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# RIVER POLLUTION IN DEVELOPING COUNTRIES - A CASE STUDY III: EFFECT OF INDUSTRIAL DISCHARGES ON QUALITY OF NGONG RIVER WATERS IN KENYA

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**ABSTRACT.** Ngong is the major river stream transversing through Kenya's major industrial belt which carries the rain runoff waters, treated and untreated industrial discharges of various types. The effect of treated and untreated industrial effluents on the quality of Ngong waters was studied over a period of one year (Nov. 1985 to Oct. 1986). To assess and characterise the quality of river waters, ten parameters, namely; temperature, pH, conductivity, biochemical oxygen demand, chemical oxygen demand, dissolved solids, suspended solids, chloride, nitrate and total phosphate were monitored at five sampling points at regular monthly intervals and during different times of a day. In addition to the ten parameters, profiles of various elements both in suspended and soluble forms in all the aquatic samples were determined using X-ray fluorescence. The overall quality status of the water was mathematically evaluated using combined data, according to the water quality index (WQI), to enable comparison of this water system with similar bodies of water internationally.

## INTRODUCTION

The problem of river water pollution in the acute form in which it exists in many industrialised countries began in the $19^{th}$ century with the coming of industrial revolution and resulting phenomenal growth of population [1]. In the developing countries there is an increasing awareness to minimise the levels of pollutants discharged into the environment [2]. World bodies like United Nations Environmental Programme (UNEP) are drawing the attention of Nations towards consequences of pollution. The root cause of river pollution has been man's tendency to dilute and disperse wastes than to remove at the source. With the ever increasing population levels, urbanisation and industrialisation, the environment, particularly the rivers and lakes, is considerably polluted even in the developing countries. As a result many river streams in urban areas of developing countries have been converted into heavily polluted drains.

The wastes which are discharged into waterways can be classified into three general types; domestic, industrial and agricultural. Industrial pollution, particularly the presence of organic or inorganic substances is the commonest type and is the most intractable [3].

This communication is the third in the series of river streams investigated in Kenya. The results on Nairobi and Ruiruaka rivers of Kenya have been reported earlier [4,5].

Ngong river, which flows through Kenya's major industrial belt, taking in a whole burden of all types of treated, partially treated and raw effluents, stands as an example of state of river streams in urban areas of most developing countries.

Ngong river acquires it's name from it's place of origin, the Ngong hills, 20 km away from Nairobi. The river flowing through Ngong forest runs into Nairobi dam (occupying approximately 7.5 sq. km) which is a place of various watersports but not surrounded by any sources of pollution. After flowing about 4 km downstreams from the dam, the river enters the country's main industrial belt covering a distance of over 10 km collecting industrial pollutants from industrial activities which include processing of various foods, paints and dye-stuff manufacturing, galvanizing and electroplating, rubber retreading, tanneries and motor repairing. The river then passes through uninhabited land for a distance of about 12 km before reentering residential areas. Effluents from the industrial area oxidation ponds enter the river in the downstream (Fig. 1). The river finally joins Athi river together with Nairobi river [4]. Ngong river has water flow throughout the year but with varying flux depending on the season. In the summer months the flow was lean and the river had an estimated flow of $110 \pm 50$ $m^3$ per minute and $400 \pm 150$ $m^3$ per minute respectively at the first and last sampling points. In the rainy season, such as in the month of May, the volume of flow increased. The flux was about $600 \pm 180$ $m^3$ per minute at the first sampling site while it swelled to about double the volume at the last sampling point.

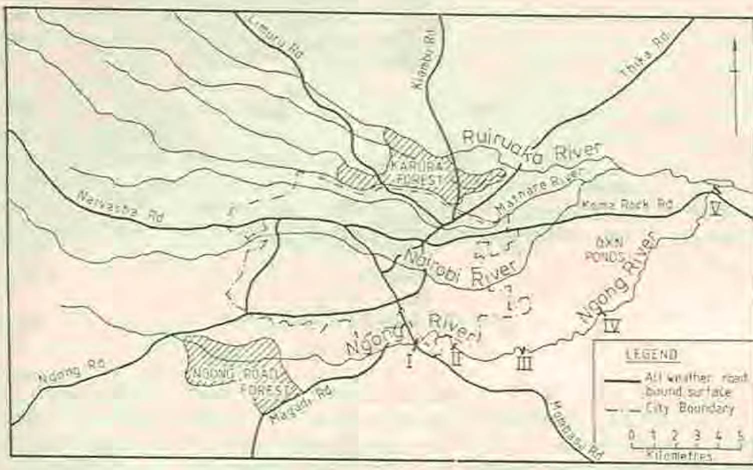


Fig. 1. Map of Nairobi area showing river streams and sampling points on Ngong river.

In the present paper, the results of the detailed studies conducted on Ngong river at 5 sampling points over a period of a year (Nov. 85 to Oct. 86) are communicated.

## EXPERIMENTAL

*Sampling.* Water samples were collected at the identified points about the midstream avoiding air bubbles. All the samples were collected either in 1000 mL or 250 mL polythene bottles, which were soaked in nitric acid and washed with distilled water before sampling. The samples for elemental analysis were collected in 250 mL containers and the pH of the sample was adjusted to about 2 with nitric acid to inhibit metabolic processes and to reduce adsorption of metal compounds to the surface of container [6].

*Methodology.* The temperature of water samples was noted on the site. pH and conductance were measured immediately after reaching the laboratory. All the parameters, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved solids (DS) and suspended solids (SS) were determined employing standard procedures [7-8]. Chloride was determined using Volhard's method [9] and nitrate using the Brucine method [10]. Total phosphate was determined colorimetrically as molybdophosphoric acid [9].

The levels of selected heavy metals in the dissolved form and also in the suspended form were analysed separately, since they exist as soluble and suspended species in the aquatic samples, using X-ray spectrometer comprised of Ortec (SiLi) detector (HWFW-200 eV at 5.9 k eV) and Canberra multichannel analyzer (MCA-40) linked to a professional 350 computer. The excitation source was $^{109}$Cd of energy 22.1 k eV and half life of 453 days [11,12].

*Sampling sites.* Five sites were selected for sampling to study the water quality of Ngong river waters. The selected points stretched over a distance of about 20 km (Fig. 1). Description of the sampling sites is as follows: NGN I (Mombasa road bridge) - point prior to the industrial area, waters flowing from Nairobi dam carrying low levels of pollutants; NGN II (Industrial area pedestrian bridge) - approximately 2 km from NGN I, centre of major industrial activity; NGN III (Enterprise road bridge) - about 3 km from NGN II, surrounded by various industries; NGN IV (Outer ring road bridge) - about 4 km from NGN III, outskirts of industrial area; and NGN V (Njiru) - about 12 km from NGN IV, effluents from industrial area oxidation ponds enter prior to this point.

## RESULTS

The results of the determinations of the various water quality parameters are presented. The analytical data obtained for a typical set of samples are shown in Tables 1 and 2. The profiles of variation of parameters at each sampling point over the seasons are summarised in Figures. A perusal of Figs. 2 to 7 indicates the trends in temperature, hydrogen ion concentration, levels of BOD, COD, DS, SS, chloride, nitrate and phosphate at each point and also broadly areas of origin of pollutants. Figs. 8 to 12 show trends in heavy metal concentrations and Fig. 14 shows WQI values calculated using combined data.

Table 1. Quality parameters of Ngong river water sampled on February 6th 1986.

| Parameter | Sampling points | | | | |
|---|---|---|---|---|---|
| | NGN I | II | III | IV | V |
| Temperature (°C) | 21.9 | 23.5 | 22.1 | 22.0 | 22.1 |
| pH | 7.3 | 8.8 | 9.3 | 7.3 | 7.5 |
| Conductivity(µS $cm^{-1}$) | 254 | 2134 | 401 | 464 | 451 |
| $BOD_5$ (mg $l^{-1}$) | 4 | 230 | 170 | 55 | 6 |
| COD (mg $l^{-1}$) | 88 | 538 | 385 | 395 | 23 |
| DS (mg $l^{-1}$) | 260 | 416 | 360 | 440 | 436 |
| SS (mg $l^{-1}$) | 24 | 228 | 218 | 66 | 6 |
| Chloride (mg $l^{-1}$) | 38 | 36 | 41 | 52 | 58 |
| Nitrates (mg $l^{-1}$) | 0.91 | 0.50 | 0.12 | 0.20 | 0.41 |
| Phosphates (mg $l^{-1}$) | 0.05 | 0.25 | 0.31 | 0.55 | 0.57 |

Table 2. Ngong river waters – concentrations of soluble and suspended matter elements (15th November 1985).

| Element | Precision % | NGN I | II | III | IV | V |
|---|---|---|---|---|---|---|
| | | Sampling sites | | | | |
| soluble elemental concentrations | | | | | | |
| Ti (ppb) | 5.9 | * | * | * | * | * |
| Mn (ppb) | 11.1 | 1,660 | 301 | 740 | 477 | 287 |
| Cu (ppb) | 14.4 | 15 | 48 | 115 | 26 | 10 |
| Zn (ppb) | 12.6 | 31 | 54 | 891 | 200 | 67 |
| Pb (ppb) | 15.4 | * | 58 | 68 | 41 | * |
| suspended matter elemental concentrations | | | | | | |
| Ti (ppb) | | 85 | 180 | 1,440 | 187 | * |
| Mn (ppb) | | 154 | 100 | 30 | 58 | * |
| Cu (ppb) | | * | 50 | 41 | 35 | 16 |
| Zn (ppb) | | 13 | 64 | 146 | 188 | 16 |
| Pb (ppb) | | * | 131 | 195 | 178 | * |

*Below the minimum detectable limit.
These data are the mean of 10 analysed samples.

## DATA ANALYSIS AND DISCUSSION

*Temperature.* Temperature of the Ngong waters at NGN I varied between 18.7 and 22 °C depending on the season. A relative increase in temperature was observed at NGN II in all seasons and the maximum temperature recorded was 24.5 °C. Temperature was found to increase by approximately 1 to 2° at NGN III. Either the same temperature or a slight decrease was observed at NGN IV. In most samples the temperature at NGN V was lower than that at NGN IV, but at least 0.5 to 1° higher than at NGN I, which could also be due to the difference in day temperature during the two hour time difference in sampling time between points I and V. The temperature increase invaribly observed at NGN II and III relative to I suggests modest thermal pollution at these points (Fig. 2).

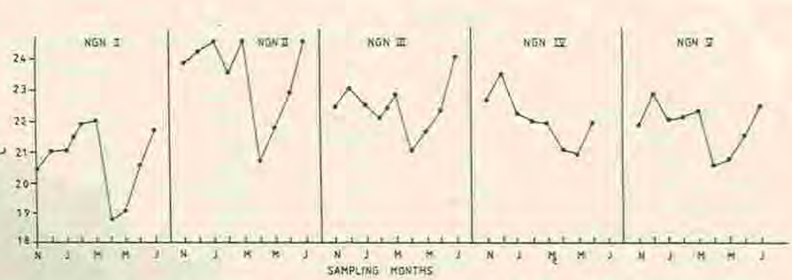


Fig. 2. Temperature profile of Ngong river waters at sampling points.

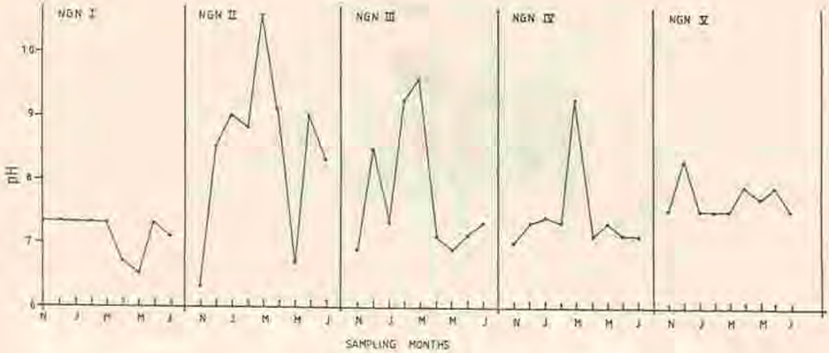


Fig. 3. pH profile of Ngong river waters.

*Hydrogen ion concentration.* A careful look into the pH data (Fig. 3) shows that the pH of the waters at NGN I remained constant at about 7.3 except in the rainy season (April and May 86) during which it was lowered down to pH 6.5. At NGN II and NGN III pH values varied over a wide range, between 6.3 and 10.6, from which one could infer that a complex variety of effluents enter the stream prior to these points [13]. In most of the samples the pH at NGN V stabilized at about 7.5–7.9 except for the occasional high pH values due to influx of alkaline effluents from industrial oxidation ponds.

*Conductance.* The specific conductivity of waters at NGN I was in the range 170–300 µS $cm^{-1}$ indicating little variation in the quality of the water flowing through this point. Lower values were observed during rainy months due to dilution. Conductance values sharply increased at NGN II to as high as 2100 µS $cm^{-1}$ and values remained high even at NGN V, suggesting that considerable amounts of dissolved ionic substances enter the stream and stay in the waters.

*Biochemical oxygen demand (BOD).* Low BOD levels observed at NGN I over the period of study (4 to 8 mg $l^{-1}$) reflect the good quality of waters passing at that point. High BOD values were recorded at NGN II (about 560 mg $l^{-1}$) and NGN III (320 mg $l^{-1}$) showing high concentration of oxygen demanding pollutants in this region. Farther down, at NGN IV and NGN V BOD values were relatively low (6 to 30 mg $l^{-1}$) indicating that self purification processes are very active in this stretch of the stream [14] (Fig. 4).

*Chemical oxygen demand (COD).* COD values in samples at NGN I varied between 40 to 90 mg $l^{-1}$. Perusal of Fig. 4 shows a sharp increase at NGN II relative to NGN I, a 5-fold increase being the common feature, and at occasions increases of up to 20 times were observed. A maximum of a 20 fold increases were observed occasionally. This pinpoints NGN II region as the source of heavy contamination of the river. At NGN IV and V the COD values showed a decreasing trend indicating progressive purification of river waters.

*Dissolved solids (DS).* At NGN I levels of DS varied between 140 and 290 mg $l^{-1}$, lower values being in the rainy season. High values in the range of 1800 mg $l^{-1}$ were noticed at NGN II and NGN III. Values tended to decrease at NGN IV and V, except for the occasional increases at NGN V due to the effluents from the oxidation ponds (Fig. 5).

*Suspended solids (SS).* At NGN I the SS values ranged from 8 to 60 mg $l^{-1}$ over the period of study, higher values being in rainy season. Relative to NGN I high values were recorded at NGN II and III pinpointing these regions as sources

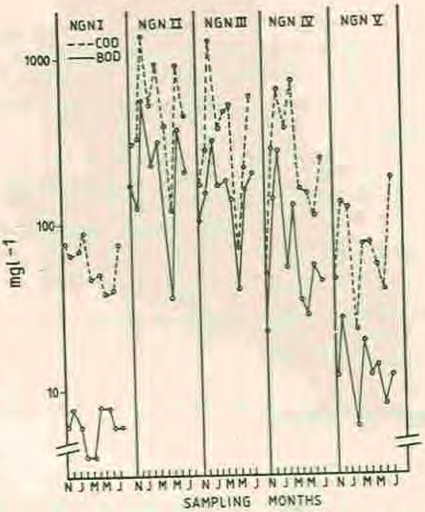


Fig. 4. Biochemical and chemical oxygen demand levels in Ngong river waters at the 5 sampling points in various seasons.

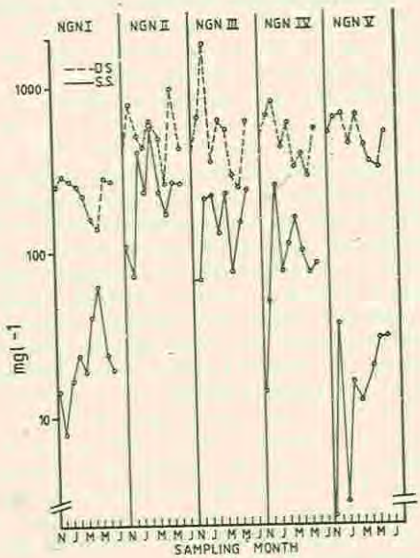


Fig. 5. Dissolved and suspended solid levels in Ngong river waters at different sampling points.

of pollution. Similar to DS, SS also recorded a decreasing trend at NGN IV and V. At NGN V values were in the range of 4 to 40 mg $l^{-1}$ suggesting considerable sedimentation of substances (Fig. 5).

*Chloride*. Chloride ion concentrations at NGN I were found to be in the range 15 to 38 mg $l^{-1}$. A look at the chloride profiles at each point in Fig. 6 indicates that the values at NGN II and III tended to be much higher, but with no distinct trend. High chloride levels at NGN V could be attributed to the effluents from the oxidation ponds.

*Nitrate ($N-NO_3^-$).* Nitrate levels in the water samples ranged from 0.1 to 1.6 mg $l^{-1}$ between NGN I and V during the study period. Nitrate levels were towards the higher limit only in one set of samples (June 86).

*Total phosphate.* Phosphate concentrations at NGN I were quite low, ranging between 0.04 and 0.40 mg $l^{-1}$ $P-PO_4^{3-}$. At all the other points, phosphate levels were observed to be low (Fig. 7) with the exception of the June samples where the levels were upto 1.6 mg $l^{-1}$ at NGN IV.

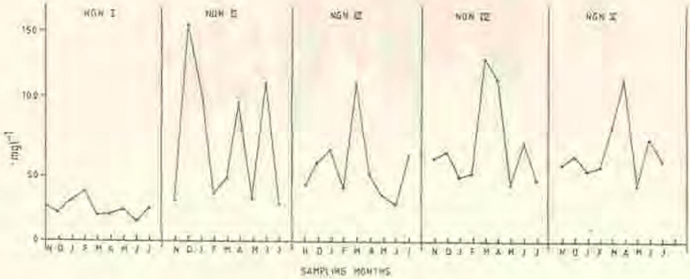


Fig. 6. Chloride levels in Ngong river waters.

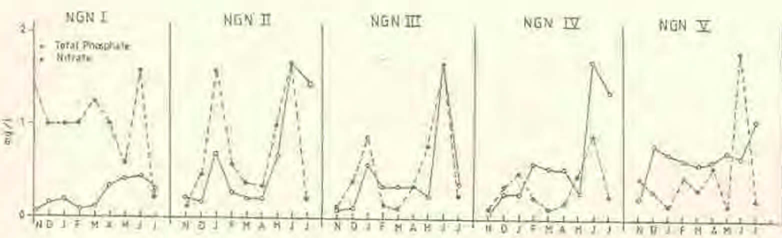


Fig. 7. Nitrate and total phosphate levels in Ngong waters.

*Soluble elemental concentration.* Levels of soluble elements at NGN I were, in general, observed to be lower than those observed in the downstream except in the case of Mn which was found to be higher at NGN I (Figs. 8-12). Levels of soluble zinc increased form 20 to 80 ppb at point I to a maximum of about 300 to 1400 ppb at NGN III. Lead concentrations were observed to be higher at NGN II and NGN III, reaching a peak value of 780 ppb at NGN II (Fig. 12). Copper concentrations also showed a similar trend of high values at NGN II and III, the maximum being 250 ppb at NGN III. Concentrations of all soluble forms of elements were observed low at NGN V, possibly due to precipitation and sedimentation processes.

*Suspended elemental concentration.* Profiles of suspended elemental concentrations are shown in Figs. 8 to 12. While no soluble form of titanium was observed, suspended form was detected in appreciable amounts. At NGN I concentrations in the range of 80 to 580 ppb were recorded during the period of study. Much higher concentrations were recorded at all the points during the rainy season (April and May) (Fig. 11). Although an increasing trend in downstream waters continued, the concentrations of Cu, Zn and Pb were found to be always low and below 30 ppb in most of the samples. At NGN V, in general, all suspended elemental levels decreased to levels comparable to NGN I. The same trend also observed with SS suggests that suspended substances are removed through sedimentation processes [14-16].

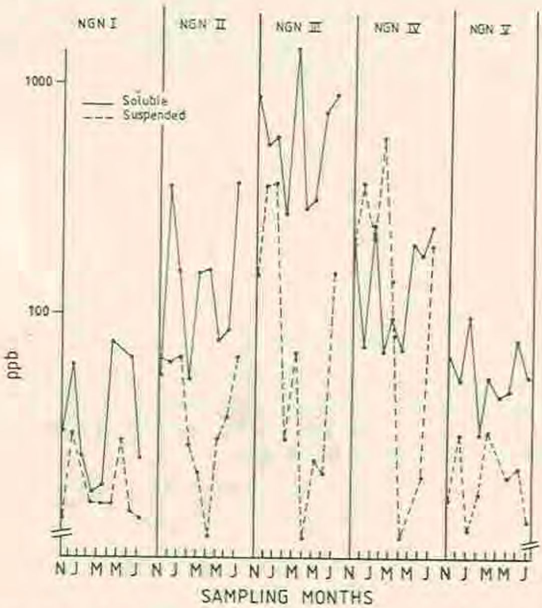


Fig. 8. Dissolved and suspended zinc concentration levels in Ngong river waters.

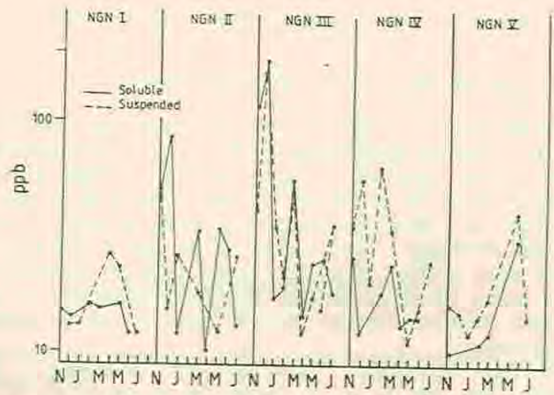


Fig. 9. Dissolved and suspended copper concentration levels in Ngong river waters.

*Diurnal variations in quality parameters.* A perusal of the analytical data obtained for water samples collected in the morning, noon and evening of the same day at sampling points NGN I, II and III show the trends in the pollutant levels during a typical day. A typical day variations in parameters are

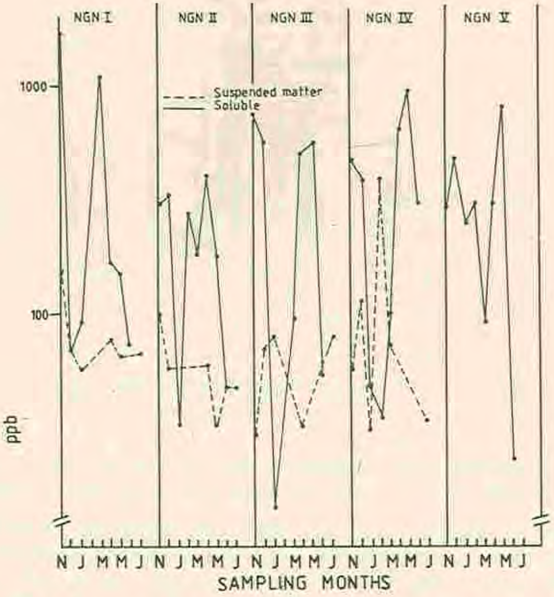


Fig. 10. Dissolved and suspended manganese concentration levels in Ngong river waters.

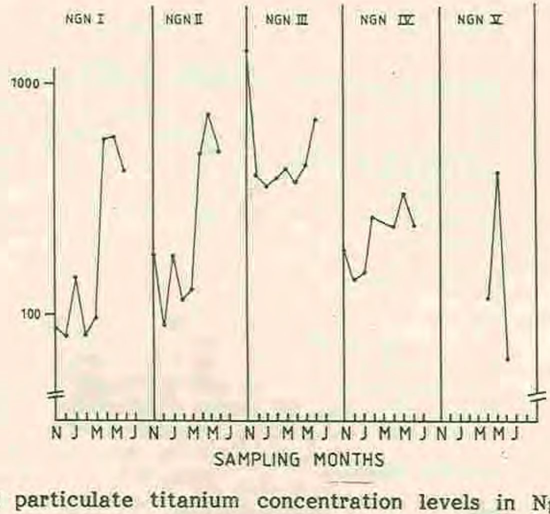


Fig. 11. Suspended particulate titanium concentration levels in Ngong river waters.

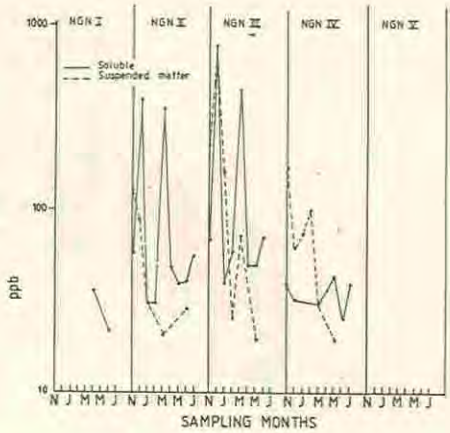


Fig. 12. Dissolved and suspended lead concentration levels in Ngong river waters at different sampling points in different months.

summarised in Tables 3 and 4. At NGN I the pH remained fairly constant, suggesting that no appreciable pollution occurred prior to that point due to the day activities. At NGN II the pH varied over a wide range (7.15 to 8.90) and in some cases it went as high as 11.2 indicating the complex nature of effluents entering the stream.

Table 3. Diurnal variations of quality parameters (19th August, 1986).

| Parameter | Sampling time | | |
|---|---|---|---|
| | 07:00 | 12:00 | 16:00 |
| **Sampling point I** | | | |
| pH | 7.15 | 7.20 | 7.15 |
| Conductivity (µS $cm^{-1}$) | 290 | 316 | 307 |
| BOD (mg $l^{-1}$) | 6 | 6 | 6 |
| COD (mg $l^{-1}$) | 76 | 77 | 84 |
| DS (mg $l^{-1}$) | 282 | 246 | 251 |
| SS (mg $l^{-1}$) | 17.3 | 16.4 | 16.8 |
| **Sampling point II** | | | |
| pH | 8.90 | 7.20 | 7.15 |
| Conductivity (µS $cm^{-1}$) | 279 | 381 | 10,480 |
| BOD (mg $l^{-1}$) | 40 | 475 | 550 |
| COD (mg $l^{-1}$) | 124 | 1,540 | 2,500 |
| DS (mg $l^{-1}$) | 300 | 352 | 5,046 |
| SS (mg $l^{-1}$) | 39.2 | 60 | 367 |
| **Sampling point III** | | | |
| pH | 8.90 | 8.00 | 8.50 |
| Conductivity (µS $cm^{-1}$) | 541 | 454 | 602 |
| BOD (mg $l^{-1}$) | 80 | 315 | 375 |
| COD (mg $l^{-1}$) | 220 | 1,680 | 1,400 |
| DS (mg $l^{-1}$) | 456 | 516 | 666 |
| SS (mg $l^{-1}$) | 29 | 38.4 | 61 |

Table 4. Diurnal variations in soluble and suspended elemental concentration (19th August, 1986).

| Soluble elemental concentrations | | | |
|---|---|---|---|
| Parameter | Sampling time | | |
| Element (ppb) | 07:00 | 12:00 | 16:00 |
| Sampling point I | | | |
| Cu | 13 | 14 | 12 |
| Zn | 53 | 23 | 25 |
| Pb | 52 | 24 | 35 |
| Ti | * | * | * |
| Sampling point II | | | |
| Cu | 18 | 46 | 60 |
| Zn | 50 | 87 | 204 |
| Pb | 89 | 107 | 558 |
| Ti | * | * | * |
| Sampling point III | | | |
| Cu | 27 | 34 | 421 |
| Zn | 173 | 258 | 891 |
| Pb | 96 | 136 | 903 |
| Ti | * | * | * |
| Suspended matter elemental concentrations | | | |
| NGN I** | | | |
| Ti | 116 | 66 | 70 |
| NGN II** | | | |
| Ti | 49 | 32 | * |
| Sampling point III | | | |
| Cu | * | 30 | 39 |
| Zn | * | 18 | 17 |
| Pb | * | 22 | 25 |
| Ti | 17 | 107 | 891 |

* Below the minimum detection limit.
** Levels of suspended Cu, Zn and Pb were below the detection limit.

The diurnal conductance values at NGN I varied in the range 290 to 320 µS $cm^{-1}$. The values increased considerably at NGN II and III with the progress of the day. Similarly, low BOD and COD levels were noticed at NGN I throughout the day, while substantial increases were recorded at Points II and III. A 20 to 30 fold increase in COD recorded from morning to evening at NGN II is an index of serious nature of pollution occurring at this point. While the levels of dissolved and suspended susbstances at NGN I remained the same for the whole day, the levels at NGN II and III were found to rise with the progress of the day. The considerable increases in DS at NGN II and III very much agree with the high COD levels observed in the same samples.

The concentrations of trace elements observed at NGN I were generally low and diurnal variations were insignificant. Maintaining the same trend as the other quality parameters the levels of soluble elemental concentrations at NGN II and NGN III were found to increase from morning to evening. It is a distinct proof that level of pollution of the stream is associated with the daily anthropogenic activities in the vicinity.

*Levels of pollutants in the oxidation pond outlet.* Since effluents from industrial area oxidation ponds flow into Ngong river between NGN IV and V, the diurnal variations in the quality of waters flowing out from oxidation ponds were monitored on different days. Tables 5 and 6 summarise the diurnal variations on a typical day. A perusal of the results in Tables 5 and 6 show that although no distinct pattern is noticeable, in general, the pollutant levels were higher than at NGN IV.

Discharges from oxidation ponds were more alkaline and had high phosphate levels in the range of 5 mg $l^{-1}$. Elemental concentrations in the oxidation ponds discharges, particularly the soluble form, were higher than in the stream

Table 5. Quality parameters for oxidation pond (outlet) sampled on (20th August, 1986).

| Parameter | Sampling time of the day | | |
|---|---|---|---|
| | 07:00 | 12:00 | 16:00 |
| Temperature (°C) | 18 | 19.8 | 23.5 |
| pH | 9.2 | 9.0 | 9.0 |
| Conductivity($\mu S\ cm^{-1}$) | 633 | 639 | 635 |
| $BOD_5$ ($mg\ l^{-1}$) | 13 | 16 | 14 |
| COD ($mg\ l^{-1}$) | 108 | 139 | 124 |
| DS ($mg\ l^{-1}$) | 508 | 528 | 516 |
| SS ($mg\ l^{-1}$) | 58 | 52 | 58 |
| Chloride ($mg\ l^{-1}$) | 73 | 75 | 77 |
| Nitrates ($mg\ l^{-1}$) | 0.75 | 0.71 | 0.68 |
| Phosphates ($mg\ l^{-1}$) | 5.02 | 4.57 | 4.63 |

Table 6. Quality parameters of the water samples from industrial area oxidation pond outlet at defferent times of day, 20th August 86. Soluble and suspended elemental concentrations.

| | Sampling time | | |
|---|---|---|---|
| Parameters | 07:00 | 12:00 | 16:00 |
| Soluble elemental concentrations | | | |
| Cu (ppb) | 15 | 21 | 12 |
| Zn (ppb) | 60 | 258 | 69 |
| Pb (ppb) | 21 | 75 | 31 |
| Mn (ppb) | 1012 | 1231 | 2704 |
| Suspended elemental concentration | | | |
| Cu (ppb) | * | * | 13 |
| Zn (ppb) | * | 15 | * |
| Pb (ppb) | * | 20 | 18 |

* Below the minimum detectable limit.

water at NGN IV, explaining the observed occasional increases in levels of pollutants at NGN V compared to NGN IV.

The monitoring of the various quality parameters and levels of pollutants in Ngong river samples over a period of one year show that the river waters are polluted indiscriminately by industrial effluents throughout the whole year. A steady and sustained increase in pollutant levels at NGN II and III with the progress of the day clearly indicates a relationship between pollution levels and industrial activities. From the quality parameters recorded at NGN V, although some self purification of the river is evident, strict measures need to be taken to treat the industrial effluents controlling the pollutant levels prior to discharge into waterways. Industries should be encouraged to give secondary and tertiary treatments to the wastes before discharged into the streams. Prevention is always better than cure.

*Mathematical assessment of the quality status of the waters using combined data.* The overall quality status of the Ngong river waters was estimated using the National Sanitation Foundation Water Quality Index, NSF-WQI, commonly used in the USA [16] with some modifications to accommodate differences in the actual parameters. This combines nine water quality parameters into one numerical indicator of water quality [17-20]. This mathematical assessment provides an easily visualizable single figure for comparison of the quality status of this water with similar bodies of water internationally. The nine pollutant variables commonly used are DO, fecal coliforms, pH, $BOD_5$, nitrates, phosphates, temperature, turbidity, and total solids. Ten water quality parameters were monitored in the evaluation of the Ngong river waters. These were pH, conductivity, $BOD_5$, COD, $NO_3^-$, $P\text{-}PO_4^{3-}$, temperature, suspended solids, total solids and chlorides. All the ten parameters were considered in the evaluation. DO, fecal coliforms and turbidity were not monitored in the NGN study and parameters like conductivity, COD and suspended solids are not commonly included in the WQI assessments. These differences are accommodated through appropriate modifications. DO is a very important parameter but was not measured in this survey. It is, however, represented indirectly by $BOD_5$ and COD values. Generally $BOD_5$ and COD values are inversely proportional to DO values, although this might change depending on the turbulance of the water system. Fecal coliforms were not important here because the pollutants of interest were mostly physicochemical rather than microbiological. Turbidity is represented by suspended solids because the two are directly proportional to each other.

The importance weights were modified slightly to accommodate the tenth parameter. The importance weights were allocated as follows: pH, $BOD_5$ and COD were considered most important and were each given an importance weight of 0.12; $NO_3^-$, $P\text{-}PO_4^{3-}$, conductivity and temperature were given a weighting of 0.10 and the rest were given an importance weight of 0.08. The rationale for these weightings is from a survey carried out by Ott in 1972 using a number of environmental scientists in the United States [17,18]. The sum of the importance weights is 1.00. The ten parameters were aggregated using the geometric mean

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

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

Graphs to estimate the various subindices for the various parameters were based on the curves by Ott with minor modifications to accommodate the changes in the internationally accepted river water quality standards [21]. Graphs used to obtain subindices for $Cl^-$, SS and conductivity are shown in Figs. 13a, b and c respectively. Table 7 shows a sample calculation of the WQI values at NGN II for samples collected on 6th February, 1986. The overall WQI values obtained are summarized in Table 8 and illustrated in Fig. 14.

The overall quality of the water started from a WQI values of about 65 at NGN I, then fell down to between 20 and 40 at NGN II, III and IV, and went back up to about 50 to 60 at NGN V. This indicates a change in the quality of the water from medium to very bad on progressing from point I to IV and a recovery back to medium at point V. This description follows the stream water classification system suggested by Ott [16,17] which is as follows: 0-25,

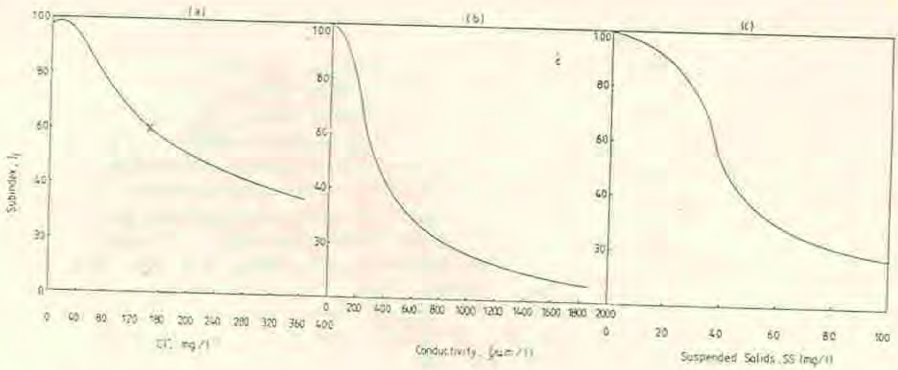


Fig. 13. Variation of subindex values, $I_i$, for river water as a function of (a) chloride, (b) conductivity and (c) suspended solid levels.

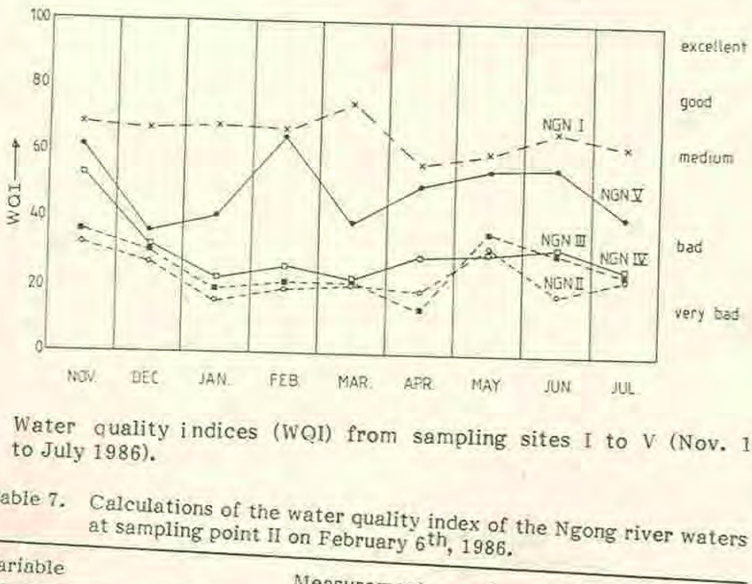


Fig. 14. Water quality indices (WQI) from sampling sites I to V (Nov. 1985 to July 1986).

Table 7. Calculations of the water quality index of the Ngong river waters at sampling point II on February 6th, 1986.

| Variable | Measurement | $I_i$ | $W_i$ | $I_iW_i$ |
|---|---|---|---|---|
| pH | 8.8 | 50 | 0.12 | 1.60 |
| Conductivity($\mu S\ cm^{-1}$) | 2134 | 10 | 0.1 | 1.26 |
| $BOD_5$ ($mg\ l^{-1}$) | 230 | 2 | 0.12 | 1.05 |
| COD ($mg\ l^{-1}$) | 538 | 5 | 0.012 | 1.21 |
| $NO_3^-$ ($mg\ l^{-1}$) | 0.5 | 100 | 0.1 | 1.5 |
| $P\text{-}PO_4^{3-}$ ($mg\ l^{-1}$) | 0.25 | 40 | 0.1 | 1.45 |
| Temp. deviation (°C) | 1.6 | 92 | 0.1 | 1.57 |
| Suspended solids ($mg\ l^{-1}$) | 228 | 5 | 0.08 | 1.13 |
| Total solids ($mg\ l^{-1}$) | 664 | 20 | 0.08 | 1.27 |
| $Cl^-$ ($mg\ l^{-1}$) | 36 | 98 | 0.08 | 1.44 |

WQI value = 19.6,
$I_i$ = Subindex value for $i^{th}$ parameter, and
$W_i$ = importance weight for $i^{th}$ parameter.

Table 8. Water quality indices, WQI, for Ngong river water at points I, II, III, IV and V from November 1985 to July 1986.

| Month | NGN I | II | III | IV | V |
|---|---|---|---|---|---|
| Nov. 85 | 68.8 | 33.2 | 36.0 | 53.1 | 62.2 |
| Dec. 85 | 67.3 | 27.6 | 30.1 | 30.9 | 35.6 |
| Jan. 86 | 68.4 | 16.8 | 19.7 | 22.5 | 40.7 |
| Feb. 86 | 67.4 | 19.6 | 21.2 | 25.9 | 65.0 |
| Mar. 86 | 75.1 | 20.8 | 21.4 | 21.2 | 39.4 |
| Apr. 86 | 57.6 | 19.1 | 14.1 | 29.5 | 50.2 |
| May 86 | 60.4 | 32.2 | 36.8 | 35.0 | 55.2 |
| Jun. 86 | 67.4 | 18.4 | 30.7 | 32.2 | 56.3 |
| Jul. 86 | 62.8 | 23.1 | 24.0 | 26.3 | 41.1 |

very bad water; 26-50, bad; 51-70, medium; 71-90, good; and 91-100, excellent. Fig. 14 shows quality indices for the rest of the data from November 1985 to July 1986 at all the five sampling points.

If the waters of NGN river are compared to those of Ruiruaka river [5] using the WQI values, it can be seen that the NGN river waters are much more heavily polluted.

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