb and $10 \mu\text{g/l}$ for Cd, these concentrations are high and are noteworthy in view of the fact that the lake is a supplementary source of water to the town of Kandy. In the case of Cd, the onshore locations had a higher concentration than the offshore locations. Likewise, Pb shows the highest concentrations in the onshore areas, particularly in the southern section of the lake. This similarity in the distribution of Pb and Cd in the

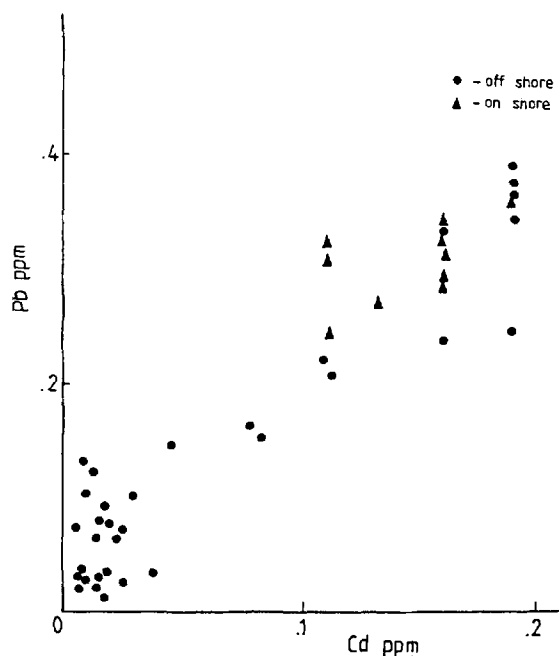


Figure 8. Variation of lead with cadmium in the onshore and offshore water samples.

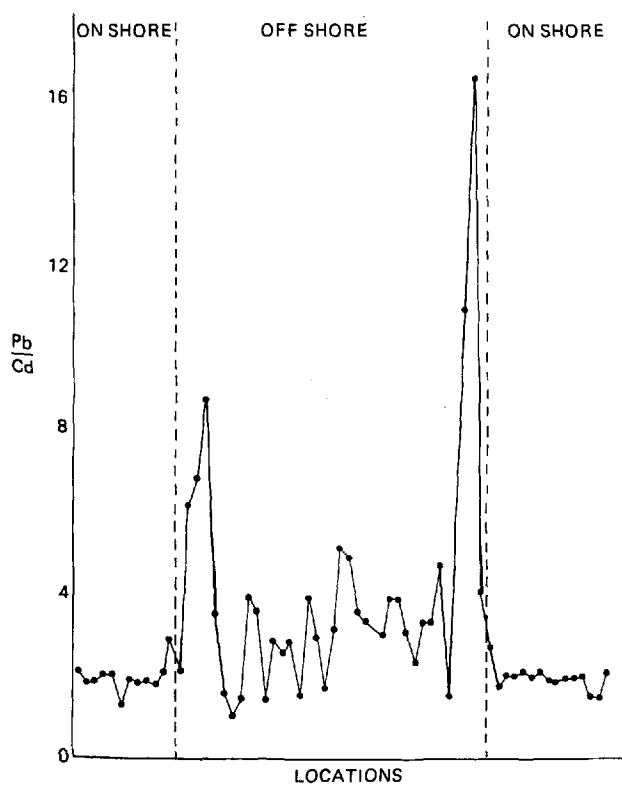


Figure 9. Variation of the lead/cadmium ratio in Kandy lake.

Kandy lake was clearly shown in Figure 4 and warrants further investigation.

The high concentrations of Pb and Cd in the

Table 2. Pearson correlation coefficient matrix for the elements and the ions studied.

	Total Fe	Cd	Pb	V	SO ₄ ²⁻
alFe	1.00	-0.15	+0.04	+0.22	-0.03
Cd		1.00	+0.94	+0.24	+0.61
Pb			1.00	-0.24	-0.05
V				1.00	-0.17
SO ₄ ²⁻					1.00

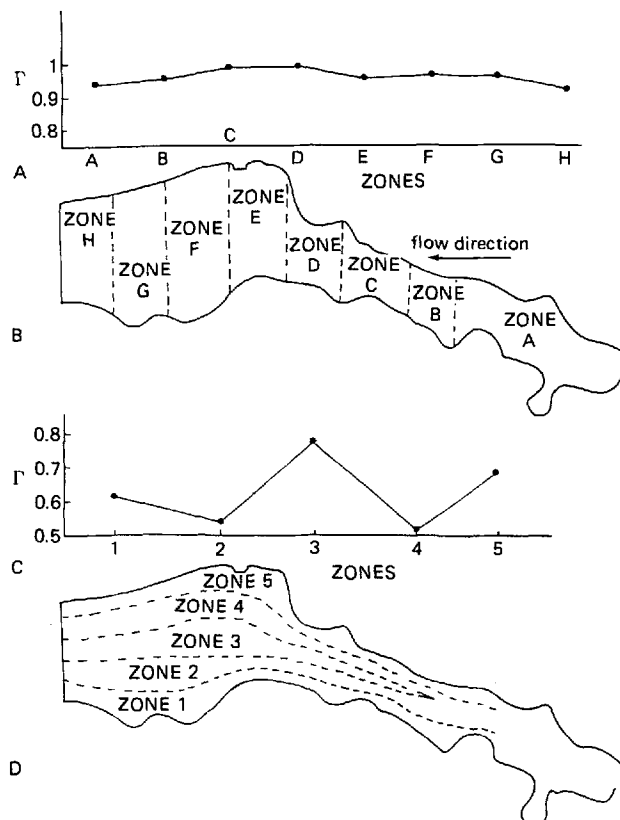


Figure 10. Variation of the correlation coefficient r for Pb in the different zones of Kandy lake.

Kandy lake could be attributed to pollutants, particularly vehicular emissions, in the case of Pb. Cd is known to associate closely with Zn and it is very likely that Cd enters the lake in the form of industrial effluents, particularly those from Zn-based small industries. In view of the large number of vehicles that use the highway circumscribing the lake, the output of Pb in particulate matter is appreciable. Figure 8 illustrates the variation of Pb with Cd, and Figure 9 shows the variation of Pb/Cd with location. The Pearson correlation coefficient r for Pb with Cd is +0.94 (Table 2) and this clearly illustrates the remarkable closeness with which Pb and Cd behave in the lake. An interesting feature that can be observed is the variation of

Table 3. Pearson correlation coefficient for lead with cadmium for the surface water samples of the Kandy lake. See Figure 10 for details of the different zones.

A		B	
Zone	r	Zone	r
A	+0.93	1	+0.62
B	+0.96	2	+0.55
C	+0.99	3	+0.78
D	+0.99	4	+0.51
E	+0.95	5	+0.70
F	+0.96		
G	+0.97		
H	+0.92		

r = correlation coefficient.

the correlation coefficient r of Pb and Cd across and along the lake as shown in Figures 10a, 10b, and 10c. Table 3 shows the Pearson correlation coefficient r of Pb with Cd for the different zones of the lake. It can be seen that along the lengthwise direction, the Pb–Cd correlation coefficient remains positive and highly significant. Across the lake however, as shown in Figure 10c, the r values are less, particularly in the region intermediate between onshore and offshore regions.

Conclusions

This study of the Kandy lake, situated in the center of a densely populated city in Sri Lanka, exemplifies the problems encountered in water quality management, particularly in an urban environment in a developing country. Anthropogenic influence is marked and contributes largely to the Pb and Cd contents of the lake water, which exceed those recommended by WHO for drinking water. In Kandy, even though there are no large-scale industries present, many small-scale industries are found, and these along with

vehicular emissions contribute largely to the heavy metal input of the lake.

Acknowledgments

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