Environment International, Vol. 7, pp. 343-351, 1982
Printed in the USA.

0160-4120/82/050343-09$03.00/0

THE ENVIRONMENTAL POLLUTION OF KANDY LAKE: A CASE STUDY FROM SRI LANKA

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(Received 12 August 1981; Accepted 12 January 1982)

The water pollution levels of Kandy Lake in Sri Lanka were monitored to probe the impacts and influences of urban environment in a developing country. Although Kandy Lake is a source of drinking water for the town, it was observed that a large number of effluent channels drained in to it, carrying a continuous flow of contaminated water. The hydrogeochemistry, pH, and bacterial levels were studied using lake and drain water samples. A high coliform count and a high degree of faecal contamination was observed in all water samples obtained from the lake and drains. The Cu^{2+} and F^- concentrations were relatively low and did not reach harmful levels, but were higher than that in the background. The pH of water remained almost neutral and provided ideal conditions for bacterial growth. All laboratory and field experiments indicated eutrophic conditions in the lake and the unsuitability of water in the unpurified state for drinking purposes. The purified water had a zero coliform count, but the chlorine content added was relatively high and may also prove to be a health hazard. On the whole, the polluted water in Kandy Lake indicated the adversities of human involvements with nature and provided a good case study for human influence on water pollution in a developing country.

Introduction

The lake under study is located in the heart of Kandy, one of the main cities of Sri Lanka, best known for its natural beauty and tourist attraction (Fig. 1). The lake covers a surface area of 0.25 km^2 and has a circumference of 3.2 km. The average annual rainfall of the area is 137 cm and the temperature ranges from 25–28 °C.

The population of Kandy is around 120,000 and shows a two- to three-fold increase during the internationally known festival season in August. The lake itself is circumscribed by a highway bordered by a canopy of trees inhabited by large swarms of birds, notably crows. A small island in the center of the lake adds to the scenic attraction, and a regular boat service is maintained mainly for recreational purposes. Being situated at a low elevation in the city, as many as 29 drains of varying sizes discharge effluents into the lake. This location also leads to washouts from roads into the lake during rainy periods. It is common to find passersby throwing wastematter into the lake perhaps ignorant of the fact that the water is used for drinking. In addition, leaves and flowers from the trees surrounding the lake fall into the water, especially during the flowering season in April and May.

During the rainy season, the lake water is mixed by the rapid inflow of surface water, causing a marked increase in turbidity. Along the edge of the water, particularly in zones closer to the drain openings, there are many small ponds filled with stagnant water inhabited by mosquito larvae and from which foul odours emanate. The lake water irritates the skin, thus indicating polluted water. In certain regions heavy algal growth was also observed; this could perhaps cause the irritation.

A marked increase of the pollution of the lake water occurs during the "Esala Perahera," an internationally known procession and festival season held each year during August. The town becomes severely crowded with pilgrims, sightseers, tourists, and others, and the lake becomes a dumping ground for garbage. A number of temporary latrines are constructed for the use of this vast influx of visitors, and these are constructed very close to the lake. Outlets from the latrines almost invariably find their way into the lake.

The geology of the lake basin consists of four rock types, namely, marble, quartzite, hornblende gneiss, and garnet-biotite gneiss. The weathering and transportation of material eroded from the surrounding hills have resulted in a very thick layer of sediment at the lake

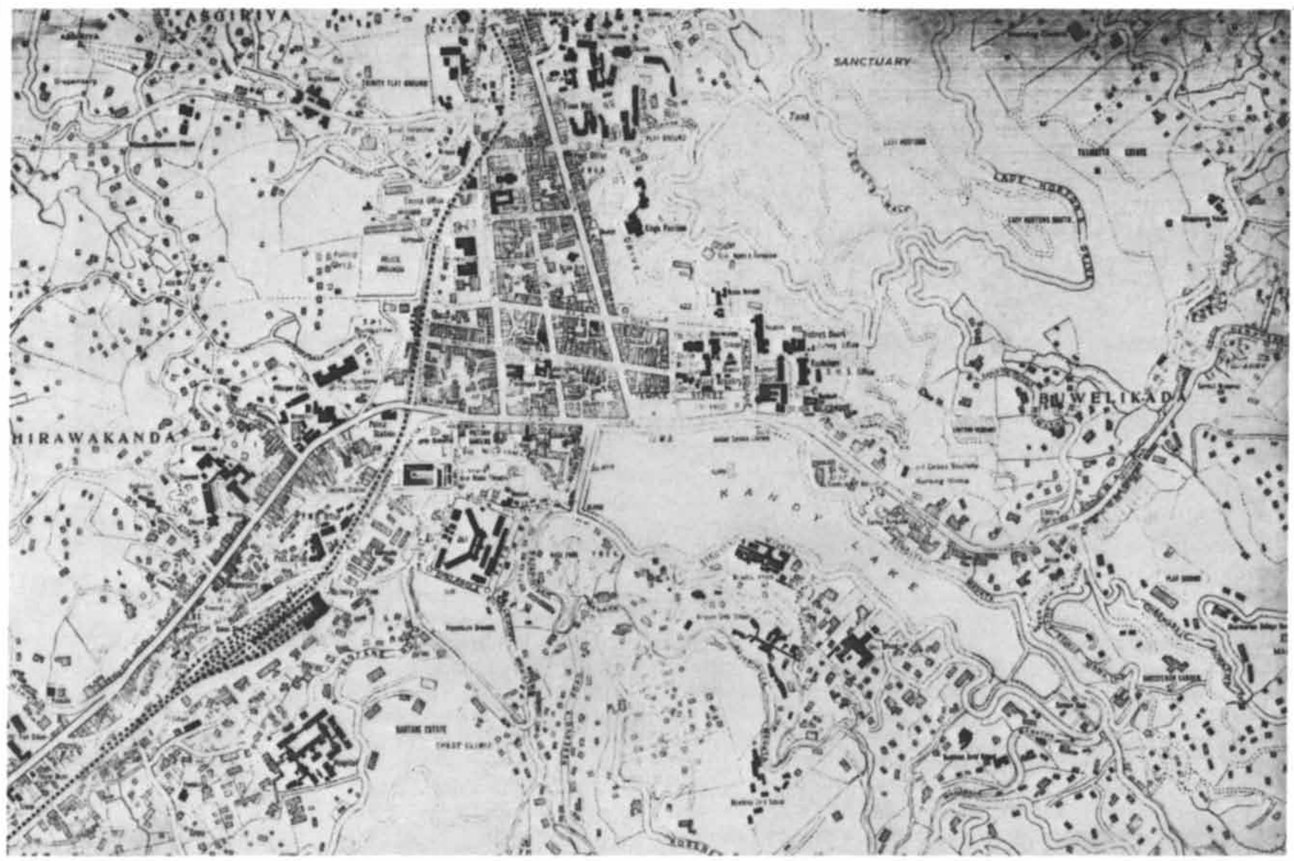

Fig. 1. Map of Kandy town and the lake under study.

bottom contributing to the extreme turbidity observed during the rainy seasons.

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 ideal case study for environmental pollution in a city in Sri Lanka. This study forms an interesting comparison with Parakrama Samudra, a large tank in the dry zone of Sri Lanka, away from the polluted urban environment and used mainly for irrigation purposes.

Materials and Methods

Figure 2 illustrates the locations of the sampling points. The offshore samples were obtained with the help of the boat service on Kandy Lake. All samples were collected in precleaned polyethylene containers and kept cool and dark until tested within 1 h after collection. The chemical analyses were carried out at the Department of Geology and the bacteriological tests were made at the Veterinary Laboratory of the Kandy Municipal Council. The samples were collected in August during the dry season.

Chemical analyses

Fluoride: The fluoride ion content was determined using a pH meter (Model 291 MK 2) with an Orion Ion Specific Electrode (fluorine electrode and reference electrode). Samples (10 ml) were diluted with an equal volume of Orion TISAB (with EDTA) buffer solution. Electrode potential of the solution was measured and the fluoride concentration was determined from a calibration graph.
Copper II ions: The Cu^{2+} content was determined in a similar manner using a copper electrode and a reference electrode.
Nitrate: Nitrate was determined by the Brucine method of Jenkins and Medsker (1964).
Total phosphorus: Total phosphorus was determined using the molybdenum blue method, as described in Jeffrey (1975).
Specific conductivity: Specific conductivity measurements were made with a Model 17250-Hach Miniconductivity Meter both in the field and in the laboratory.
pH measurements: pH was determined using a Model 291 MK 2, Pye-Unicam meter.

Coliform count and bacterial analyses

Fifteen sterilized test tubes wereused for each sample analyzed. Durham tubes were introduced into each test

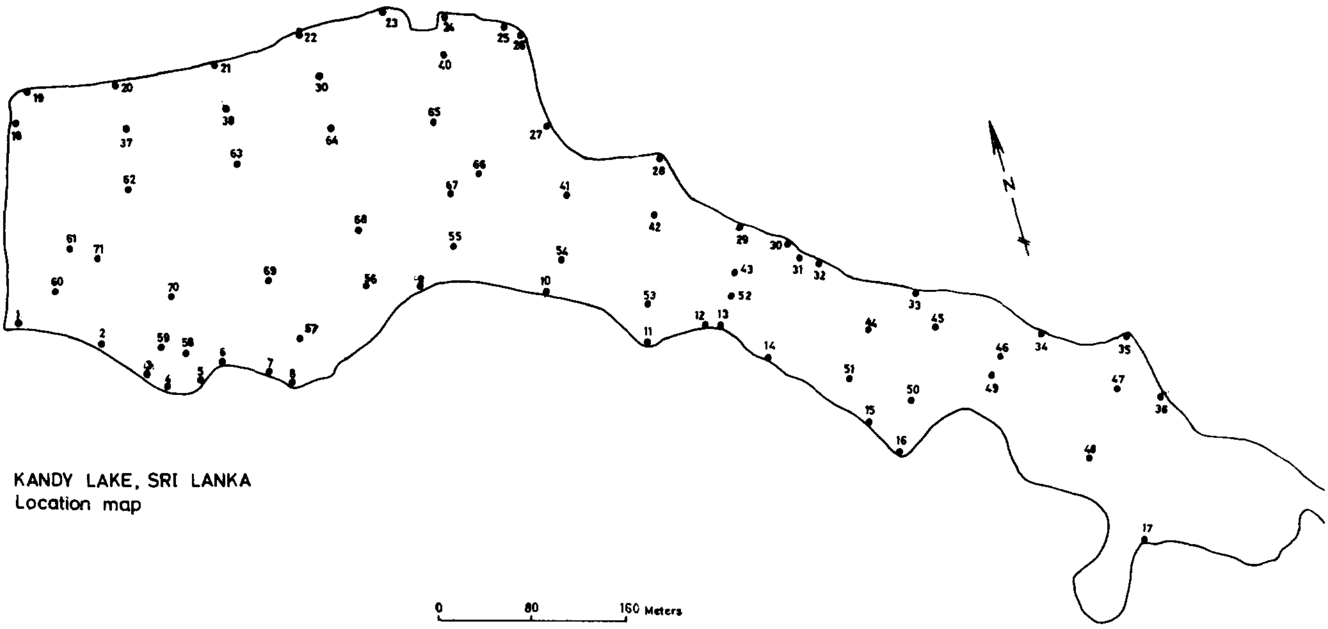

Fig. 2. Locations of sampling points in Kandy Lake.

tube in an inverted position. Into five of these test tubes 10 ml of Maclonkey Broth, prepared in double concentration, were added. To the other 10 test tubes single concentrations were introduced. The openings in the series of tubes were closed with cotton wool and sterilized.

To the first five test tubes, 10 ml of water from the sample were added with double strength. To each of the next five test tubes, 1 ml of the sample was added containing single strength Broth. Finally, to the other five test tubes, 0.1 ml of the sample was added in a dilute form. The series of test tubes incubated at 37 °C for 24 h. The extent of the yellow colour and gas production was used to estimate the coliform count.

Faecal coliform and faecal streptococci

A positive sample (with acid and gas) was plated in Maclonkey Agar and blood agar. Before plating, the dilute sample was heated to 60 °C to kill other organisms and to allow only faecal coliforms and faecal streptococci to remain. This was then incubated for 24 h at 37 °C. The type of organisms present were identified by colony pattern and by gram staining method.

Results and Discussion

Table 1 shows the kind of discharge to the lake and maximum concentration of the various constituents measured in the discharge from each inlet into the lake.

Nitrates

Figure 3 illustrates the distribution of nitrates in Kandy Lake. The monitoring of nitrate levels in the lake is of extreme importance since the water is occasionally used to supplement the town water supply. The maximum nitrate level detected was 70 mg/l at inlet 18, a drain carrying urine-contamined effluent from a nearby school. A similar observation was made at inlet 3, where the effluent carried a high concentration of nitrate. The improper disposal of sewage and human excreta have resulted in most of the inlets carrying urine-contaminated discharge and hence the presence of nitrates. As shown in Fig. 3, the maximum range of nitrate concentrations in the lake was between 5 and 10 mg/l. These levels were observed mainly in areas between inlets 1 and 9. Public latrines, large hotels, and guest houses in this area discharge wastes into the lake. Even though some of the discharges contain a high nitrate content, it is probably the biological activity that would have kept the level of NO_3^- at its present level. A high nitrogen loading rate may not be reflected by a high nitrate level in the lake if the incoming nitrogen is quickly incorporated into organic forms by the lake biota.

The World Health Organization recommendation for nitrate levels in water are shown in Table 2 (WHO, 1978). Although the levels of nitrates observed in Kandy Lake are below the unacceptable limit at present, they could increase if the municipal waste and human excreta are not properly discharged. With the rapid building construction and development of the areas around the lake, mainly hotels and guest houses, proper waste disposal should necessarily take priority. If the proper sanitary precautions are not taken, Kandy Lake could well turn out to be the source of serious health hazards.

Nitrate is an end product of the decay of nitrogeneous material and could be from fertilizers or animal and human excreta. The obvious lack of fertilizer use in the vicinity of Kandy town points to the

Table 1. Chemical and bacteriological data on the effluents draining into Kandy Lake.

Inlet	NO_3^- (mg/l)	Total Phosphorus (Mg/l)	Cu^{2+} (ppm)	F^- (ppm)	Coliform Count	Remarks
1	7.35	0.46	–	–	–	Stream, densely populated valley Urine contaminated
2	4.60	0.38	0.016	0.801	275	Urine contaminated
3	very high	0.34	–	–	–	Urine contaminated
4	1.10	–	0.029	–	30	Food stuff (decayed)
5	8.35	0.65	–	–	–	Densely populated valley
6	25.00	0.95	–	–	–	Dye stuff, contaminated
7	2.35	very high	–	–	–	Food stuff, washouts
8	3.70	–	0.008	0.801	1800	Food stuff, washouts
9	–	–	0.018	0.543	250	Food stuff, washouts
10	1.55	0.65	0.008	0.632	175	Food stuff decayed
11	0.95	0.60	0.024	0.742	200	Solid washouts
12	1.79	0.25	–	–	–	Kitchen washouts
13	5.25	33.25	0.008	0.730	900	Human Excreta, urine contamination
14	1.34	0.60	0.002	0.721	1800	Foodstuff kitchen washouts (decayed)
15	30.00	1.90	0.002	0.721	1800	Nursing Home effluents. Urine contaminated.
16	6.00	0.50	0.053	0.734	250	Urine contaminated
17	5.50	2.55	0.053	0.734	35	Densely populated house washouts.
18	70.00	2.00	0.053	0.734	14	Urine contaminated
19	3.50	–	–	–	–	Urine contaminated

conclusion that most of the nitrate in the lake is due to contamination from animal and human excreta. Apart from the improper drainage of public lavatories and pit latrines, defecation in secluded places around the lake has also contributed to the general input of nitrates. It is of interest to note that Hutton and Lewis (1980), in a study of nitrate pollution in Botswana, noted that there is a strong association between groundwater pollution and population density, but the major towns served mainly by surface water were unaffected.

As Fig. 4 shows, however, the nitrate contents of the lake bear no simple relationship with the coliform contents (see below under Coliform distribution). Hutton and Lewis (1980) did not find a statistically significant relationship between bacterial population and nitrate. Brooks and Cech (1979), in their work on rural water supplies and their nitrate and bacterial distribution, arrived at a similar conclusion but inferred that there may be a complex nonlinear relationship, probably involving factors not well understood at present.

Total phosphorus

Figure 5 illustrates the total phosphorus distribution in Kandy Lake. Apart from a few isolated zones, the rest of the lake has a total phosphorus concentration of less than 3 ppm. As shown in Table 1, high phosphorus contents were observed at inlets 13 (33 ppm), 15 (1.9 ppm), 17 (2.55 ppm), and 18 (20 ppm). Fan-shaped zones can be observed to originate from these inlets. The central zone containing phosphorus in the range 1.5-2.0 ppm in the central part of the lake's western half is mainly due to the very large quantities of bird droppings added to the water from the canopy of trees between locations 10 and the western corner of the lake. Figure 6 shows the relationship between the phosphorus and nitrate contents and also phosphorus and coliform count. At some locations, particulately at 1-9, the nitrate concentrations appear to bear an apparent relationship with the total phosphorus contents (Fig. 3). Apart from the bird droppings, which could influence the nutrient cycles to some extent, the small catchment area provides some loading of phosphorus from the geographic surroundings.

Table 2. World Health Organization recommendations for nitrate levels in water (WHO, 1978).

	mg/l	Category
General population	<50	acceptable
	>50, <100	borderline
	>100	unacceptable
Infants under 6 months	over 50	unacceptable

Coliform distribution

Figure 7 illustrates the coliform distribution in Kandy Lake; the maximum coliform counts were observed at inlets 14 and 15. These inlets carry wastematter from a nearby hospital and some domestic dwellings. At the eastern end of the lake, where marshy conditions prevail, the coliform count is also high. From the western end of the lake up to location 12 and also from location 8 to 20 on the southern end of the lake, the coliform count ranges between 100 and 500 per 100 ml. Some of the inlets, particulately those with high coliform, had reached levels of as much as 1800 per 100 ml and, as seen in Fig. 7, the offshore samples had the least coliform counts. In view of the recommendation by the Environmental Protection Agency (1972) that drinking water should average less than 1 coliform per 100 ml

Fig. 3. Distribution of nitrates in Kandy Lake. Numbers indicate the location of the inlets.

sample, the concentrations observed in Kandy Lake are obviously too high and are by no means suitable for drinking purposes in the unpurified state.

As shown in Fig. 8, the coliform content depends on the pH of the medium; closer to the shore it is apparent that a higher pH is conducive for a greater coliform concentration. An increased bacteria content after a rainy period has been reported in many areas. Fair and Morrison (1967) found mean coliform levels of 30 colonies per 100 ml sample in a high mountain stream in Colorado. Pubulis (1968), sampling six Sierra Alpine lakes, found coliform densities ranging from 0–6 colonies per 100 ml, whereas Silverman and Erman (1979), who sampled Alpine lakes in Kings Canyon National Park, CA, found coliform densities ranging from 0–51 colonies per 100 ml after rains. The increased bacteria after rain, reported in many areas, are probably caused by bacteria washing in with run-off and on airborne particulates (Rosenberg, 1964; Geldreich *et al.*, 1968). Thus, further studies are necessary to estimate the coliform counts in Kandy Lake during the rainy periods, as these could be significantly higher.

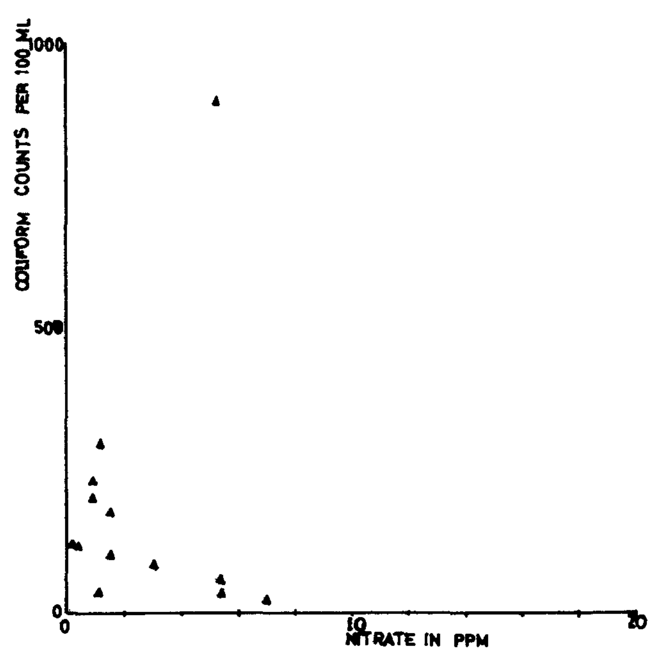

Fig. 4. Diagram showing the variation of nitrates with the coliform contents in Kandy Lake.

The faecal matter from thousands of crows falls into the lake daily, forming a major source of pollution which tends to concentrate at the lake bottom. This condition is further aggravated by the inflow of water washed from the highways after rain and also by wastematter in the form of food particles thrown into the lake by people during the festival season. However, colonies of fish which inhabit areas of the lake where wastematter is in the form of food discharged from nearby hotels, help prevent the uncontrolled growth of bacteria. Thus an equilibrium exists and a constant coliform count in the lake water remains at present.

One consequence of the highly polluted nature of Kandy Lake is that a very high concentration of chlorine must be used to make the water suitable for human consumption. However, among the clinical manifestations of excess chlorine in drinking water are irritation of eyes, bleaching of hair, gastric irritation, and wheezing.

Copper

The copper contents in Kandy Lake were monitored in order to check on the input of any industrial effluents

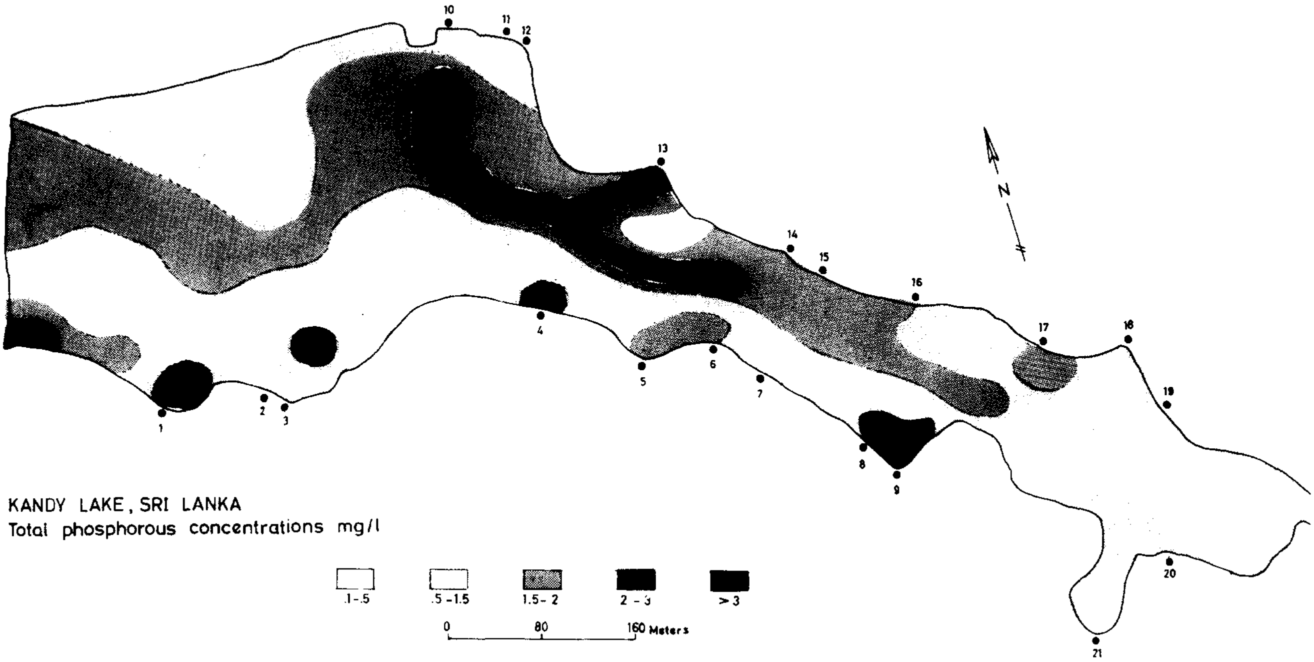

Fig. 5. Distribution of total phosphorus in Kandy Lake.

into the lake. The copper concentrations in the effluents ranged from 0.002–0.3 ppm, whereas the lake water had an average Cu^{2+} content of 0.02 ppm. The low concentration of Cu^{2+} in waste and natural water in Sri Lanka has been observed by Dissanayake and Ariyarantne (1980) and Dissanayake and Jayatilaka (1980). Industrial pollution has not reached alarming proportions in Kandy mainly due to the lack of major industries, and the Cu^{2+} concentration in the effluent is a reasonable measure of the extent of industrial pollution around Kandy. An interesting feature observed was the inverse relationship of Cu^{2+} in the samples to that of the coliform count (Fig. 8). The toxicity of copper to aquatic plants and organisms has been known for many years (Lopinot, 1963) and the speciation and rate of loss of copper from lake water with implications to toxicity has been studied in detail by Wageman and Barica (1979). The total dissolved copper is dependent on the

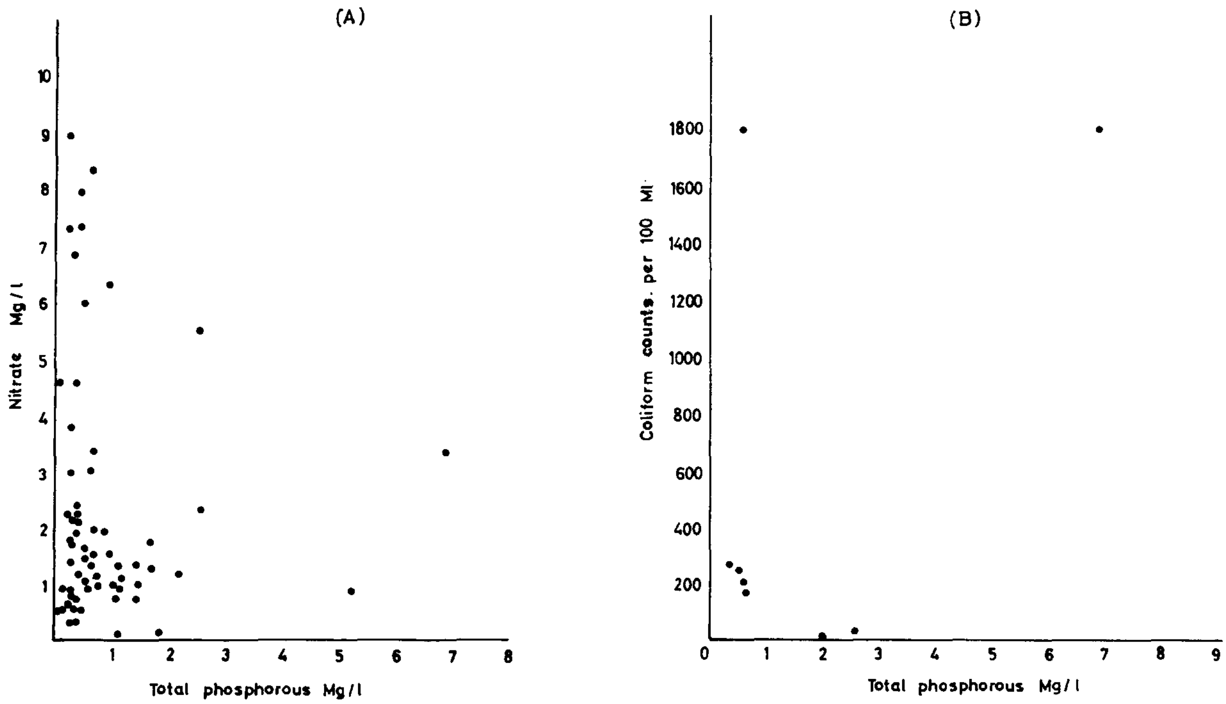

Fig. 6. Variation of phosphorus (A) with nitrates, (B) with the coliform content.

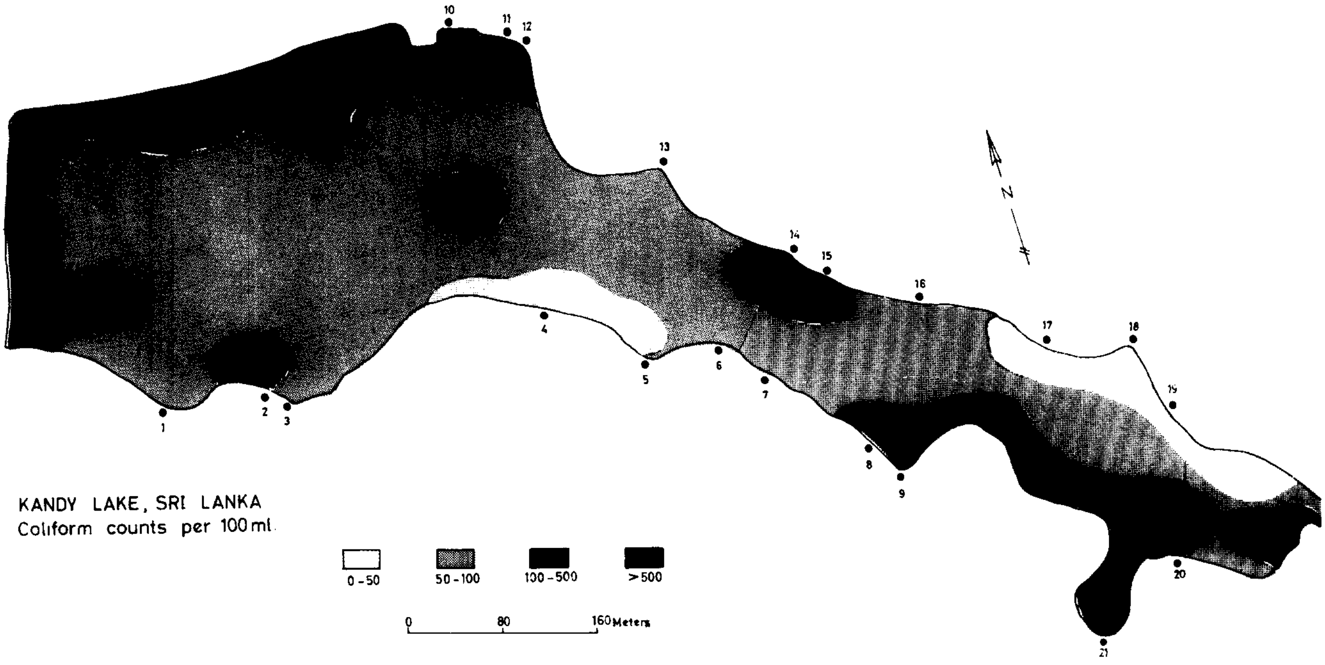

Fig. 7. Distribution of coliform in Kandy Lake.

pH, and this is a determining factor in the distribution of copper ions (Jenne, 1968). Copper is removed partly by particulate matter (including algae), presumably by adsorption on these particles by uptake or by precipitation for which such particles could serve as nuclei (Wageman and Barica, 1979).

The effectiveness of copper ions as a material toxic to organisms is clearly shown by the presence of the lowest coliform counts at the locations of the highest Cu^{2+} concentrations. It is known that the organo-cupric complexes are relatively nontoxic to fish and algae and that the water quality (hardness, pH, dissolved ions, and organics, etc.) more generally affects the toxicity of copper to aquatic organisms (Brungs *et al.*, 1976; Brown *et*

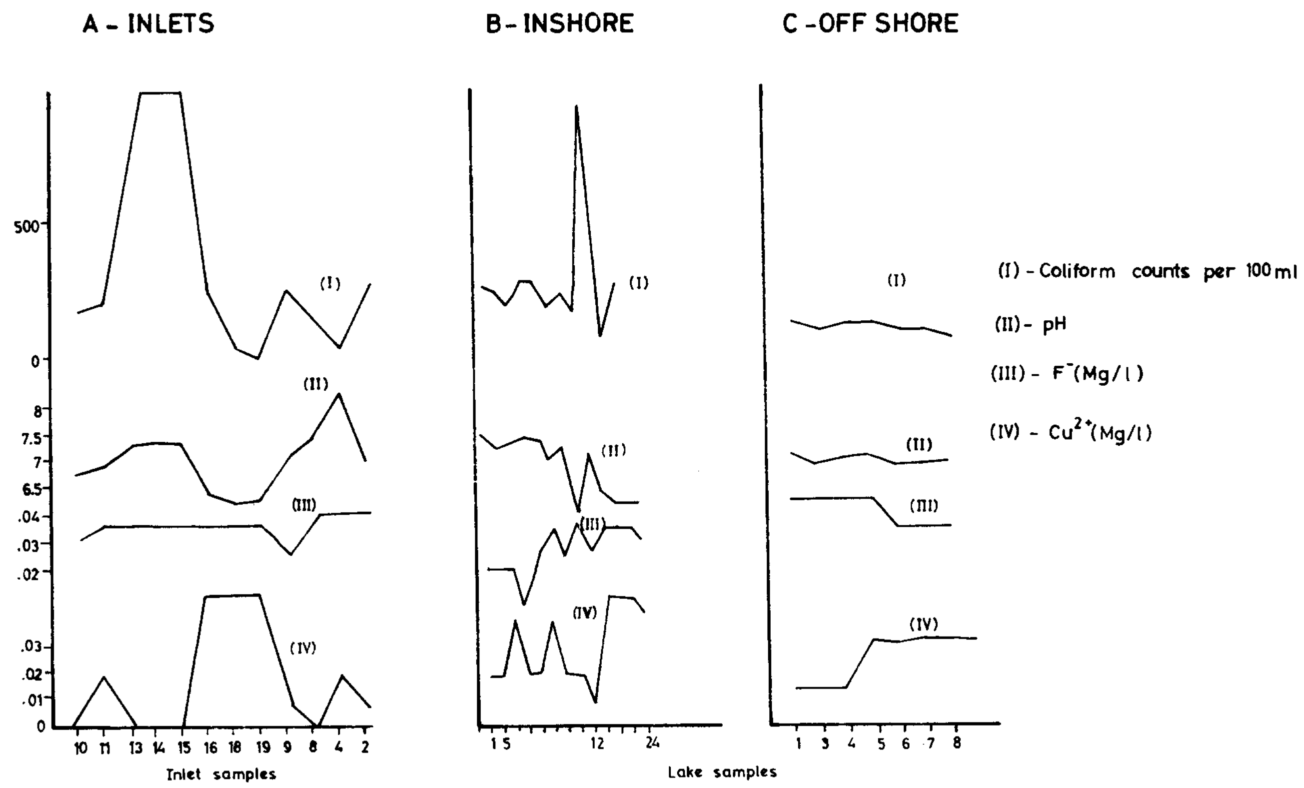

Fig. 8. Diagram showing the interrelationships of pH, F^-, Cu^{2+}, and coliform content in the inlets, inshore and offshore samples.

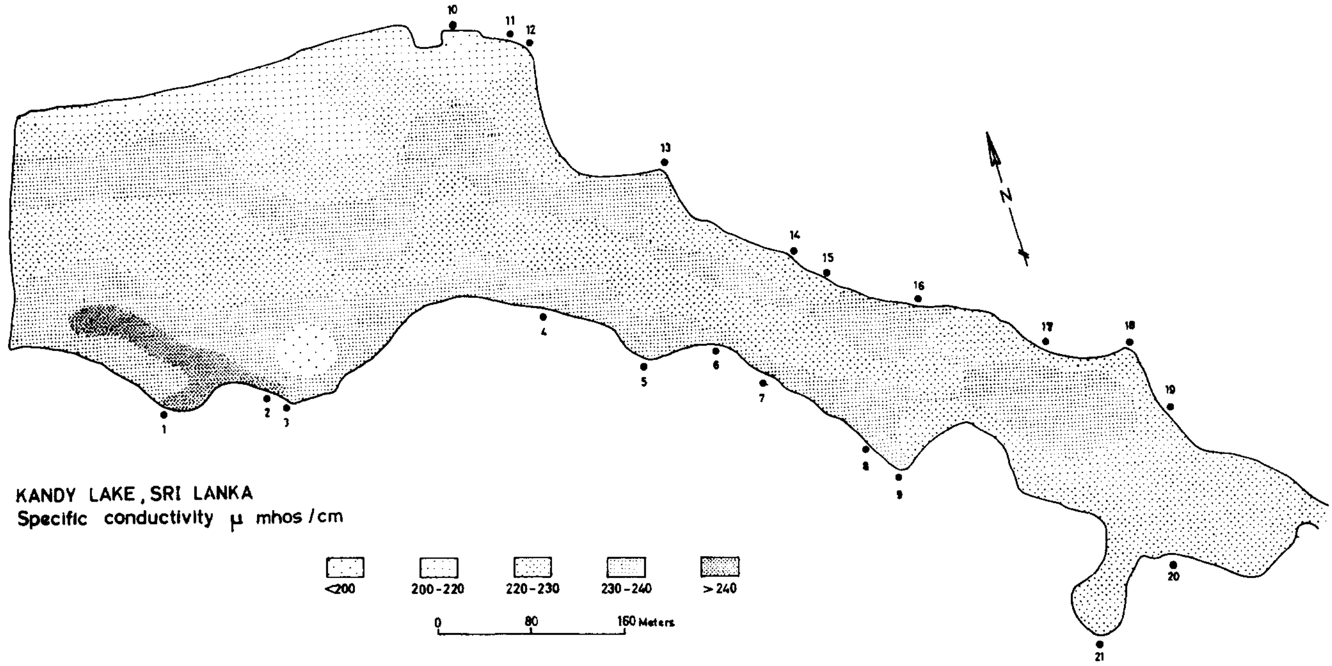

Fig. 9. Diagram showing the specific conductivity distribution in the Kandy Lake.

al., 1974; Zitko, 1976). The work of Andrew *et al.* (1977) and Andrew (1976) shows that it is the cupric ion which is most toxic to aquatic organisms.

Fluoride

The fluoride ion distribution in the lake is similar to that of Cu^{2+} and confirms the low F^- content in the waters around Kandy (Dissanayake and Hapugaskumbura, 1980). Fluoride concentration in the lake water ranged from 0.5 to 1.0 ppm and gives an indication of the F^- ions in the rocks in the immediate geologic surroundings, there being no significant F^- concentrations in the industrial effluents draining into Kandy Lake.

Specific conductivity

The specific conductivity of the lake water is illustrated in Fig. 9. In general the specific conductivity lies in the range 200–240 μ mhos/cm. Between locations 1 and 3, however, a specific conductivity of > 240 μ mhos was noted. These values are of a high order and indicates an abundant input of free ions into the lake. The large number of inlets bring in an array of effluents both from domestic wastematter and from the surrounding hills, and these contribute to the high conductivity noted. The presence of an abundance of free ions could also be due to a substantial contribution form the weathering of the more basic rocks in the vicinity and also from the sediments.

Comparison with Parakrama Samudra

Kandy Lake, situated in the wet zone of Sri Lanka, and located in the centre of a major town, can be compared with Parakrama Samudra, which is situated in the dry zone of Sri Lanka, and away from industrial and any noteworthy domestic influence. It is almost entirely subjected to natural environmental conditions and forms an important water reservoir used for irrigation of approximately 100 km² of rice fields.

The nitrate concentration of Parakrama Samudra ranges between 0.006 and 0.024 mg/l (Gunatilaka, 1980) and is lower than that of Kandy Lake by a factor of 15; this is an indication of an obvious human influence in the Kandy region. The total phosphorus concentration of Parakrama Samudra is also significantly lower (0.035–0.167 mg/l) than that of Kandy Lake, indicating a smaller loading in the former lake. The conductivity of Parakrama Samudara is also lower than that of Kandy Lake by a factor of approximately 2; this too points to a higher loading of the free ions into Kandy Lake, partly due to human influence and partly due to geological sources.

Conclusions

Kandy Lake, a lake in a Sri Lanka city, exemplifies the problems encountered in water quality management, particularly in an urban situation in a developing country. The human influence in such pollution is great; indeed, in the case of Kandy Lake, pollution due to human sources by far outweigh any excess due to geological materials. Further, as in the case of most developing countries with very little large-scale industry, biological pollution due to human influence is the predominant factor. The high nitrate and coliform contents in the inlets exceed the safety limits, and this in itself calls for proper municipal sewage disposal systems. Contamination due to human excreta is observed in many parts of the lake. With the present rate of population increase in the city, contamination from this source would reach highly unacceptable proportionals in the future. Nitrate, a potentially harmful substance, in particular must be kept at the lowest possible level, especially because the lake water is used occasionally to supplement the town water supply. The dangers of high nitrate concentration in drinking water are well documented (WHO, 1978) and essentially they are methaemoglobinaema and carcinogenesis. In a highly populated developing country in the tropics, such as Sri Lanka, pollution by nitrates could indeed pose a serious problem bearing in mind that only 15%-25% of the people have access to safe water and less than 10% to pipe water (Economic Review, 1980). The seriousness of the improper disposal of human and other wastematter through badly planned sewerage systems cannot be overemphasized, since deaths due to waterborne diseases have increased very rapidly over the past few years.

Even though its scenic beauty may well attract a large number of sightseers and tourists, Kandy Lake could indeed turn out to be the source of serious health hazards.

Acknowledgements—Grateful thanks are due to Dr. D. S. Aturaliya, Veterinary Surgeon of the Kandy Municipal Council, for providing facilities for bacteriological analyses. Thanks are also due to Miss S. J. Wijesekera and Mr. Cyril Dunuhappawa for their assistance. This work was supported by a grant from the National Science Council of Sri Lanka.

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