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RIVER POLLUTION IN DEVELOPING COUNTRIES - A CASE STUDY EFFECT OF WASTE DISCHARGES ON QUALITY OF RUIRUAKA RIVER WATERS IN KENYA

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ABSTRACT. The effect of various effluents on the quality of Ruiruaka river waters was studied over a period of nine months, November 1985 to July 1986. Water samples were collected at five selected points along the stream at regular intervals. Ten quality parameters namely temperature, pH, conductance, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved solids (DS), suspended solids (SS), levels of chloride, nitrate and total phosphate were monitored at each point. In addition, water samples were also analysed for profiles of both dissolved and suspended forms of elements with special attention to the presence of toxic metals such as mercury, lead, cadmium, copper and zinc. The study revealed that levels of pollutants varied considerably depending on the seasons. Drastic deterioration in water quality was observed at the sampling site just after the brewery. A mathematical assessment of the quality status of the water has been done based on the water quality index. Inferences were drawn based on comparison of data with internationally accepted standards.

INTRODUCTION

Pollution of water systems is one the major problems faced by most of the industrialised countries. This has lead to increased awareness to minimise water pollution in developing countries. The root cause of river pollution is man's tendency to dilute and dispose wastes instead of removing them at the source. With the ever increasing population levels, migration to urban centres and increased industrialization, the environment, in particular the water systems, is considerably polluted even in the developing world. As a result many streams and rivers which are sources of life and other activities have been converted into polluted drains. The wastes discharged into waterways can be classified into three general types - domestic, industrial and agricultural. Industrial pollution, particularly due to the presence of organic or inorganic substances is the commonest type of pollution which is most intractable.

In the Kenyan context, analysis of waters, sediments and plants for heavy metals in various lakes in Kenya, such as Lake Victoria, has been reported (1). Nitrite concentration in surface and ground waters in various parts of Kenya has also been studied. No systematic work has been done to evaluate the quality of river waters on any of the rivers in Kenya, except on Nairobi and Ngong rivers. In the present communication the results of the detailed studies conducted on Ruiruaka river water for a period of nine months from November 1985 to July 1986 are reported.

Ruiruaka river originates in the Kikuyu escarpments of Kenya and descends through coffee plantations and Karura forest land in the Kiambu district which neighbours Nairobi city. For about 10 km stretch the river runs within the Greater Nairobi city limits, flowing through large coffee plantations, agricultural farms, forest and residential areas before it enters Ruiruaka estate which is a region slowly developing as the second industrial area of Nairobi. Further down, the stream passes through a sparsely populated region with minimal or marginal industrial and farming activities and finally joins the Nairobi river (Fig. 1). The river has water flowing throughout the year, although the flow is lean in the summer months. The rainy season is in the months of April and May. Ruiruaka river has an approximated flow of 94 ± 25 m^3 per minute in the lean months at the first sampling point (RUA I) and the volume of flow at the last sampling point (RUA V) was about 250 ± 65 m^3 per minute. During the rainy season the flow rates were about 6-8 times and 4-5 times higher than in the lean periods at RUA I and RUA V respectively.

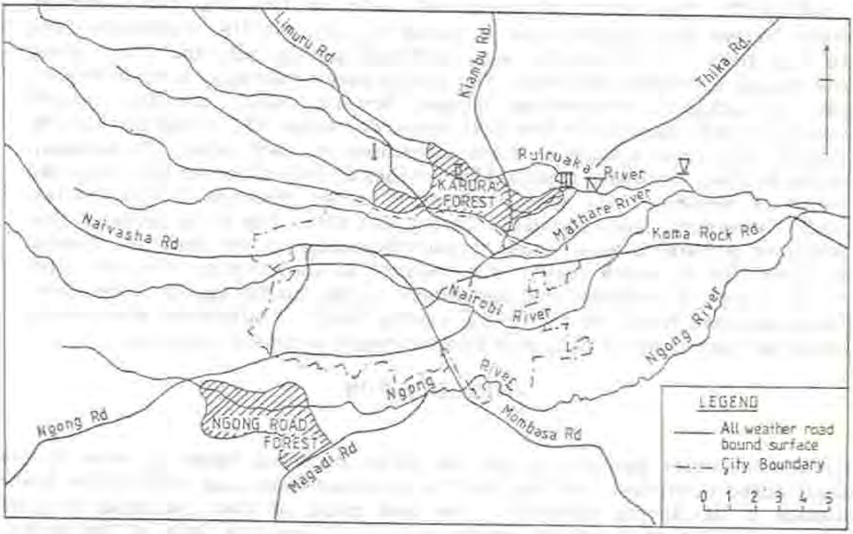

Fig. 1. Sampling sites (I - V) of Ruiruaka river.

EXPERIMENTAL

Sampling sites. In this study five sampling points were identified as follows: (i) RUA I (Limuru road bridge) - at this point, the river carries water from its upper tributaries and also run-off waters from coffee plantations and forest land; (ii) RUA II - a location within Karura forest with little human activity and about 2.5 km from RUA I; (iii) RUA III - prior to this point the river emerges from a swamp carrying partly treated domestic sewage and waters from a small tributary from farm lands, and is about 1.5 km from RUA II; (iv) RUA IV - a location about 500 m down stream from point of discharge of brewery effluents and about 1 km from RUA III; and (v) RUA V - downstream location with no industrial activity and located about 3 km from RUA IV.

Sampling. Water samples were collected at the identified sampling points about the midstream of the river, avoiding air bubbles. All the sample bottles (polythene containers) were throughly washed with water, then soaked in nitric acid and washed with distilled water before sampling. Samples were collected in 100 cm^3 bottles. The samples for elemental analysis were collected in 250 cm^3 containers and the pH of the sample was adjusted to about 2 with nitric acid to prevent metabolic processes which cause changes in samples and to reduce the absorption of metal compounds on the surface of the container. The samples were stored in a refrigerator.

Methodology. Temperature was measured immediately after the sample was collected. pH and conductivity values were determined in the laboratory in the quickest possible time. BOD_5 at 20°C, COD, DS and SS were determined employing standard procedures (2-4). Chloride was determined by Volhard's method (4) and nitrate was determined by the Brucine method (4). Total phosphate was determined colorimetrically after persulphate digestion as orthophosphate (5). The X-ray flurorescence technique was used for the analysis and complete profile of various metals both in suspended particulate form and in soluble form in the water samples (6-8). The X-ray fluorescence spectrometer comprised of an Ortec (SiLi) detector (HWFW-200 eV at 5.9 k eV) and a Canberra multi-channel analyser (MCA-40) linked to a professional 350 computer. The excitation source was ^{109}Cd of energy 22.1 eV and of half life 453 days.

RESULTS

The results of the analysis of water samples collected at monthly intervals over a period of nine months (November 1985-July 1986) at all the five sampling points identified are presented. Samples were analysed for different parameters to characterise the quality of the waters. The analytical data obtained for a typical batch of sample from five sites (19th November 1985) are summerized in Table 1 and 2. The levels of various parameters over 9 months at each sampling point, i.e. the variation of temperature and hydrogen ion concentration, the levels of BOD, COD, SS and chlorides, nitrates and phosphates are illustrated in Figs. 2-5. The levels of selected heavy metals as they exist in the aquatic samples were analysed separately, as soluble and suspended species and are shown in Figs. 6-9. The analytical data presented for metals is restricted to only the levels of zinc, copper, manganese, lead and titanium while other toxic metals were either below the detectable limits or not present.

Table 1. Qualitative parameters of Ruiruaka water on 19th November 1985.

Parameter	Sampling points				
	I	II	III	IV	V
Temperature(°C)	19.6	20.1	20.1	22.1	21.5
pH	7.1	7.2	7.1	5.9	6.0
Conductivity (µScm^{-1})	155	157	146	321	241
BOD (mg l^{-1})	6	4	64	610	300
COD (mg l^{-1})	31	23	156	2,450	750
DS (mg l^{-1})	289	296	220	1,050	424
SS (mg l^{-1})	31	8	38	516	252
Chloride (mg l^{-1})	14	14	17	19	15
Nitrate ($N-NO_3^-$) (mg l^{-1})	1:00	0.40	0.30	0.60	0.54
Total phosphates ($P-PO_4^{3-}$) (mg l^{-1})	0.05	0.05	0.06	0.50	0.40

Table 2. Quality parameters of Ruiruaka waters (19th November, 1985) soluble and suspended elemental concentration.

			Sampling points				
Elements	LLD	Precision %	I	II	III	IV	V
soluble elemental concentration							
Mn (ppb)	14	11	*	50	57	70	55
Cu (ppb)	5	14	10	*	12	74	40
Zn (ppb)	8	13	40	26	100	73	40
Pb (ppb)	10	15	38	115	25	20	*
suspended matter elemental concentration							
Ti (ppb)			243	274	188	361	98
Cu (ppb)			*	*	*	76	55
Zn (ppb)			15	17	17	25	18

LLD - Limit of lower detection. *Below the minimum detectable limit.

DATA ANALYSIS AND DISCUSSION

A persual of Figs. 2-9 indicates that in general throughout the study period the quality parameters of water samples at RUA I, RUA II and RUA III were fairly similar except for the occasional variations observed at RUA III which were possibly due to inflow of domestic or farm effluents prior to the point. At RUA IV the characteristics of the waters changed significantly due to influx of brewery effluents (Table 3).

Table 3. Analysis of brewery effluents.

Parameter /date	22-4-86	27-4-86
pH	5.4	5.4
Conductivity (μScm^{-1})	1,357	785
DS (mg l^{-1})	3,762	4,172
SS (mg l^{-1})	3,054	3,594
Total Phosphate ($P-PO_4^{3-}$; mg l^{-1})	5.70	6.25

Temperature. The temperature of Ruiruaka river waters at RUA I varied between 17.1 and 20.1°C, touching the lower in the rainy season (Fig. 2). A slight decrease in temperature, about 0.5°C, was recorded at RUA II, possibly due to slow flow through thick forest covered with trees. A relative increase was observed at RUA III in all samples. A significant increase of 12°C was observed at RUA IV, due to the influx of warm brewery effluents. At RUA V, relative to RUA IV, a lower temperature was recorded possibly due to thermal exchange with surroundings.

pH. A perusal of the data presented shows that the pH of waters between RUA I and III varied between 7.0 and 7.5 during most of the study period. The exception was the rainy season, during which the pH was about 6.5. At RUA IV the pHs dropped to 5.5 in some samples indicating acidic nature of the brewery effluents. The pH difference between RUA III and IV samples were less pronounced in the rainy months when the river carried a high volume of water. At RUA V the pH was raised to some extent in all the samples (Fig. 2).

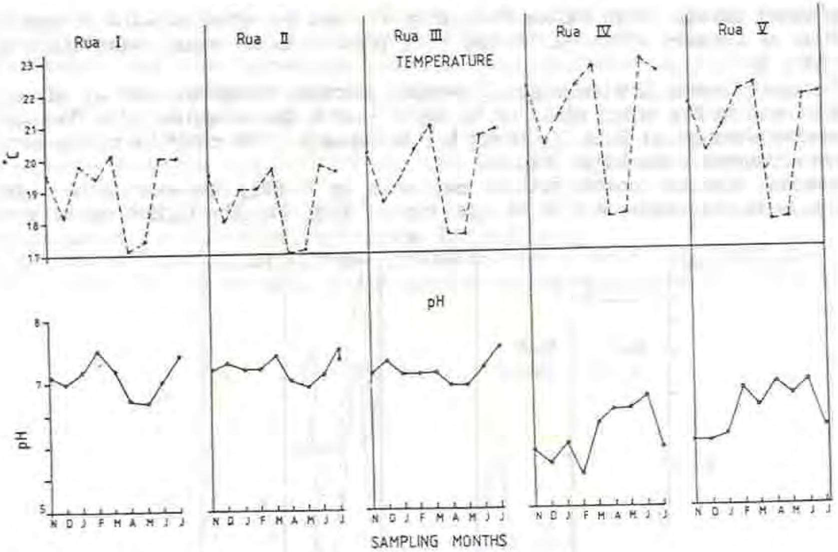

Fig. 2. Temperature and pH profile of Ruiruaka river waters.

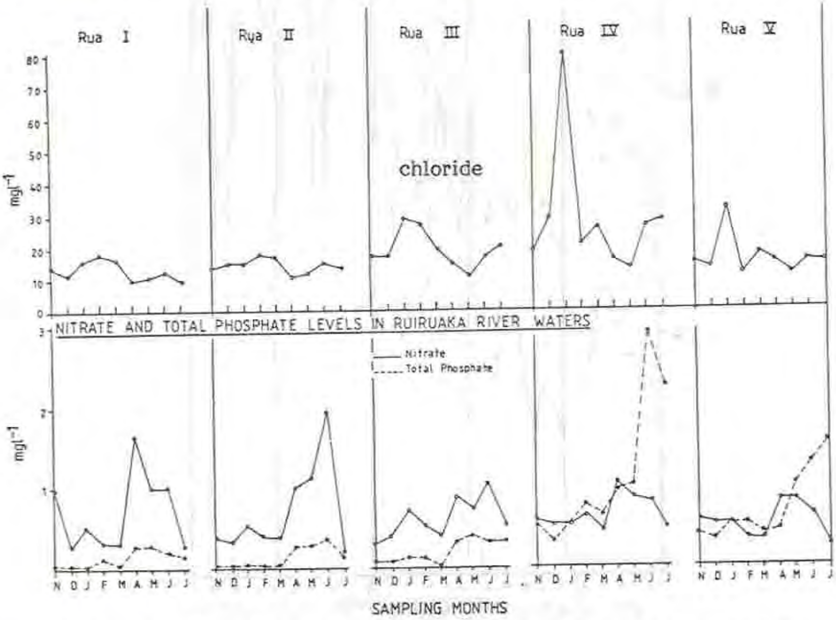

Fig. 3. Chloride, nitrate and total phosphate levels in Ruiruaka river waters.

Specific conductance. The specific conductance values at RUA I, II and III varied between 98 and 215 $\mu S cm^{-1}$. The lower values were observed during the rainy season. High values (450 μScm^{-1}) were recorded at RUA IV due to inflow of brewery effluents. Relative to RUA IV lower values were observed at RUA V.

Chloride. During the investigation period, chloride concentrations at all the points was in the range of 10 to 25 mg l^{-1} with the exception of a five-fold increase observed at RUA IV (80 mg l^{-1}) in January. This could be due to some irregular brewery discharge (Fig. 3).

Nitrates. Nitrate concentrations estimated as $N\text{-}NO_3^-$ between RUA I and III were in the range of 0.26 to 1.96 mg l^{-1} (Fig. 3). The higher values were observed during the rainy season which could have been resultant from washing off of the nitrate fertilizers from the farms. No appreciable increases in nitrate levels were observed at RUA IV. This suggests that the brewery discharges

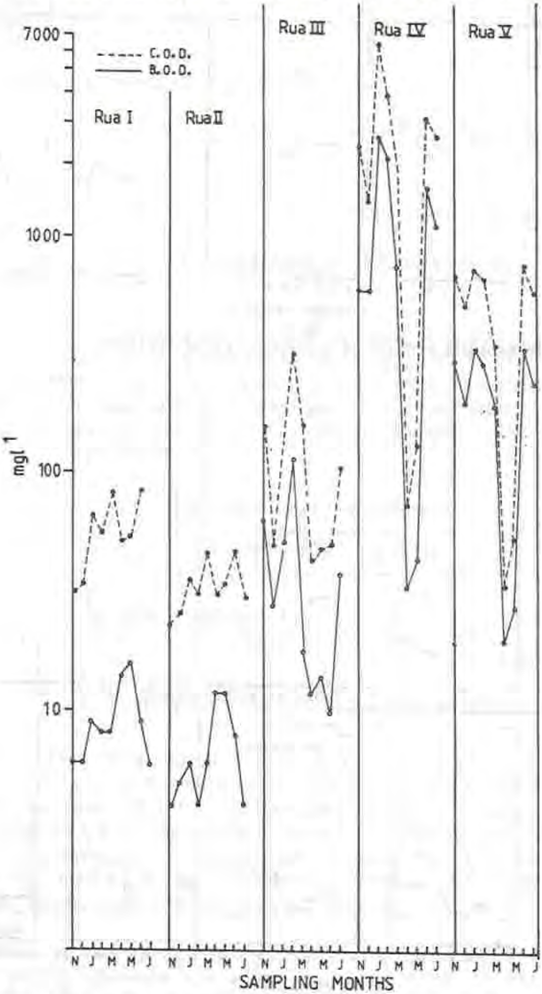

Fig. 4. Biochemical and chemical oxygen demand of Ruiruaka river waters.

also contain approximately similar concentrations of nitrate as in the receiving waters. Nitrate concentrations tended to be lower at RUA V.

Phosphates. The total phosphate concentrations estimated as $P\text{-}PO_4^{3-}$ were found to be in the range of 0.01 to 0.28 mg l^{-1} at RUA I, II and III, higher levels observed being in the rainy season. Marked increases were recorded at RUA IV reaching as high as 2.90 mg l^{-1} (June 1986) which is far above the WHO acceptable standards (0.2 mg l^{-1}) (8). This was due to brewery effluent which contained high concentrations of phosphate (5.7 mg l^{-1}). Phosphate levels at RUA V varied in the range of 0.31 to 1.57 mg l^{-1}. These levels are considerably higher compare to corresponding levels at RUA I (Fig. 3).

BOD. The biochemical oxygen demand determined after 5 days incubation at 20°C were found to be quite low in all the aquatic samples at RUA I, II and

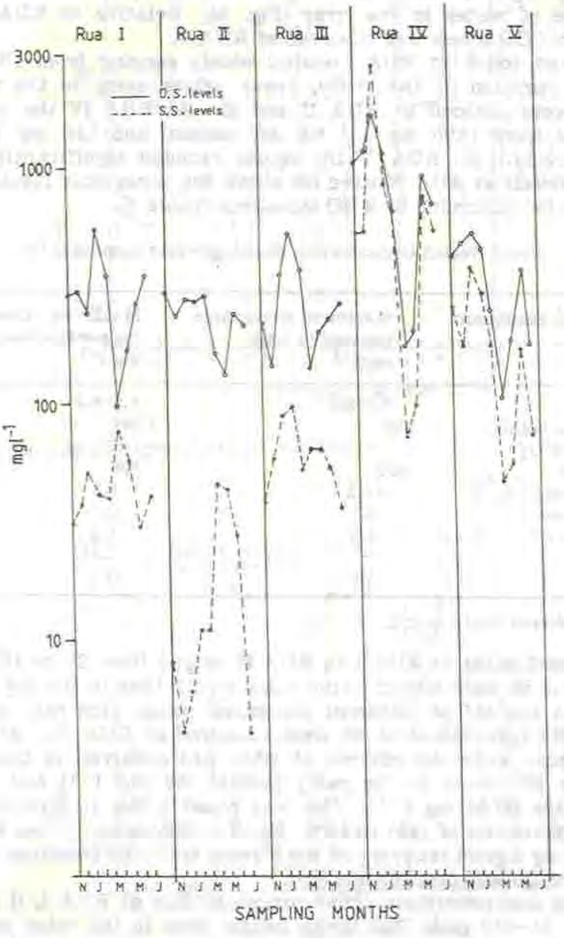

Fig. 5. Dissolved and suspended solid levels of Ruiruaka river waters.

III ranging mostly between 6 to 16 mg 1^{-1} during the study period (Fig. 4). Fairly low BOD values all the way down to RUA III indicate the good state of the waters upstream. Higher BOD levels maximum reaching up to 2700 mg 1^{-1} during rainy season due high dilution of effluents by rain waters. The levels of BOD at RUA V were found to be significantly low compared to values at RUA IV pointing towards the rapid self-purification process, which could be due to the quality of waters prior to RUA IV and due to efficiency of natural cleaning processes (8).

COD. The chemical oxygen demand values at RUA I and III were not affected much by seasonal changes remaining fairly in the same range 34 to 84 mg 1^{-1} over the study period (Fig. 4). Low COD values observed indicate that the waters were fairly clean up to this point. COD levels at RUA IV were considerably high, and in the dry season, January 1986 were as high as 6,520 mg 1^{-1}, but fairly low values were observed in rainy months of April and May 1986 due to the high volume of water in the river (Fig. 4). Relative to RUA IV, about a 10% reduction in COD levels was observed at RUA V.

DS. The dissolved solids at RUA I varied widely ranging from 104 to 550 mg 1^{-1} during the duration of the study, lower values being in the rainy season. Similar levels were noticed at RUA II and III. At RUA IV the maximum and minimum values were 1690 mg 1^{-1} (in dry season) and 180 mg 1^{-1} (in rainy season) respectively. At RUA V DS values reduced significantly relative to IV (Fig. 5). DS levels at RUA IV were far above the acceptable levels for drinking water consideration according to WHO standards (Table 4).

Table 4. World Health Organization drinking water standards (9).

Chemical Substance	Maximum acceptable concentrations mg 1^{-1}	Maximum allowable concentrations mg 1^{-1}
pH*	7.0-8.5	6.5-9.2
Dissolved solids	500	1500
Nitrate (NO_3^-)	-	45
Chloride	200	600
Phosphate (PO_4^{3-})	<0.2	0.2
Manganese	0.1	0.5
Copper	1.0	1.5
Lead	-	0.01
Zinc	5.0	15.0

* Units do not apply to pH.

SS. The suspended solids at RUA I to RUA II ranged from 30 to 70 mg 1^{-1} (Fig. 5). The values of SS were higher in the rainy month than in the dry season which could be due to run-off of different suspended solids with rain waters. In all seasons relatively high values of SS were observed at RUA IV. At RUA IV the seasonal influences were the reverse of what was observed at the other points recording lower SS levels in the rainy months (80 mg 1^{-1}) and higher levels in the dry months (2760 mg 1^{-1}). This was possibly due to dilution of brewery effluents by high volume of rain waters. Significantly lower values were observed at RUA V, showing a good recovery of the stream from the pollution in a distance of only 3 km through self purification (10).

Soluble elemental concentrations. Zinc concentrations at RUA I, II and III varied in the range of 31-110 ppb. The lower values were in the rainy season, except for occasional increase observed at RUA III (154 ppb). At RUA IV values ranged between 55 ppb (rainy season) and 530 ppb (dry season) which indicates that the brewery effluents carry high concentrations of zinc. Relatively lower values were recorded at RUA V (Fig. 6).

Soluble copper concentrations at RUA I to III were below the detectable limit and in the dry seasons the maximum detected was about 28 ppb. An increase in concentration was recorded at RUA IV where the concentration ranged between 28 ppb (rainy season) and 15 ppb (dry season). Relatively lower values were observed at RUA V (Fig. 7).

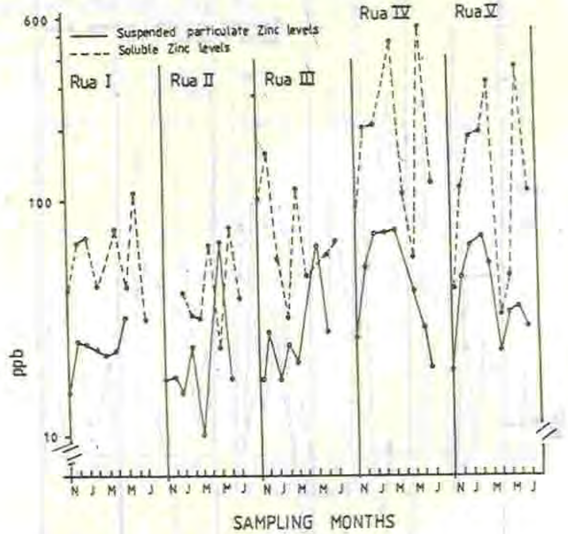

Fig. 6. Zinc levels in Ruiruaka river waters.

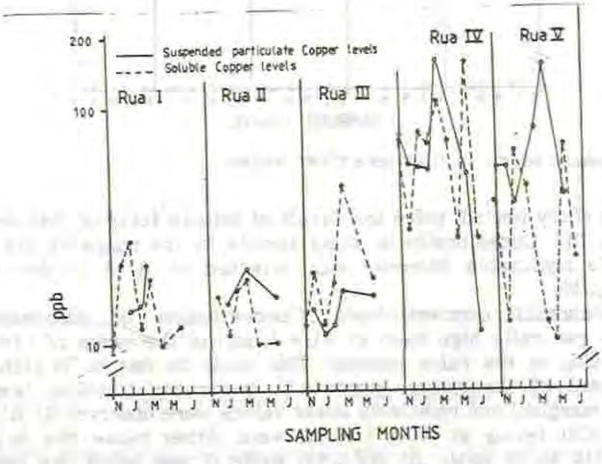

Fig. 7. Copper levels in Ruiruaka river waters.

Soluble form of manganese at RUA I varied between 80 to 4800 ppb, the higher being in April 1985 during rainy months. In the same batch of samples the concentration of Mn at RUA II further increased reaching a value of 6360 ppb. Relatively lower values were observed at RUA III. No significant increase in Mn levels were observed at RUA IV. Substantial increase in soluble form of Mn at RUA I and II suggest run off waters come from Mn rich soils (Fig. 8).

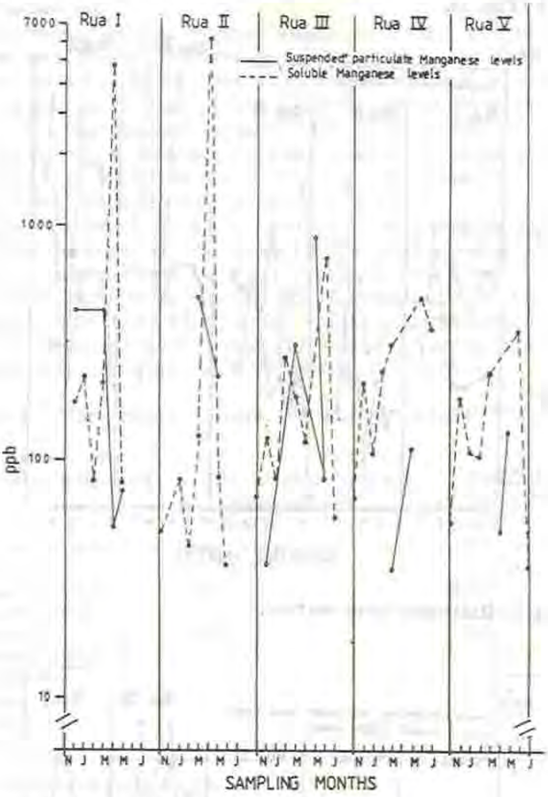

Fig. 8. Manganese levels in Ruiruaka river waters.

During the study period, quite low levels of soluble form of lead were observed at RUA I to III. Occasionally in some sample in the range of 110 ppb Pb was detected. No noticeable increase was detected at RUA IV due to influx of effluents (Fig. 9).

Suspended elemental concentrations. Concentration of suspended form of titanium was generally high even at RUA I, and in the range of 170 to 970 ppb, the higher being in the rainy season. This could be due to Ti rich soils in the catchment area of the river. Increase in suspended titanium levels at RUA IV were only marginal and relatively lower values were observed at RUA V.

Suspended zinc levels at RUA I to III were either below the detection limit or very low (10 to 20 ppb). At RUA IV, while it was below the detection limit in the rainy season, the maximum recorded in the dry season was about 160 ppb (Fig. 7).

Suspended form of Mn was generally low in dry seasons at RUA I to III and the higher values observed in the rainy season suggest that the source of both the suspended and soluble form of manganese was prior to the first sampling point. Influx of brewery effluents had no marked effect on the suspended Mn levels evident from data obtained at RUA IV (Fig. 8).

Suspended lead concentrations in water samples at RUA I to III were below the detection limit except in a few samples at RUA II. Data obtained at RUA IV suggests that there is occasional washing of trace levels of suspended form of lead from breweries (200 ppb) (Fig. 9)

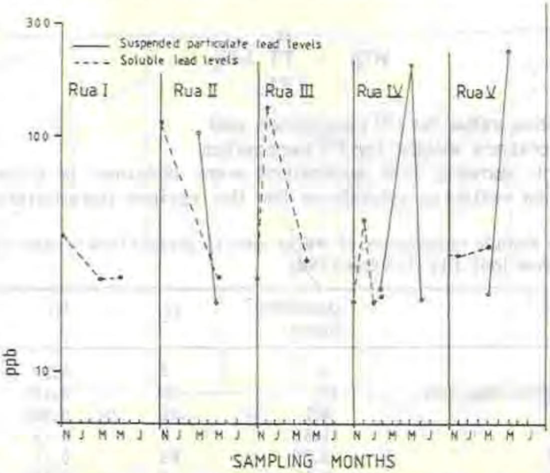

Fig. 9. Lead levels in Ruiruaka river waters.

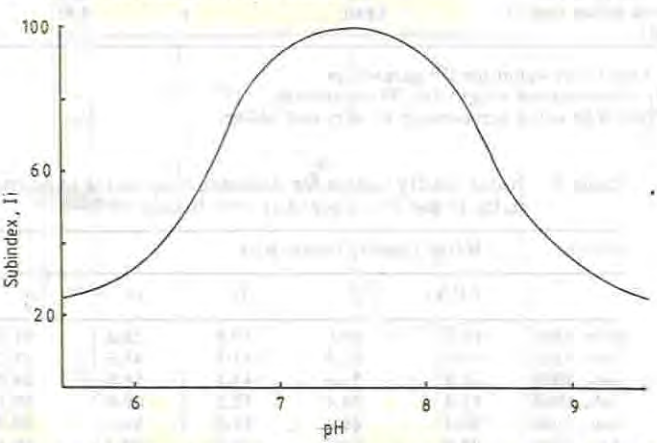

Fig. 10. Variation of Subindex values, I_i, for river water as a function of pH.

A mathematical assessment of the quality status of the water using combined data. The overall quality of the Ruiruaka river waters was estimated using the National Sanitation Foundation Water Quality Index (WQI) commonly used in the USA (10). This combines nine water quality parameters into one numerical indicator of water quality (11-14). The nine parameters used are DO, fecal coliforms, pH, BOD_5, nitrates, phosphates, temperature, turbidity, and toatal solids. Parameters which were not available from Ruiruaka river monitoring data like DO, fecal coliforms and turbidity were estimated using the best judgement from available information. DO was estimated from BOD values based on the general observation that high BOD values are associated with low DO levels. Although DO levels to some extent depend on the turbulance of the waters, high BOD (or COD) qualitatively represent low DO levels. The information was aggregated using a geometric mean:

$$WQI = \prod_{i=1}^{n} I_i W_i$$

where I_i = subindex value for i^{th} parameter, and
W_i = importance weight for i^{th} parameter.

A sample graph showing how subindices were obtained is shown in Fig. 10 for pH. Graphs to estimate subindices for the various parameters were drawn

Table 5. A sample calculation of water quality parameters of Ruiruaka river (point IV) in June 1986.

Variable	Quantity found	I_i	W_i	I_iW_i
DO (mg/l)	3	2	0.17	1.13
Fecal Coliforms (No./ml)	10	90	0.15	1.96
pH	6.7	78	0.12	1.69
BOD (mg/l)	1.68	1	0.10	1.00
NO_3^- (mg/l)	0.78	99	0.10	1.58
PO_4^{3-} (mg/l)	2.9	2	0.10	1.07
Temperature (°C)	2.9	79	0.10	1.55
Turbidity (JTU)	130	3	0.08	1.09
Total solids (mg/l)	1680	3	0.08	1.09
WQI				* 11.7

I_i = subindex value for i^{th} parameter.
W_i = importance weight for i^{th} parameter.
* This WQI value corresponds to very bad water.

Table 6. Water quality indices for Ruiruaka river water at points I, II, III, IV and V in November 1985 to July 1986.

Month	Water Qualtiy Index, WQI				
	RUA I	II	III	IV	V
Nov. 1985	87.7	88.0	70.9	28.3	31.9
Dec. 1985	95.5	52.0	41.7	55.6	47.3
Jan. 1986	81.2	51.8	43.7	56.0	38.3
Feb. 1986	92.4	34.4	42.9	50.8	30.1
Mar. 1986	80.4	89.1	61.5	18.5	35.2
Apr. 1986	65.6	72.3	70.5	50.4	58.6
May 1986	64.8	67.4	62.2	50.5	48.6
Jun. 1986	74.4	71.3	71.6	11.7	26.4
Jul. 1986	84.6	90.4	57.2	20.9	24.9

based on the curves developed by Ott with minor modifications to accommodate the changes in the internationally accepted river water quality standards (11,15). Table 5 shows a sample calculation of WQI values at RUA IV in May 1986. The water quality index obtained was 50.5, which indicates that the water at this point was bad. This follows the stream classification system which is as follows: 0-25, very bad; 26-50, bad; 51-70, medium; 71-90, good; and 91-100, excellent (11). Quality indices for the rest of the data from November 1985 to July 1986 at points I to V are shown in Table 6. The WQI values obtained indicate that

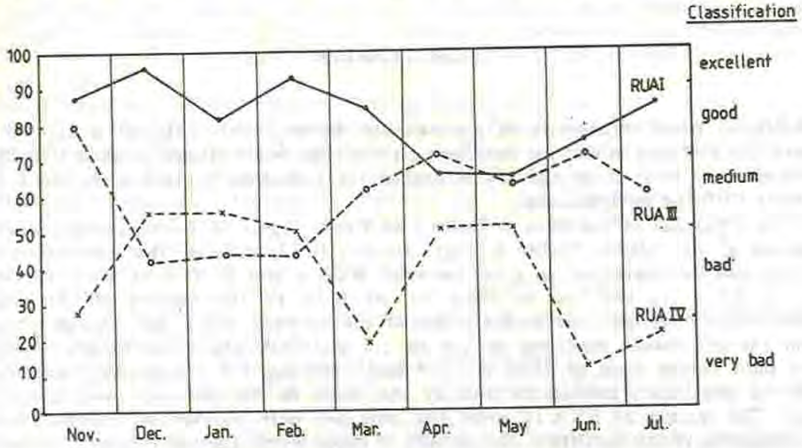

Fig. 11. Comparison of water quality indices at points RUA I and RUA IV.

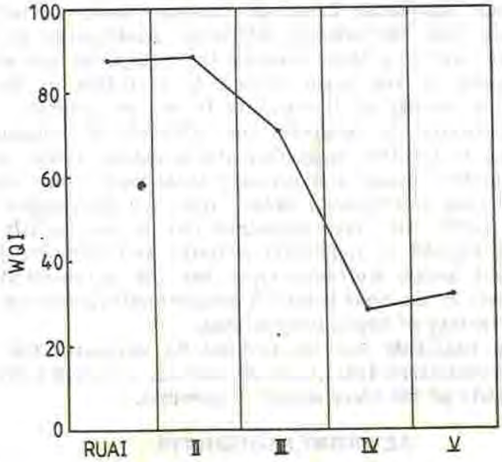

Fig. 12. A graph showing changes in water quality on moving from sampling points I to V in November 1985.

the quality of the water ranged from excellent to good at points I and II, good to medium at point III and deteriorated sharply to very bad to bad at points IV and V. Point V showed some signs of recovery but was still bad. The changes in the water quality indices from points I to V are shown clearly in Figs. 11 and 12.

The drastic change in the quality of waters at RUA IV indicates that brewery discharges is the main point source for the pollution of the Ruiruaka waters. This is supported clearly from the very high levels of quality parameters of brewery discharges as summarized in Table 3.

CONCLUSIONS

Ruiruaka river represents in general and broadly the state of a number of rivers and streams in various developing countries, where there is some industrial development, lack of enough commitment for pollution control to strike a fair balance with the environment.

After a perusal of the data in Table 1 to 4 and Figs. 2-9 and a mathematical analysis of the results (Table 6, Figs. 10-12), the quality of the Ruiruaka river waters can be classified as good between RUA I and II, fair at RUA III, very bad at RUA IV, and bad at RUA V. At RUA IV the quality of the water deteriorated obviously due to the influx of the brewery effluents. This is evident from the pH values reaching as low as 5.5 and BOD and COD values reaching very high values such as 2700 mg 1^{-1} and 2760 mg 1^{-1} respectively explicitly indicate the heavy burden carried by the river in the summer months of the year. The waters at RUA IV were also enriched with substantial concentrations of phosphate which facilitate the growth of biota which further depletes dissolved oxygen in waters. A sign of recovery of the stream was observable in 2-3 km stretch from RUA IV to V. This was some self purification process but was slow. In the rainy months the qualtiy parameters at RUA IV and V clearly show that the river effectively dilutes the pollutants entering in and quickly recovers to a class of moderately polluted river.

Both the soluble and suspended forms of elements observed were well within the acceptable levels, and the brewery effluents contributed to only marginal increase in elemental concentrations. Overall the analytical data clearly pinpoint the brewery discharges as the main source of pollution of the river. This drastically impairs the quality of the waters in the dry season. This could be quite effectively controlled by retaining the effluents in oxidation ponds over a period of few days to let the suspended and dissolved solids to settle down. The retention in oxidation ponds and primary treatment would also bring down the BOD and COD levels of effluents before they are discharged into the river (9). At this stage (1986) the river appeared not to be heavily polluted, but considering the fast growth of industrial activity and increase in settlements in the rain catchment areas, Ruiruaka river has the potential of turning into a heavily polluted drain in the near future if proper controls are not implemented. This would lead to a variety of hygienic problems.

In general aquatic pollution can be tackled by imposing and implementing controls to minimize pollutions from various sources, to avoid a situtation where by no recovery in quality of the river waters is possible.

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