THE EFFECTS OF INDUSTRIAL AND DOMESTIC EFFLUENTS ON THE QUALITY OF THE RECEIVING WATERS OF NAIROBI, NGONG' AND RUIRUAKA RIVERS.

BY

ROWLAND WITKINS ODIPO

A thesis submitted in partial fulfilment for the degree of MASTERS OF SCIENCE of the University of Nairobi.

This is my original work and has not been presented in any other University

Odipo

ROWLAND WITKINS ODIPO

This work has been submitted for examination with our approval as University Supervisors.

(1) Sreekanth

DR. J.B. SREEKANTH
DEPARTMENT OF CHEMISTRY
UNIVERSITY OF NAIROBI

(2)

PROFESSOR SHEM O. WANDIGA
DEPUTY-VICE CHANCELLOR
(ADMINISTRATION AND FINANCE)
UNIVERSITY OF NAIROBI

ACKNOWLEDGEMENTS

I greatly appreciate the active assistance and support provided by my Supervisors, Dr. J.B. Sreenkanth and Professor Shem O. Wandiga which made completion of this project possible. I am also grateful to the Centre of Nuclear Science, the Ministry of Water Development (Research Division), and the City Commission for the great assistance they offered during the study. The author is most grateful to the National Council for Science and Technology for the sponsorship of my studies at the University of Nairobi and financial support for the project.

I also wish to thank the Chairman of the Department of Chemistry Dr. A.H. El-Busaidy for his assistance, UNEP staff for photocopying assistance and to all those unmentioned who contributed towards the success of the project.

Last but not the least, I would like to extend my appreciation to my parents, brothers and sisters for their continued encouragement during these times.

CONTENTS

CHAPTER ONE

CHAPTER TWO

LIST OF CONTENTS PAGE.

CHAPTER THREE

LIST OF CONTENTS. PAGE

CHAPTER FOUR

LIST OF CONTENTS PAGE

CHAPTER FIVE

LIST OF CONTENTS PAGE

LIST OF TABLES

LIST OF FIGURES

APPENDIX (TABLES)

ABSTRACT

The effect of various pollutants on the quality of the major river streams passing through Nairobi Province namely Nairobi, Ngong' and Ruiruaka rivers is studied. The investigations have been carried out over a period of one year (Nov. 1985 to Nov. 1986) collecting water samples from the river streams at different identified points at regular monthly intervals. To assess and characterise the quality of the river waters, the following parameters were monitored in the water sample:-

(a) Temperature
(b) Hydrogen-ion concentration
(c) Conductivity
(d) Biochemical oxygen demand
(e) Chemical oxygen demand
(f) Dissolved solids
(g) Suspended solids
(h) Chlorides
(i) Nitrates
(j) Total phosphates

In addition to the above parameters the profile of the various elements present in the aquatic sample was monitored with special attention to the presence of toxic elements using X-ray fluorescence. The type of pollutant and reaction of pollutions in all the three river streams were identified.

Variation in levels of pollutants and changes in the level of pollutants were studied at selected points at different times of the day.

The study revealed that the level of pollutants varied considerably in different samples at the same sampling points depending on the season and the time of the day.

The result for Temperature, Hydrogen-ion concentration and Conductivity showed a general trend for all the three rivers, with lower values being observed during the rainy season (April and May). Biochemical oxygen demand values were noted to be higher during the dry seasons, and were observed to range between 20-400, 36-560 and 34-2,700 mg l^{-1} at the same sampling points on the three rivers Nairobi, Ngong' and Ruiruaka respectively, with the lower values being observed during the rainy seasons. Chemical oxygen demand values showed similar trends. Dissolved solid concentrations were noted low during the rainy seasons, whereas at these times higher concentrations of suspended solids were recorded. Nitrate and Total phosphate concentrations were observed to be higher during the rainy seasons.

The suspended matter elemental concentrations were generally observed to be higher than the soluble elemental concentrations during the rainy season.

Pollution trends in the rivers was found to be generally dependant on the time of the day (i.e. on human activity). This was evident from the increasing trends adopted by the Conductance, Biochemical oxygen demand, Chemical oxygen demand, Dissolved and Suspended solid values recording during samplings at selected sampling points on the rivers at 07:00,

12:00 and 16:00 hours. This trend was most evident in Ngong' and Nairobi river waters.

Elemental concentrations recorded during these samplings also support the fact that pollution along these rivers was time dependant. In the Ngong' river waters the increases in elemental concentration with the progress of the day was most significant. Copper was recorded between 27-421 ppb, Zinc 173-6,891 ppb and Lead 96-903 ppb at the same sampling point with the progress of the day. The high concentrations were generally recorded in the later afternoons. In most cases observed, the elemental concentrations in Ngong' waters tend to be above the legislative limits for drinking waters. All the analytical data were presented in the form of figures and tables.

The result obtained were discussed.

CHAPTER ONE

1.1 INTRODUCTION

The problem of river pollution in the acute form in which it exists in many countries began in the 19th century with the coming of industrial revolution and the resulting phenomenal growth of population. The history of our country, Kenya, has also been characterized both by a continous growth in population and by an increase in per-capita use of water. The country has also undergone considerable industrial growth in the recent years. Thus due to ever increasing population level, urbanization and industrialisation being experienced in this country, some of the enviroment has and is being polluted, particularly the rivers, as during the growth of most of the towns and cities many of the streams have been enclosed or otherwise converted into drains

The root cause of the river pollution problem has been man's tendency to dilute and disperse wastes than to remove them at the source. Thus river water has always been an obvious diluent for wastes. The commonest of pollution causing the most trouble to river authorities are liquids (which include solids in suspension) and this is generally caused by discharge of sewage and industrial wastes into rivers.

The waste which are discharged into our waterways can be clasiffied into three general types; domestic, industrial and agricultural. Chemical pollution due to the presence of organic or inorganic substances is in general the commonest type of pollution and the most intractable.

Organic pollution is due to the presence of protein, fats, carbohydrates and other organic substances and materials found in sewage and trade wastes. These carbohydrates when discharged into the stream supply an abundant food source for bacteria and fungi. The metabolic activities of these organisms consume these wastes and deplete the dissolved oxygen through biochemical reactions and the stream quickly become anaerobic. Two decades ago, interest in organic contaminants per se in surface water was limited principally to concern about taste and odour in drinking water. Today several hundreds of thousands of natural and synthetic organic compounds are collectively or individually of interest in the evaluation of water quality. The effect of organic contaminant on surface water and it's use are becoming increasingly important. The effects may be classified as effect on man, stream and industry. The industrial sources contain the greatest concentration of organics in their waste stream. Domestic waste concentration have been found to be intermediate among the concentration found in the industrial sources [1].

It is known that an important means of understanding the chemical conditions which prevail in the natural water is through the measure of the hydrogen-ion concentration (pH) [2]. Owing to the great variety of substances which occur in water or make contact with it, numerous compounds may be present which contribute ionized hydrogen . In various kinds of natural unmodified water, hydrogen-ion concentration vary from at least 5.5 to 10.5 inclusive. Ordinarily the surface water of larger lakes undergo relatively small changes in pH from season to season [3]. Most unpolluted major streams, exhibit a pH value on the alkaline side of neutrality. Maintenance of a normal pH range in aquatic ecosystem is fundamental to the survival of fish population. Fish can tolerate unpolluted water between pH 5 and 9. But even within this range pH can have marked effect upon behaviour of certain species of fish [4]. The chemistry of the water particularly the pH, has a marked effect upon the toxicity of substances commonly present in industrial waste [5]. Several sources contribute to a lowering of the natural pH range below an acceptable level. These include discharge of industrial effluents, flushing of peat bogs by heavy rainfall and contamination from mine acid drainage. A more recent cause of increase acid level occur as a result of the formation of 'acid rain' from airborne smelter emissions. It is observed that there is a general decline in spermatogenesis in fish with declining pH.

Temperature of a watercourse also has a marked effect on the toxicity of effluents, in general, toxicity of a substance increase when water temperature increase. Temperature of a watercourse varies, even seasonally due to weather conditions and also can be markedly affected by the discharge of heated effluents [6]. Thermal pollution is potentially one of the most critical of all water pollution problems. Fish in common with most living organisms can tolerate a relatively narrow range of temperature. It is known that water temperature is of prime importance in determining the distribution of fish species [5]. Increase in water temperature has a marked and measurable effect upon the other organism in the stream including the aquatic bacteria. When a rise in temperature occurs in a stream polluted by organic matter there is not only a disapperance of dissolved oxygen due to lower solubility of oxygen at high temperature but also an increased rate of utilization of dissolved oxygen by biochemical reaction which proceed much faster at higher temperature. Another harmful consequence of a discharge of water is that it tends to encourage excessive growth of sewage fungus and of water weeds, which may in some cases interfere with the stream flow and so cause flooding. The temperature of water will affect both reaction rates so that these factors must be allowed for in developing a relationship between receiving water flow and degree of treatment required.

The temperature of water of receiving stream has a direct bearing on organic waste assimilation capacity, the temperature of air and other climatic parameters govern the dissipation of waste heat. The temperature of water is important to aquatic life and it influences the microbial self-purification of the stream [7 - 8].

Specific conductance measurements are frequently used in water analysis to obtain rapid estimates of the dissolved solid content of a water sample. In general the range of specific conductance of natural water should approximate that of the total dissolved solids [9]. Conductance values may be used as a guide in selection of laboratory procedures for determining dissolved constituents and to indicate the dissolved solid content of water closely enough for many other purposes. The total concentration of dissolved substances or minerals in natural water is also a useful parameter in describing the chemical density as a fitness factor and as a general measure of edaphic relationship that contribute to productivity within the body of water [10]. In drinking water the maximum recommended total dissolve solid concentration is 500mg l^{-1}.

The amount of suspended solid in river water not only depends on the quality and quantity of discharge waste, but also on process occuring in the whole catchment and in the river bed itself [11].

The insoluble matter in suspension is one of the commonest form of pollution being present in sewage and in most industrial wastewaters. The suspended matter in sewage is largely organic in nature [12]. It has been found that fish can exist in river containing upto 75 ppm of suspended solids of various types [13]. It is however, difficult to draw an exact demarcation line between harmful and harmless suspended solid concentrations. Certain conditions of acidity may liberate toxic metals in a soluble condition from suspended matter contaminated by metallic compounds and so lead to fish mortality. Light penetration can be reduced by about 50% in muddy water and by about 75% in very turbid water [14].

Nitrate in drinking water was first associated in 1945 with a temporary but sometimes fatal blood disorder in infants. Nitrates do not occur normally in high concentrations in natural surface water because it is readily taken up by plants, concentrations of nitrates in surface water is usually below 5mg l^{-1} [15]. The presence of substantial concentrations of ammonium, nitrite or nitrate forms of nitrogen often is an indication of contamination by organic wastes. Nitrates presence in water can arise from sewage effluents, drainage from agricultural land applied with industrial nitrogeneous fertilizer and effluents from certain industries [16].

European standard for drinking water recommend a nitrate concentration of between 50 and 100 mg l^{-1} nitrate as NO_3 and this is defined as acceptable range [17]. Nitrogen compounds normally exhibit conspicous seasonal fluctuations and pronounced variations along the gradient in small streams. Nitrate concentrations are of importance in natural water for many reasons e.g. the importance in eutrophication and their responsibility for methaemoglobinaemia. It has been observed that young infants receiving artificial feed of milk diluted with water containing more than 10 - 20 ppm of nitrates (expressed as N) may develop a disease called methaemoglobinaemia where no causes are observed amongst breast-fed infants.

Phosphate compounds of streams are derived from biological and chemical process along the course of the stream. The phosphate content of sewage has risen appreciably as a widespread use of synthetic detergent which always contain phosphate as a builder and this has caused a corresponding increase in the phosphorous contents of the receiving streams. Fairly there is a general agreement that municipal and private treatment works contribute the largest amount to the receiving waters. Substantial increases in this nutrient occur in the portion of the river that receive these effluents.

One of the more important reasons for determining the concentration of this nutrient is that it is often the nutrient that also limit the growth of **photosynthetic** aquatic macro and micro-organisms.. Reliable data on phosphate content of surface water are scarce because this determination is not generally included in the chemical analysis of water. Except in unusual instances the amount present in natural surface water is small. Total phosphorous concentration in United States rivers now range from roughly 0.01 to 1.00mg l^{-1} although local geochemical factors and industrial activity such as mining can cause higher values [18].

Chloride occur in all natural waters in widely varying concentrations. Natural unpolluted waters may contain upto 10 - 20mg l^{-1} chloride. The chloride content increase and gains access to natural water in many ways but in reasonable concentrations it is not harmful to human. Concentration above 250mg l^{-1} give a salty taste to water which is objectionable to many people [19]. In small concentrations it is harmless to fresh-water fish. Drainage from a salt works and brine from water softening plants using ion exchange method of softening are liable to contain large amounts of chloride which may pollute a freshwater stream.

Biochemical oxygen demand (B.O.D.) is one of the most widely used measures of aquatic pollution.

B.O.D. test is essentially a bioassay method including measurement of quantities of oxidizable organic wastewater under controlled conditions. The test is useful for providing an estimation of the amount of oxygen likely to be consumed by a given amount of waste upon discharge to a receiving water [20]. BOD test is subjected to interference from certain substances which exhibit toxic effect on organisms involved in the biological breakdown of organic matter.

One of the other important parameters for water quality analysis is chemical oxygen demand (COD), which is based on measurement of dichromate consumed in the oxidization of organics. Chloride and oxidizable inorganic materials found in industrial waste-water, present certain interferences for this test. The test is very valuable for evaluation of waste for which BOD test is not applicable due to the presence of toxic material. In many instances the COD test is much more useful as a non-specific analytical method even for estimating the oxygen requirement of industrial wastewaters, than is the BOD test.

Heavy metal and other trace elements are a natural constituent of the aquatic enviroment and of living matter. Elements can be divided into those which are known to be essential for animal (human) life and those with no known functions in living organisms (non-essential). The latter type are characterized by severe toxicological effects at extremely low levels. At present, 14 elements are believed to be essential for animal life viz iron, iodine, copper, zinc, manganese, cobalt, molybdenum, selenium, chronium, nickel, tin, silicon, flourine and vanadium [21]. Mercury, cadnium, chronium, vanadium etc are non-essential elements whose toxicity is of major enviromental concern. The fact that a metal is toxic, does not automatically imply that it will produce adverse health or enviromental effects when released into the enviroment. Toxicity refers to the potential of a given metal to cause harm in organisms, and particularly the extent of such damage. Indeed, all metals are probably toxic, if ingested in excessive amounts. The toxicity of heavy metal is a result of their binding to active site of important enzyme systen in the cells and to some ligands in the membrane of the cells, thereby interfering with membrane and cell function. Heavy metal are generally considered to be toxic chiefly in the soluble ionic form. Toxicity is known to be reduced in hard water and although bicarbonate hardness may decrease some active metal concentration by precipitation this alone is insufficient to explain the observed reduction in toxicity [22].

The natural concentration of heavy metal in the hydrosphere are extremely low. This is due to the high reactivity of metals in solution, as they may be removed by a variety of physiochemical and biochemical process to the biotic and inorganic particulate phase. The extent to which heavy metal ions (Cu, Pb, Zn and Cd) are removed from aqueous solutions by clay suspension has been shown to vary with the nature of the clay solution, pH concentration of competing cations and the nature of the concentration of any ligand present (22). The amount absorbed increases gradually with pH until the threshold value for formation of sparingly soluble hydroxyl complexes is reached.

In surface waters the concentration of various elements may be increased beyong their natural levels due to the release of industrial, agricultural, domestic and other waste. Though some elements are mainly available in dissolved forms. the major part and especially the heavy metal, may be bound to particulates. The ecology impact of these heavy metal is receiving increasing attention. The trace heavy metals are absorbed to suspended matter or dissolved in the water may ultimately be hazardous to health, when they become available to man either directly via drinking water or indirectly through various food chains. The metal can sometimes have adverse effects on living organisms in receiving water [23]. The intrusion of heavy metal and their salts into the interrestial and aquatic enviroment and their accumulation in biotic system can induce several structural and functional alterations in the biota.

Lead is a natural constituent of air, water and biosphere. Lead is relatively abundant in nature and occurs in association with zinc and copper in polymetallic ores. It is a highly toxic metal which is widely distributed in the enviroment, primarily because of its emission in automobile exhaust. It's largest single use is in the manufacture of storage batteries, more than half of which is recycled so that this source is not widely distributed in the enviroment. The second largest use of lead is as an antiknock additive in gasoline. Smaller amounts are used in smelter process, paints, pigments, solder bearing metal etc. The natural emission of lead to the atmosphere result mainly from soil erosion and volcanic activity.

Lead has been of some concern to the health of man for centuries. Human exposure to lead is via food, air and water. About 90% of airborne lead is derived from the exhaust gases of the automobile industry. Plumbism, a disease attributable to acute pb poisoning has been known since the antiquity of Greek poet physician, Nicander having described it over 2,000 years ago [24]. The toxicity of lead is based on the fact that it is a potent enzyme inhibitor because it binds sulphdryl (SH) group. It also inhibits the synthesis of heme and utilization of iron in the body. The first sign of physiological impairment due to lead, is the inhibition of the enzyme catalizing formation of heme. The clinical manifestations of lead poisoning are:- abdominal colic, anaemia, renal damage, neuropathy are rarely encephalopathy. It has been found that the body can excrete upto about 0.3 mg of lead daily. If the intake of lead exceeds 1.0 mg day^{-1}, clinical disorders will occur [25].

Anaemia is an early manifestation of acute or chronic lead intoxication. The anaemia that occur in lead poisoning is reversable. If over-exposure is stopped; however, the recovery may be slow. Subtle effects include a shortened red blood cell lifespan and lowered haemoglobin.

In fish lethal effects occur only at high concentrations. Long tern destructive effects are found in more sensitive fish species such as trout, brook trout and oysters at levels close to 100 mg l^{-1} [26].

Copper production in the world has steadily increased. The major uses of copper includes:- in the electrical industry in the production of generators, light bulbs, telephones etc, in alloyed form, coinage, chiefly in brasses and bronzes, in mechanical engineering, for decorative purposes and in the chemical industry e.g. copper fungicides.

Copper is essential to all organisms. There are numerous copper activated enzymes and cuproproteins in plants and animals. It occurs in metalloproteins such as hemocyanin, cytochrome oxidoses and plastocyanine.

Human exposure to copper is predominantly via food (general population). Copper deficiency may cause anaemia and its implication in mental health has been reported. Hepatolenticular degeneration (Wilson's disease) is an inherited autosonnal recessive disorder, described first in 1912. In this hereditary metabolic disorder in humans manifested by accumulation of potentially toxic concentrations of copper, the characteristics are:- increased liver copper concentrations, leading to cirrhosis; neurological symptoms due to elevated brain levels; in kidney, renal tubular damage and in the cornea leads to a characteristic 'Kayser-Fleischer ring [27].

In sheep and cattle, particularly, a catastrophic liberation of a high proportion of liver copper into the blood system may occur due to continued ingestion of copper in excess of the required, may occur with resultant extensive hemolysis and jaundice, followed by death.

The toxicity of copper to algae and bacteria is utilized in controlling excessive algal bloom.

Zinc metal is used in galvanizing brass and bronze products, castings and rolled zinc. Zinc oxide finds application in the paint, rubber, chemical industries and in agricultural etc. Zinc is also a common pollutant in industrial effluents such as; from textile mills, electroplanting and motors.

Zinc is essential to all organisms and is present in enzymes. As early as 1939, zinc was found to be a constituent of the enzyme carbonic anhydrase. Zinc was found to act as a co-factor in a variety of enzyme systems including arginase. Some over 20 different zinc metalloenzymes are known, including carbonic anhydrase, alkaline phosphate, alchoholic dehydrogenase and other zinc activated enzymes [28].

Human main intake of zinc is via foodstuff viz: fish, shellfish, meat products, whole grain cereals and legumes. Although zinc is an essential element at micronutrient excessive amount have caused acute gastroenteritis upon ingestion [29]. Ingestion of zinc sulphate causes drowsiness, lethargy and increased serum lipase and amylase levels; finally acute zinc toxicity was observed in a patient with renal failure following hemodialysis who suffered from vomiting, fever and severe anaemia.

The World Health Organization has recommended daily dietary zinc intake ranging from 6 mg (infants) to 27 mg (lactating mothers).

Manganese is one of the more abundant elements in the earth's crust. Manganese or its compounds are used in making steel alloys (over 90% manganese world production) and in the production of non-ferrous alloys such as manganese, bronze, for machinery requiring high strength and in alloys with copper, nickel or both in the electrical industry. It is also used as an oxidizing agent in the chemical industry. Manganese has also found use in medicine as antiseptics and germicides.

Human are exposed to manganese via food, air and water, but food is the major source. Manganese is an essential element and occurs in all living organisms. Manganese was first shown to be required by plants and micro-organisms in 1923. Pyruvute carboxylase is a manganese containing metalloprotein with a fixed amount of metal protein molecule of protein. Manganous ion has been recognised as an activation of enzymes which require the presence of a divalent ion in the assay medium.

Chronic manganese poisoning is a hazard mainly associated with the mining activites, dry-cell battery industries and in welding. The disorder is characterized by psychological and neurological manifestations. Skeleton abnormalities ranging from gross and crippling deformities to mild rarefaction of bone occur in all species.

Mercuty is one of the less abundant elements in the earth's crust. Mercury has no known beneficial biological function and because of it's increased economic consumption in electrical apparatus, paints, fungicides and plastic catalysts, mercury has become a serious enviromental pollutant. When considering that mercury wastes eventually flow back into the aquatic enviroment, highest concentration are expected to occur in water and aquatic life of circumscribed areas.

Organic mercury, especially methyl mercury, is more toxic and accumulate in the muscle of fish, swine amd bovine. Inorganic mercury may be converted to methyl mercury by microbes, in some aquatic enviroments [29]. Methyl mercury toxicity has been reported by Lu et al [30]. In this incident in Japan where fish and shellfish are a major portion of human diet, a serious episode of mercurial pollution occured. Between 1953 and 1970, 121 cases of neurological disorder were reported in Minamata, where a vinylchloride plant was discharging 600 kg yr^{-1} of a mercury catalyst into the stream. In 1965, 47 officially reported cases of mercury poisoning were listed in Nigata, Japan, where an acetaldehyde plant had been discharging methylmercury into the water [31].

In another incident in Ghana in 1967, a total of 17 out of 65 persons died in Keta Government Hospital following ingestion of stolen maize which had been treated with merkura. The range was reported to contain 10 - 20 ppm of mercury.

Over 90% of methylmercury ingested is absorbed in the gastro-intestinal tract. Methylmercury accumulates in blood cells and is transported to and concentrated in the brain and central nervous system tissues, where it can lead to irreversible damage to the nervous system. The lowest whole blood level of methylmercury at which neurological systems have been observed in adults is 0.2 mg l^{-1} which result from an intake of 300 mg day^{-1}. The World Health Organisation has made a provisional recommendation of 33 mg day^{-1} of methylmercury and 50 mg day^{-1} total mercury.

Mercury toxicity in non-human is limited. Aquatic life is unlikely to be seriously affected by mercury concentration present in water and even sub-lethal concentration for algae, crustacea and fish are 5 mg l^{-1} of higher. Some growth retardation in algae has been reported to occur at concentrations as low as 0.06 - 0.6 mg l^{-1}.

Chromium is released into the enviroment in many ways. It is released into the atmosphere with the burning of fossil fuel and is one of the constituents of a large numbers of industrial effluents e.g. tanneries.

Chromates have been found to be water soluble with chromium (VI) state being the most toxic. Although chronium is an essential micronutrient for plants and animal at trace level, it is toxic at high concentrations. The metal induces marked changes in the swimming and feeding pattern of fishes at high concentration. There are reports indicating that chronium is a human carcinogenic agent [32].

1.2 SCOPE OF THE PROJECT

In a preliminary literature survey carried out in this work, it was established that some data have been collected by a number of individuals and groups involved in research work, as well as the Ministry of water development, municipalities, the City Commission, regarding pollution trends in surface waters.

To mention just a few. Analysis of waters from seven Kenyan lakes for heavy metal concentration in the water, sediments and plants was done by Shem O. Wandiga and co-workers [33]. Samples mostly collected in the more polluted areas of the lakes indicated that heavy metal concentration in Kenyan lake waters satisfactorily compared to the drinking water standards as given by World Health Organization (WHO).

J.M. Onyari has worked on heavy metal concentrations in sediments and fish of Lake Victoria and from the Coastal town of Mombasa [34].

Work on nitrate and nitrite concentrations in surface waters, bore-holes, wells etc has been carried out by Steven A.M. Nyanzi [35]. Nitrate content was found to vary depending on the type of water, but although there were a few cases where levels of nitrate and nitrite in water were inexcess of the acceptable levels in general the nitrate and nitrite level were low and may not constitute a health hazard at present.

Other works on lakes have been undertaken by workshop participants (1978 and 1979), with special interest in heavy metal concentration specifically Cu, Zn, Cd and Pb.

The Ministry of Water Development, pollution control division, the City Commission and several municipalities do monitor some of the water quality parameters in several rivers and lakes in the country. Results though not published are kept as records. The results by these divisions suffer from irregular samplings. Nitrate and Nitrite records were lastly carried out by the Ministry of Water Development about six years ago.

In view of the rapid industrialization and population trends during the present century in this country, new enviromental problems have been created, one of which is river water pollution. The rivers considered in this study pass through the country's most populated and industrialized urban centre. The industries release effluents of varying composition and quality. The three rivers identified are Nairobi, Ngong and Ruiruaka (map figure 1) pass through the residential and industrial areas of the city of Nairobi, thus carrying with them both treated and untreated discharges.

Although the rivers are small in size and infact have very lean flow during the dry season, they handle most of the burden of wastewaters from untreated domestic and industrial effluents other than the discharges from the sewage treatment plants and from the oxidation ponds.

Nairobi river passes through the residential areas of Nairobi city collecting discharges from minor industrial activities going on along it's banks and drainage of domestic sewage (treated and untreated) and the rainwaters.

The Ngong' river traverses through the heavily industrial belt accumulating various types of industrial pollutants and also the final effluents from the industrial oxidation ponds.

The Ruiruaka river enters Nairobi city areas taking with it discharges from residential areas and effluents from the Kenya Breweries and other minor activities.

To monitor the quality of the waters and to access the extent of pollution in the rivers the following parameters were systematically determined over a year's period (1985/86).

(i) Temperature

(ii) Hydrogen-ion concentration (pH)

(iii) Conductivity

(iv) Biochemical Oxygen demand (BOD)

(v) Chemical Oxygen demand (COD)

(vi) Dissolved solids

(vii) Suspended solids

(viii) Chlorides

(ix) Nitrates (as $N-NO_3$)

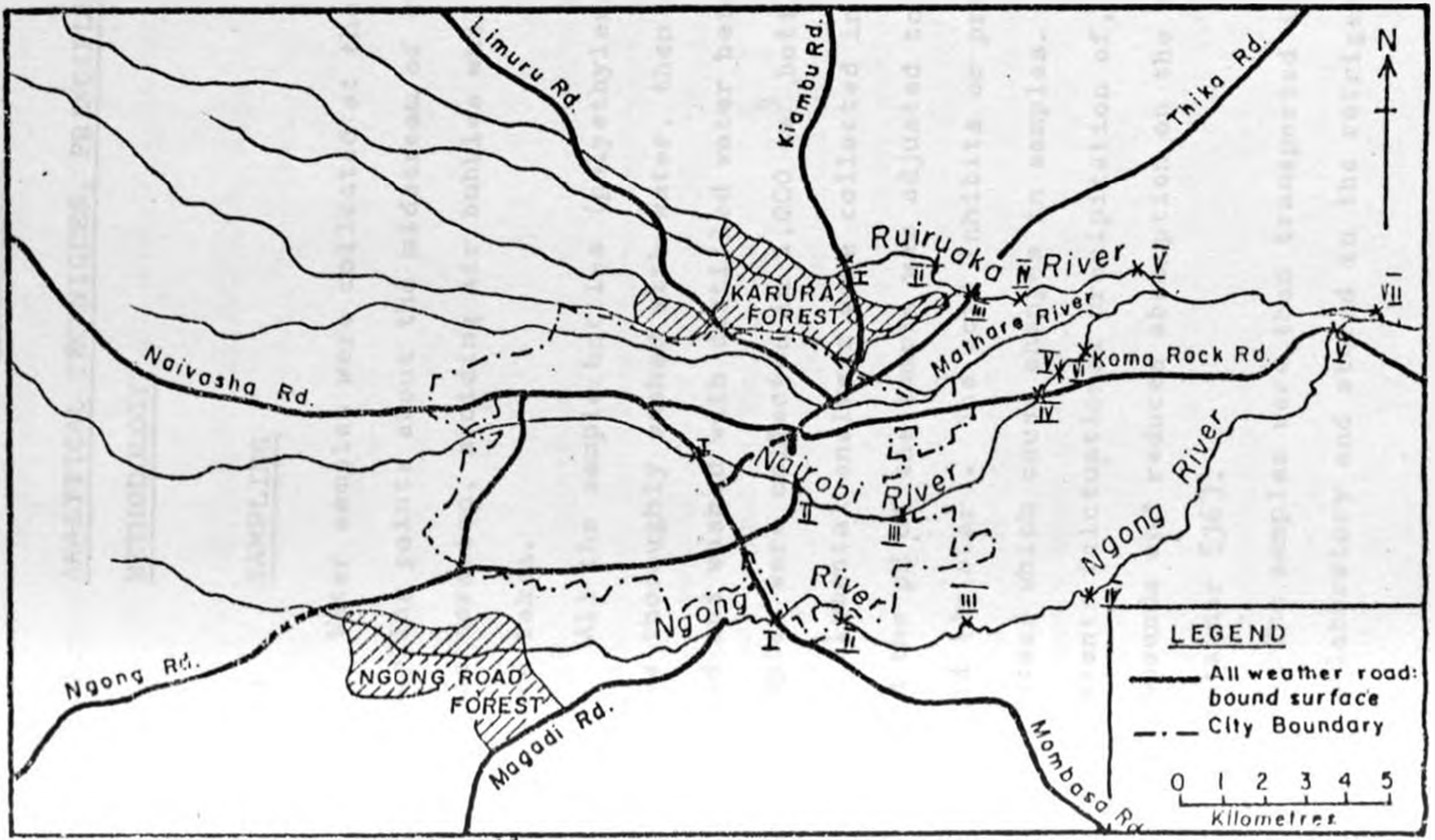
(x) Total phosphate (as $P-PO_4$)

In addition to the above parameters, a general profile of elements present in the waters were also monitored, with special attention to the levels of toxic elements Hg, Pb, Cu, Ni, Zn, Mn, Ti, etc. The results obtained were analyzed to characterize the type of pollutants and their possible effect on the quality of the receiving waters.

Based on the studies inferences were drawn and possible suggestions were made to contain the effect of particular pollutants either through controlling at the source or through tertiary treatment.

It is important to know the content of natural and man-made pollution in the rivers and other water enviroments for proper management and full utilization of these water systems for health, industrial and aesthetic purposes. This will have a positive role to play in economic development of the country. It is important also to keep monitoring the quality of the rivers enviroment from time to time to preserve the life in the rivers and the consequence of that extinction due to pollution.

MAP FIGURE 1: Map showing the three rivers and the sampling locations



Source : Survey of Kenya Y503 1965

CHAPTER TWO

2.0 ANALYTICAL TECHNIQUES, PRINCIPLES AND METHODOLOGY

2.1 SAMPLING

Water samples were collected at the identified sampling points about the midstream of the river under consideration, avoiding air bubbles while the samples were taken.

All the sample bottles (polyethylene containers) were thoroughly washed with water, then soaked in nitric acid and washed with distilled water before sampling. Samples were collected in 1,000 cm^3 bottles. The samples for elemental analysis were collected in $250cm^3$ containers and the pH of the sample was adjusted to about 2 with nitric acid (Aristar). The acid inhibits or prevents metabolic process which cause changes in samples. Furthermore it prevents falctuational precipitation of, for example, metal compounds and reduces absorption on the surface of the container [36].

The samples were then transported immediately to the laboratory and stored in the refrigerator.

2.2 ANALYTICAL TECHNIQUES AND METHODOLOGY

2.2.1 Temperature: Temperature was determined using a mercury thermometer (0.05°C) on site, by immersing the thermometer into a sample container ($1,000cm^3$).

2.2.2 Hydrogen-ion concentration: pH was determined in the laboratory using a refrence glass electrode.

2.2.3 Conductance: (specific conductivity). Conductance values were determined in the laboratory using a conductivity bridge.

2.2.4 Biochemical Oxygen Demand: (BOD). BOD is defined as the amount of oxygen required by bacteria while breaking down decomposable organic matter under aerobic conditions.

The standard BOD test conditions are incubation at 20°C in the dark for a specified period of time usually five days. The reduction in dissolved oxygen concentration during this incubation period is a measure of the biochemical oxygen demand and expressed in $mg\ l^{-1}$ oxygen or $mg\ l^{-1}$ BOD.

Reagents:- The following stock solutions were used for BOD determination

(a) Phosphate buffer solution - 8.5 of KH_2PO_4; 21.7g K_2HPO_2; 34.49g Na_2HPO_2. $7H_2O$ and 1.7g NH_4Cl were dissolved in $500cm^3$ of distilled water and diluted to $1,000cm^3$ with double distilled water.

(b) Magnesium Sulphate solution - 22.5g of $MgSo_4$. $7H_2O$ was dissolved in distilled water and dilluted to 1,000cm^3

(c) Calcium Chloride solution - 27.5g of anhydrous $CaCl_2$ was dissolved in distilled water and diluted to 1,000cm^3.

(d) Ferric Chloride solution - 0.25g of $FeCl_3.6H_2O$ was dissolved in distilled water and dilluted to 1,000cm^3.

(e) Standard 1M sulphuric acid and 1M sodium hydroxide solutions were prepared.

The desired volume of distilled water was placed in an aspirator bottle and then 1cm^3 of the phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solution were added to each litre of distilled water that was used. The distilled water was then aerated for more than 45 minutes.

The sample pH was adjusted to about 7 with the standard acid or alkali solutions using a pH meter. The BOD bottles (250-300cm^3) used were rinsed with hydrochloric acid and thoroughly with distilled water. Different dilutions of a sample were prepared and each dilution placed in a set of two BOD bottles, one was placed for incubation and the other for the determination of the initial dissolved oxygen in the mixture. The dilution water used was also placed into a set of two, this was to serve as a 'blank'.

One BOD bottle from each set of dilluted sample and blank were then incubated for 5 days at 20°C. The bottles were water sealed.

The dissolved oxygen concentrations in the remaining bottle from each set was then determined.

Reagents for determination of dissolved oxygen (D.O.)

(a) Manganese Sulphate solution - 480g of $MnSO_4.4H_2O$ was dissolved in distilled water and diluted to 1,000cm^3.

(b) Alkali-Iodine Azide solution - 500g of NaOH and 135g of NaI were dissolved in distilled water and diluted to 1,000cm^3. 10g of sodium azide dissolved in 40cm^3 of distilled water was them added to this mixture.

(c) Concentrated Sulphuric acid

(d) Starch indicator

(e) Sodium thiosulphate stock (0.1M)
Standard sodium thiosulphate (0.02M)

The stopper of the BOD bottles was removed and in quick succession 2cm^3 of each $MnSO_4$ solution and alkali-azide iodine reagent were added with the tip of the pipette well below the surface of the liquid. The bottle was then stoppered carefully and the contents were mixed by inverting the bottle. The resulting precipitate was allowed to settle, after which 2cm^3 of concentrated sulphuric acid was added carefully and slowly to the mixture. The bottle was then restoppered and the contents were mixed as above until the precipitate dissolved.

A volume of 203cm^3 was then measured out of the bottle and titrated against standard sodium thiosulphate solution using starch as an indicator.

CALCULATION:-

$$\text{BOD } (20^{\circ}\text{C}) \text{ in mg } l^{-1} = (D_1 - D_2)\ \frac{Z(X-Y)}{Z+1}\ (Z+1)$$

where D_1 = DO in diluted sample before incubation

D_2 = DO in diluted sample after incubation

X = Initial DO in the blank

Y = Final DO in the blank

Z = Volume of dilution water to that of sample

2.2.5 Chemical oxygen demand (COD): This is a measure of the quality of oxygen required to oxidise the organic matter in a waste water sample under specific conditions of oxidising agent, temperature and time.

Organic substances in the sample are oxidised by potassium dichromate in sulphuric acid solution at boiling temperature under reflux conditions. The excess dichromate is then titrated with standard ferrous ammonia sulphate solution.

Reagents for COD determinations are as follows:-

(a) Standard potassium dichromate solution (0.04167M)

(b) Sulphuric acid concentrated containing 22g of silver sulphate per 2.5 litres of acid

(c) Standard ferrous ammonium sulphate solution (0.10M)

(d) Powdered mercuric sulphate (for removal of chloride interference)

(e) Ferroin indicator solution

Reaction procedure:-

To about 0.4g of $HgSO_4$ placed in a refluxing flask, $20cm^3$ of a sample or aligout diluted to $20cm^3$ with distilled water and $10cm^3$ of standard potassium dichromate solution were added together with glass beads. The condensor was then connected to the flask and $30cm^3$ of concentrated sulphuric acid was added to the contents in the flask, through the opening of the condensor. The mixture was then refluxed for 2 hours, cooled and the condensor washed down into the mixture with distilled water. The mixture was diluted to about $150cm^3$ with distilled water and cooled to room temperature. The resulting mixture was titrated against standard ferrous ammonium sulphate solution using ferroin indicator.

A 'blank' consisting of $20cm^3$ of the used distilled water together with reagents was also refluxed and then treated as above.

CALCULATION:-

$$\text{COD}(\text{mg } l^{-1}) = \frac{(A - B) \times M \times 8{,}000}{\text{cm}^3 \text{ of sample}}$$

where $A = cm^3$ of titrant used for the blank

$B = cm^3$ of titrant used for the sample

M = molarity of the titrant.

2.2.6 Suspended and dissolved solids: Solids are usually defined as the matter that remains as residue upon evaporation and drying at 103 to 105°C.

Suspended solids (S.S.). - This class of solids are removed by filtration, portion of sample is filtered through asbestos glass fibre filter and the filter is dried at 103°C.

Procedure: for suspended solid measurement:

A filter was dried in the oven at 103°C to 105°C for 1 hour and then stored in a desicator. The filter was weighed just before use, mounted onto a suction pump and a known volume of the sample filtered through. The filter was then carefully removed and dried in an oven at 103°C to 105°C to a constant weight. It was restored in a desicator and the weighed.

The difference in weights of the filter paper gave the amount of suspended solids in a given sample volume.

Dissolved solids (D.S.) - This class of solids are the non-filterable residue. A portion of sample is filtered through a diatomaceous earth filter and then evaporated and dried at 103°C.

Procedure: A known volume of a filtered sample was placed into a crucible, which was previously washed and dried in an oven to a constant weight at 103°C. The crucible was cooled in a desicator before weighing.

The difference in weight of the crucible gave the amount of dissolved solids in a given volume of sample.

2.2.7 Chloride: Chloride may be readily measured by means of volumetric procedures employing internal indicators. The endpoint cannot be detected by the eye unless an indicator capable of demonstrating the presence of excess Ag^+ is present.

Reagent used were as follows:

(a) Silver nitrate solution (0.0282M)

(b) Potassium chromate solution (Indicator)

The volhard method was used.

CALCULATION:-

$$\text{Chloride as } cl^- \ (\text{mg } l^{-1}) = \frac{(A - B) \times M \times 35450}{\text{volume of sample}}$$

where A = Volume (cm^3) of titrant used in sample

B = Volume (cm^3) of titrant used in blank

M = Molarity of titrant.

2.2.8 Nitrates: Colorimetry, U.V. Spectrometer and polagraphy have frequently been used for nitrate determination in natural and waste effluents. The acid method and the brucine method are two colorimetric procedures more frequently used.

The reaction of nitrates and brucine produces a yellow colour which can be used for the concentration estimation of nitrates. The intensity of the colour is measured at 410nm.

The brucine method has been used for nitrate determination in the present studies.

Reagent used were as follows:-

(a) Stock nitrate solution - 721.8 mg of anhydrous KNO_3 was dissolved in distilled water and diluted to 1,000cm^3.

(b) Sodium arsenite solution - 5g of $NaASO_2$ was dissolved in distilled water and diluted to 1,000cm^3.

(c) Brucine sulphanilic acid solution - 1 g of brucine sulphate and 0.1 g of **sulphanilic** acid were **dissolved** in approximately 70cm^3 of hot distilled water. 3cm^3 of concentrated sulphuric acid was then added and the solution cooled before the volume was made upto 100cm^3.

(d) Sulphuric acid - 500cm^3 of concentrated sulphuric acid was added to 125cm^3 of distilled water carefully then allowed to reach room temperature.

(e) **Sodium** chloride - 300g of sodium chloride was dissolved in distilled water and then diluted to 1,000cm^3.

Reaction procedure: Standard nitrate solution were prepared freshly from the stock solution, by dilution of 10cm^3 of the stock solution to 1,000cm^3. From which various concentrations in the range 0.10 to 1.00 mg l^{-1} were prepared.

10cm^3 of sample of aliquot diluted to 10cm^3 was placed into a reaction tube and 2cm^3 of NaCl added while stirring. 10cm^3 of sulphuric acid solution was then added and the mixture swirled, before allowing it to cool. A 'blank' ($10cm^3$ of distilled water) and the various concentration ranges of the standards, were also treated as above.

The reaction tubes were then placed in a cold water bath inside a fume chamber and $0.5cm^3$ of brucine sulphanilic acid reagent added, with swirling. The reaction tubes were then transferred into a well stirred boiling water bath at a temperature above 95°C for exactly 20 minutes, after which the tubes were again transferred back into the cold water bath, until thermal equilibrium was reached.

The spectrophotometer (PERKIN ELMER 35) used in this study was capable of giving direct concentration readings. Thus the spectrophotometer was calibrated using the 'blank' and the standard solution at 410nm, after which direct concentration reading of nitrate as $N\text{-}NO_3$ was taken for the samples.

2.2.9 Total Phosphate: The most common analytical method for inorganic phosphate is based on colorimetric determination of phosphomolybdenum blue complex. Other modes of measurements are coulometric titration and activation analysis.

The principle behind the colorimetric methos is the reaction between orthophosphate and ammonium molybdate in acid solution to form molybdophosphoric acid. But this reaction is often taken further by reacting with a reducing agent to give a blue complex .

Phosphates analysis embody two general stages:-

(I) conversion of phosphorous form of interest to soluble orthophosphate

(ii) to colorimetric determination of soluble orthophosphate

(I) Persulphate digestion

(A) Reagents used were as follows:-

(a) Sulphuric acid solution - 300cm^3 of concentrated sulphuric acid was added carefully to 600cm^3 of distilled water.

(b) Potassium persulphate

(c) Sodium hydroxide solution (1M)

(B) Determination process:-

100cm^3 of the sample was placed in a clean beaker and a drop of phenolpthalein indicator added. In cases where a red colour developed, sulphuric acid was added dropwise to discharge the colour, after which 1cm^3 of sulphuric acid was then added together with about 0.4g of solid potassium persulphate. The mixture was then boiled until the final volume was about 10cm^3. The content was then cooled. One drop of phenolpthalein indicator was again added to the mixture and neutralized with NaOH to a faint pink colour. The volume of the mixture was restored to $100cm^3$ with distilled water. A 'blank' ($100cm^3$ of distilled water) was also treated as above.

(II) Ascorbic method.

(A) Reagents used were as follows:-

(a) Sulphuric acid (5M)

(b) Ammonium molybdate solution - 20g of $(NH_4)Mo_7O_{24}$ was dissolved in $500cm^3$ of distilled water.

(c) Ascorbic acid solution (0.1M)

(d) Potassium antimony (III) oxide solution 4.4g of the above was dissolved in $200cm^3$ of distilled water.

(e) Stock phosphate solution - 219.5g of anhydrous potassium dihydrogen phosphate was dissolved in distilled water and diluted to $1,000cm^3$.

Standard phosphate solution - $50cm^3$ of stock phosphate was diluted to $1,000cm^3$.

Combined reagent:- For $100cm^3$ of combined reagent, $50cm^3$ of 5M H_2SO_4, $5cm^3$ of potassium antimony (III) oxide, $15\ cm^3$ of ammonium molybdate and $30cm^3$ of ascorbic acid were mixed, in that order and allowed to reach room temperature.

(B) Procedure

Different concentration of phosphate standards were prepared by dilluting the standard phosphate solution.

$50cm^3$ of the 'blank' and an equal volume of sample solution from the previous digestion, together with $50cm^3$ of the different standard concentrations, were pipetted into clean beakers. A drop of phenolpthlein indicator was added to each beaker and if a red colour was observed, 5M sulphuric acid was added dropwise just to discharge the colour. $8cm^3$ of combined reagent (freshly prepared) was then added to each beaker and the content then allowed to stand for about 10 minutes to allow for colour development.

The spectrophotometer (Perkin Elmer 35) was then calibrated using the 'blank' and standards at 810nm. The direct total phosphate concentrations of the samples as $P\text{-}Po_4$ was then taken.

All the above methods of analysis were done using standard method [37].

2.3 ELEMENTAL ANALYSIS.

2.3.0. X-ray fluorescence spectrometry

The measurement of elemental concentration level in water and other enviromental media require equipment and methodologies that have capabilities for detecting the presence of trace minor and major concentrations with high precision, accuracy and speed.

X-ray fluorescence specrometry is now a well-established technique. In the recent years the detection of characteristic x-ray for trace element analysis has increased significantly because the Si(Li) detector has made possible the resolution of lines from adjacent elements heavier than aluminium.

Energy dispersive x-ray fluorescence (EDXRF) offers several unique advantages over other analytical methods. It allows simultaneous detection and analysis of several el elements, it is sensitive and reproducible. The technique also offers the advantage of acceptable speed and ecenomy and ease of automation [38]. The use of radioisotope or x-ray tube as sources of primary radiation and a Si(Li) detector make it possible to construct a compact and low cost apparatus.

The chemical identification of element by x-ray fluorescent (XRF) analysis began when it was observed that new x-ray radiators discovered by Rontegen (1895) contained characteristic energies that are specific to each element. For qualitative analysis the spectometer must be correctly calibrated and the elements are identified from their characteristic x-ray line with the help of tables. The energy of the x-ray is characteristic of the element (qualitative analysis), while the number (intensity) of the entitled x-ray is related to the amount of atom (quantitative analysis) [39].

2.3.1 Sources of exciting radiations

In x-ray flourescence analysis electromagentic radiation from x-ray tube or radioisotopes are used as sources for the excitation of the target atoms.

The radioisotopes available for use are like ^{55}Fe, ^{109}Cd and ^{241}Am. Radionuclides offer the advantage of their small size, absence of continous background, monochromatic character of the radiation, simplicity and low cost.

TABLE 1 - Characteristic of radioactive sources used in XRF analysis.

RADIOISOTOPE	HALF LIFE (YRS)	DECAY	PHOTON EMISSION AND ENERGIES	ELEMENT X-RAY EXCITED USEFULLY
^{55}Fe	2.7	Electron capture	Mn K X-rays 5-9 and 6-5 Kev	Al-V K X-rays
^{109}Cd	1.3	Electron Capture	Ag K X-rays 22 and 25 Kev	Ca-Mo K X-rays Ce-U L X-rays
^{241}Am	458	α- Emmission	Gamma rays, 59.6 Kev; Np L X-rays 14 - 21 Kev	Ag - Tm K X-rays

2.3.2 Interaction of X-ray with matter

If a beam of x-ray interacts with a substance, the x-ray beam intensity is attenuated due to photoelectric absorption and to various modes of scattering, according to the equation shown.

$$I_{(E)} = I_o e^{-\mu(E)\rho d}$$

where $I_{(E)}$ is the intensity of the photon beam after traversing an absorbing layer of density ρ (g/cm^3) and thickness d(cm)

I_o:is the intensity of the incident photon beam.

μ:is the total mass attenuation coefficient being the sum of the scattering coefficients and photoelectric absorption coefficient.

Photoelectric absorption is the dominant process in the energy range below 100Kev and the photoelectric mass absorption coefficient decreases with increasing energy with sharp limits or discontinuities which relate to critical energies (Figure 1). The magnitude of a discontinuity is referred to as the absorption jump. Photoelectric absorption strongly increases with growth of the atomic number of the absorbing medium. The photoelectric absorption coefficient represent in practice the excitation yield or precisely the photon excitation yield of an element with a given atomic number Z as a continous function of the energy of the exciting radiation.

If a photon strikes a bound electron and the energy of the photon is greater than the binding energy of the electron in it's shell, then it is possible for the electron to absorb the total energy of the photon. The photon disappears in this process and it's energy is transferred to the electron which is ejected from it's shell. The minimum photon energy that can expel an electron from a given level in an atom of a given element is known as the absorption edge of that level of the element. The ejected electron is called a photoelectron.

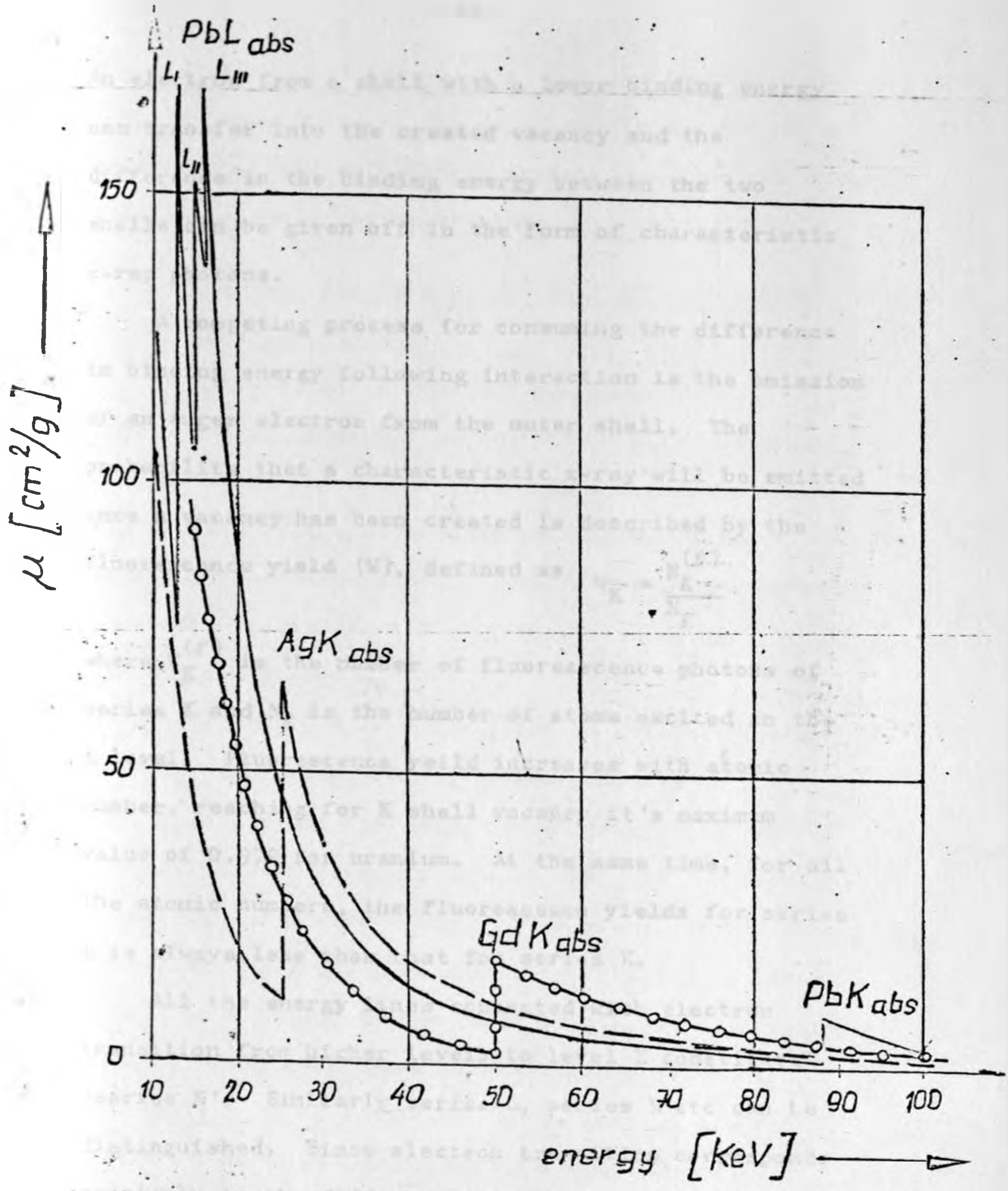


Figure 1: Photoelectric absorption coefficient as a function of radiation energy.

An electron from a shell with a lower binding energy can transfer into the created vacancy and the difference in the binding energy between the two shells can be given off in the form of characteristic x-ray photons.

A competing process for consuming the difference in binding energy following interaction is the emission of an Auger electron from the outer shell. The probability that a characteristic x-ray will be emitted once a vacancy has been created is described by the fluorescence yield (W), defined as $W_K = \frac{N_K^{(f)}}{N_K}$

where $N_K^{(f)}$ is the number of fluoresecence photons of series K and N_K is the number of atoms excited in the K level. Fluorescence yeild increases with atomic number, reaching for K shell vacancy it's maximum value of 0.972 for uranium. At the same time, for all the atomic numbers, the fluorescence yields for series L is always less than that for series K.

All the energy lines connected with electron transition from higher levels to level K constitute 'series K'. Similarly series L, series M etc can be distinguished. Since electron transition corresponds precisely to the difference in energy between the two atomic orbitals involved. The emitted x-ray photon has energy characteristic of this difference and thereby of the atom. The intensities of the particular lines in the K, L or M x-ray series of an element depend on the probabilities of electron transitions from the outer shells to a shell having a vacancy.

2.3.3 Quantitative XRFA by fundamental parameter technique (FPT)

Quantitative analysis depends upon the correlation of elemental concentration with observed fluorescence x-ray intensities. This correlation is respresented by the basic equation derived using fundamental parameters. The equations are general and represent a basis for all different methods of quantitative analysis.

The accuracy of the quantitative determinations parameter technique (FPT) is worse compared to calibration method approach, but accuracy with 10% can easily be achieved as well as the full flexibility in analysis of a wide variety of samples. It has been established that the method is competitive with other techniques mainly from the point of view of simplicity, rapidity and independence from the use of standards.

Derivation of equations for quantitative XRFA by FPT is based on the following assumptions:-

(a) a monochromatic primary radiation source is used to excite characteristic x-ray from the sample.

(b) the sample is homogenous i.e. the density is well defined and constant throughout the sample volume;

(c) a fixed geometry of sample, source and detector orientation must be maintained. However, elemental determination by FPT requires correction for matrix effects.

2.3.4 Intensity of characteristic radiation

The intensity of the secondary radiation should be understood as the number of photons emitted from the sample per unit time. The geometry shown in figure 2 is used to calculate the intensity, I_i of fluorescent radiation from element "i" within the sample, excited by primary radiation of energy E_1.

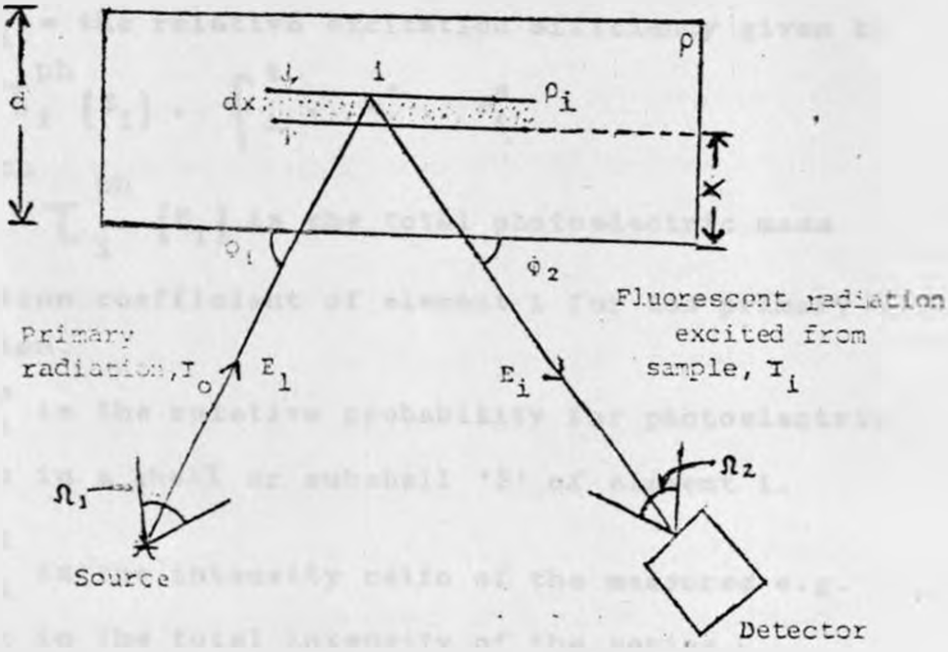


Fig. 2 Schematic representation of XRF experiment.

The dependence of the intensity of element i on it's concentration in a sample of a given mass per unit area, is given by the following equation [40]

$$I_i = GoK_i^1 \left(\rho_i d\right) \left\{\frac{1 - \exp(a\rho\, d)}{a\rho\, d}\right\} \varepsilon\left(E_i\right) \quad - (1)$$

Where Go = geometry constant = $I_o\Omega_1\Omega_2 CSC\phi_1$.

In which Ω_1 and Ω_2 = solid angles the source and detector 'sees' the sample respectively.

I_o is the intensity of the primary radiation and $CSC\phi_1$ is the cosecant of average angle ϕ_1.

ϕ_1 and ϕ_2 = the angles formed by direction of primary and fluorescent radiation with the sample surface.

K_i^1 = the relative excitation efficiency given by

$$K_i^1 = \tau_i^{ph}\left(E_1\right) \cdot f_i^t \cdot W_i^s \cdot P_i^s$$

in which

$\tau_i^{ph}\left(E_1\right)$ is the total photoelectric mass absorption coefficient of element i for the primary radiation.

P_i^s is the relative probability for photoelectric process in a shell or subshell 'S' of element i.

f_i^t is the intensity ratio of the measured e.g. $K\alpha$ line to the total intensity of the series.

$$f_i^{K\alpha} = I(K\alpha)/I(K\alpha + K\beta)$$

W_i^s is the fluorescent yield.

ρ and ρ_i = density of the sample and partial density of element i within the sample respectively.

$a = \mu_S(E_1)\ \mathrm{CSC}\phi_1 + \mu_S(E_i)\ \mathrm{CSC}\phi_2$, being combined absorption coeficient for primary and fluorescent x-ray in the sample.

$\mu_S(E_i)$ and $\mu_S(E_1)$ = are the total mass absorption coefficients of the sample for the characteristic, E_i, and the primary radiation, E_i, respectively in cm^2/g.

$\varepsilon(E_1)$ = is the relative efficiency of the detector for x-rays of energy E_i.

The equation (1) can also be written as:-

$$I_i = GoK_1(\rho_i d) \left\{ \frac{1 - e^{-a\rho d}}{a\rho d} \right\} - (2)$$

in which $K_i = K_i^1 \varepsilon(E_i)$

As seen in the above equation the intensity of the fluorescence radiation is not only a function of concentration of a given element 'i' but also of the concentration of the other elements. In the sample because the absorption coefficients (μ) depends on the composition of the sample. The influence of sample composition on the intensity of characteristic x-ray of the determined element is referred to as matrix effect.

If the mass per unit area of a given sample is low that is of the order of a few hundred $\mu g/cm^2$ the equation (2) can be greatly simplified using the approximation $e^{-x} = 1 - x$, thus $I_i = GoK_i(\rho_i d)$ - (3).

Thus the dependence of intensity of the fluorenscence radiation of a given element on it's concentration in the sample is a linear one.

Thus using the above equation (3) one can determine the concentration of many elements, using tabulated fundamental parameters [41 - 42], detection efficiency values and Go value. The latter has to be determined experimentally with the use of a thin sample of exactly known mass per unit area of a given element.

An alternative method, in cases where the tabulated values are not readily available, the standard method can be adopted for analysis.

2.3.5 Sample preparation for EDXRF analysis

In the sample preparations for EDXRF analysis the co-precipitation technique is adopted. For the analysis of dissolved trace metal in water one often uses a method which involves formation of insouble metal chelates via co-ordination with dithiocarbamate, filtration through a membrane filter and the analysis of the precipitate. The complexes formed are highly insoluble in water and can therefore be trapped on a membrane filter which serves as a target matrix.

Procedure: Preparation of membrane filters - the filters were soaked overnight in a 1:3 nitric solution, after which they were washed thoroughly with distilled water until the 'washing' distilled water acquired a pH of 7. The filters were then left soaked in distilled water, covered against dust.

The acidified water sample was filtered through 0.45 μm membrane filter(previously prepared as above) to collect the suspended matter. This filter was then air dried and submitted for XRF analysis. The filtrate (100cm^3) which was to be analyzed for soluble elemental concentrations was placed into a clean beaker; (which had been soaked in nitric acid and rinsed thoroughly with distilled water), the pH adjusted to 4.0 and 10cm^3 of freshly prepared 1% Ammonium pyrolidine dithiocarbamate (APDC) added. Prior to precipitation with APDC, 200 μg of cadmuim carrier solution was added to the filtrate solution, this was due to the low concentration of trace elements in the samples. The resulting precipitate for about 30 minutes, after which it was filtered through a membrane filter. The filter was air dried and kept into a clean petridish, before submission for XRF analysis.

A similar volume of filtrate of the same sample was treated in a similar manner except that the pH in this case was 9.0. This was due to the low recovery noted for Cr and Mn at a pH of 4.0.

The 'loaded filter were then mounted on the Si(Li) detector source set up and the spectra collected in 1024 channel memory group over a period of 3,000 seconds.

2.3.6 Preparation of calibration standard solutions

2.3.6.1 Preparation of stock solutions: For the preparation of the stock solutions high purity chemicals were used. All the salts used were dried at 105°C. 0.1% metal solution (1,000 $\mu g/cm^3$) were prepared by dissolving the corresponding weight of metal salt in Analytical grade Nitric acid of pH equal to 2 and then adjusting the volume to $100cm^3$ with double distilled water. The stock solution were stored in a refrigerator.

2.3.6.2 Preparation of calibration standard solutions: Multielement standards were prepared by aliquoting stock solutions and diluting them with double distilled water to a volume of $100cm^3$.

For preparation of standard solutions in the ppb range, the stock solutions were diluted twice, 1:100 and then 10:100. The pH was then adjusted to the appropriate value and the metal carbamates were precipitated with $10cm^3$ of 1% APDC, Cd^{2+} carrier (200 μg) being added to facilitate precipitation. A blank containing only the co-precipitating element and APDC was prepared for use in obtaining net counts in the calibration and analyses.

Standard samples of known concentration of elements to be determined were measured and calibration curves obtained by plotting the measured net intensity (or net counts) of characteristic x-ray of single trace element versus the mass (μg) of each element standard. The coefficient of the calibration equation $y = mx + b$ where m is sensitivity (counts/ μg) and b (background) were calculated by least square method. When a sample is analyzed the concentration of the element to be determined can be calculated from the calibration equation [43].

2.3.7 Detection Limits:

The lower limit of detectability (LLD) or detection limit applies to detection of the analyte, that is to qualitative analysis. The lower limit of determination or determination limit for a quantitative analysis is substantially greater and infact, is defined as 3 times the detection limit.

To estimate the lower limit of detection the following equation is often used,

$$\text{CLLD} = \frac{3.29}{m} \left\{ I_B \Big/ T_B \right\}^{1/2} \quad - \quad (4)$$

where m is the slope of the calibration curve (counts/ μg)

I_B is the intensity of the background and T_B is the analysis time.

The detection limit is defined as the quantity which gives a peak height greater than 3 times standard deviation of the background over its value. T_B in the present study was 5,000 seconds. Table 2 shows the result obtained.

TABLE 2: Lower limit of detectability (LLD).

(* Calculated for a water volume of $100cm^3$)

ELEMENT	$\mu g/cm^2$	ppb*
Chromuim	0.18	18
Manganese	0.16	16
Iron	0.06	6
Nickel	0.10	10
Copper	0.03	3
Zinc	0.03	3
Molybdnum	0.05	5
Zirconium	0.04	4
Lead	0.05	5

2.3.8 Precision:

In analytical chemistry jargon the term 'precision' means the variability of the method when used to make repeated measurements under specified conditions. The term 'precision' is generally used to describe the distribution of reproducibility of replicate measurements. The precision of the method depends on statistical error, instrumental error, errors connected with the preparation of a given sample and standard solution and precipitation [44].

Quantitatively, precision pi is the difference between the individual measurement m_i or analysis and the mean $\bar{m}$ of a large number set of independent replicate measurements of analyses usually expressed relative to the mean and as a percent that is,

$$P_i = \frac{m_i - \bar{m}}{\bar{m}} \times 100 \quad - (5)$$

Standard deviation (σ) is a measure of absolute precision. The standard deviation expressed relative to the mean is the relative standard deviation of coefficient of variation (ε). The coefficient of variation is a measure of relative precision, that is, precision relative to the 'amount' of analyte present.

That is $$\varepsilon = \frac{\sigma}{\bar{x}} \text{ or } \frac{100\sigma}{\bar{x}} \quad 6$$

where $\bar{x}$ is the mean.

Table 3 shows the precision of the method for the determination of Ti, Mn, Fe, Cu, Zn, Mo, Zr and Pb.

The precision of the method was estimated in the following way, ten separately prepared samples of a river water sample were analysed. The single measurement time was 5,000 seconds.

Table 3: Precision data obtained by trace metal determination in a water (river) sample. (Values in ppb) (* - below the lower limits of detectability)

	ELEMENTS				
Sample	Fe	Cu	Zn	Pb	Ti
1	6 ± 0.1	10 ± 1.0	57 ± 2	25 ± 2	366 ± 18
2	6 ± 0.1	12 ± 2.0	56± 2	17 ± 2	369 ± 23
3	6 ± 0.1	11 ± 1.1	58 ± 3	19 ± 1	363 ± 14
4	6 ± 0.1	9 ± 1	59 ± 3	23 ± 2	348 ± 25
5	6 ± 0.1	10 ± 1	56 ± 2	19 ± 2	392 ± 35
6	5 ± 0.1	9 ± 1	57 ± 3	20 ± 2	326 ± 19
7	6 ± 0.1	10 ± 1	56 ± 4	17 ± 2	403 ± 29
8	6 ± 0.1	13 ± 2	61 ± 3	19 ± 2	370 ± 21
9	4 ± 0.1	12 ± 2	53 ± 2	15 ± 2	260 ± 24
Mean	5.7	10.7	57.0	19.3	355.2
Standard deviation	0.7	1.4	2.2	0.8	39.4
Coefficient of variation (%)	12.4	13.2	3.9	13.3	11.2

ACCURACY: The accuracy of the proposed procedure was assessed by analysis of *IAEA standard reference materials (cabbage leaves and Hay)

The results obtained were generally equivalent to IAEA value attesting to good accuracy.

In view of the excellent accuracy and precision obtained, (ranging between 3.9 and 13.3 depending on the element), the proposed method can be used as a routine procedure for analysis of river water sample.

* IAEA - International Atomic Energy Agency

± Error due to statistical counts.

CHAPTER THREE

3.0 ANALYSIS OF QUALITY OF NAIROBI RIVER WATERS.

3.1 Introduction:-

Nairobi river which originates in the Dagoretti Forest 10km from Nairobi, flows across the city area of Nairobi covering approximately a 30km stretch within the city boundaries. (map figure 1). Within the city area, the river basically carries rain runoff waters, untreated effluents from residential areas and from small scale industries along the banks and treated waters from Kariobangi sewage treatment works (K.S.T.W.). In the downstream, Ngong river, Mathare river and the the Ruiruaka river join the Nairobi river which finally flow into the Athi river. The river has water flow throughout the year although the stream is thin in the dry summer months.

The description of the sampling points selected on the stream for the studies is as follows:-

NBI I (Chiromo Road Bridge) - A point where upstream waters are fairly less polluted. Prior to this point there is minimum human activites leading to pollution.

NBI II (Kariokor Bridge) - A location 3 kms from NBI I, with brisk small scale industrial activity surrounded by residential areas of lower income group.

NBI III (Shauri Moyo) - 2 Km from NBI II. A thickly populated residential area and is a location of considerable small scale industrial activity.

NBI IV (500 metres upstream KSTW effluent discharge point) - A point 6.5 Km from NBI III with relatively less activities on the banks; mainly residential areas.

NBI V - Final effluent from KSTW. Sample NBI V included in the analysis routine, since significant volume of treated waters were constantly discharged into the stream from KSTW.

NBI VI - KSTW downstream. A location about 500 metres from NBI V, surrounded by thickly populated residential areas.

NBI VII - Nyiru upstream. A location about 10 km from NBI VI prior to the point where the Ngong river joins the river. Sparcely populated with minimal activities in the vicinity but between NBI VI and NBI VII, a tributary, the Mathare river enters the river carrying untreated domestic sewage etc from the densely populated Mathare Valley. Also the Ruiruaka river joins the Nairobi river between these two points.

3.2 Results:-

3.2.1 Monthly sampling:

Water samples were collected at all the seven sampling points identified at monthly intervals over a period of one year and the samples were analysed for different parameters to characterise the quality of the waters. The analytical data obtained are tabulated in the Tables 3.2.1 - 3.2.9. The values of temperature, hydrogen-ion concentration (pH) and conductivity, the levels of Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Dissolved solids (DS), Suspended solids (SS), chlorides, nitrates and phosphates are presented in series A. In series B, the levels of selected heavy metals analysed separately as soluble and suspended species as they exist in the aquatic samples are shown. Using x-ray fluorescence although the general profile of the elements present was obtained for all the water samples, the analytical data presented is restricted to only the levels of selected heavy metals Mn, Cu, Zn, Ti and Pb. When the elements were present below the detection limits at all the sampling points, then those were not included in the tables.

The data obtained is also shown in figure 3.2.1 to 3.2.11. The rainy season was in the months of April and May 1986.

FIG. 3.2.1 TEMPERATURE PROFILE OF NAIROBI RIVER WATERS

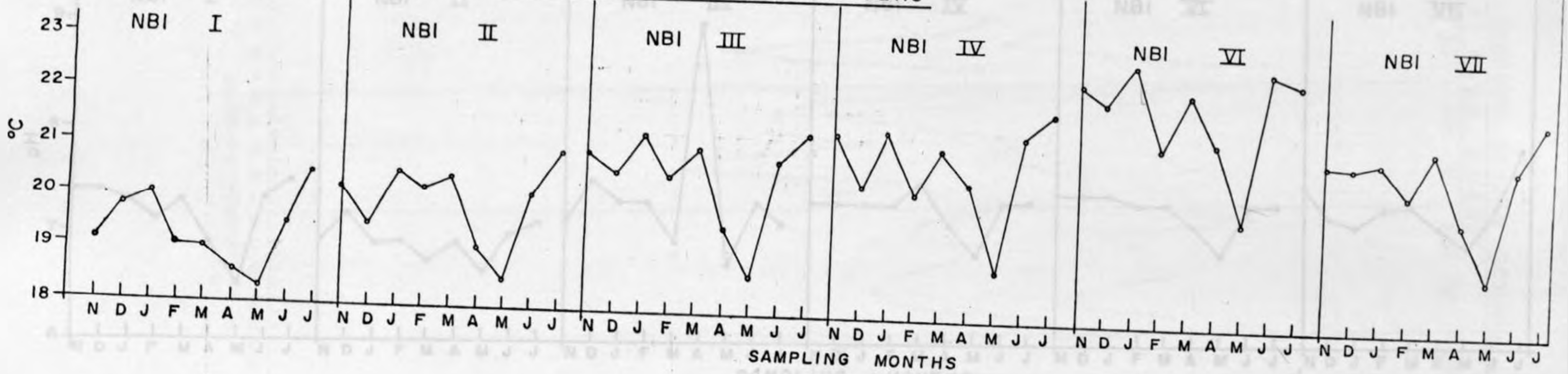


FIG. 3.2.2. p.H. OF NAIROBI RIVER WATER

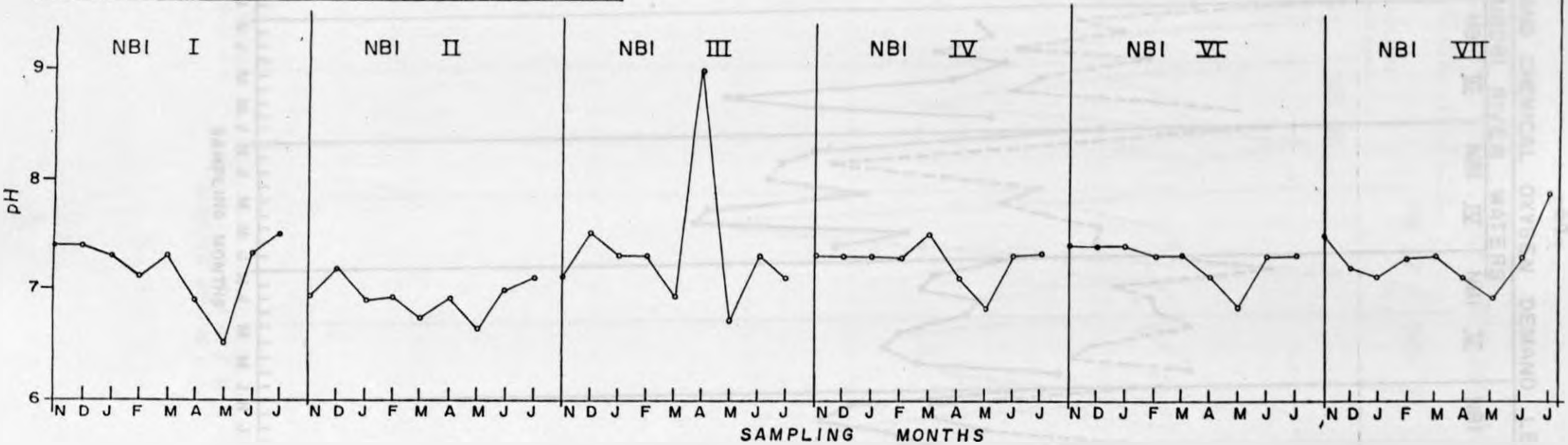


FIG. 3.2.3 BIOCHEMICAL AND CHEMICAL OXYGEN DEMAND LEVELS IN NAIROBI RIVER WATERS

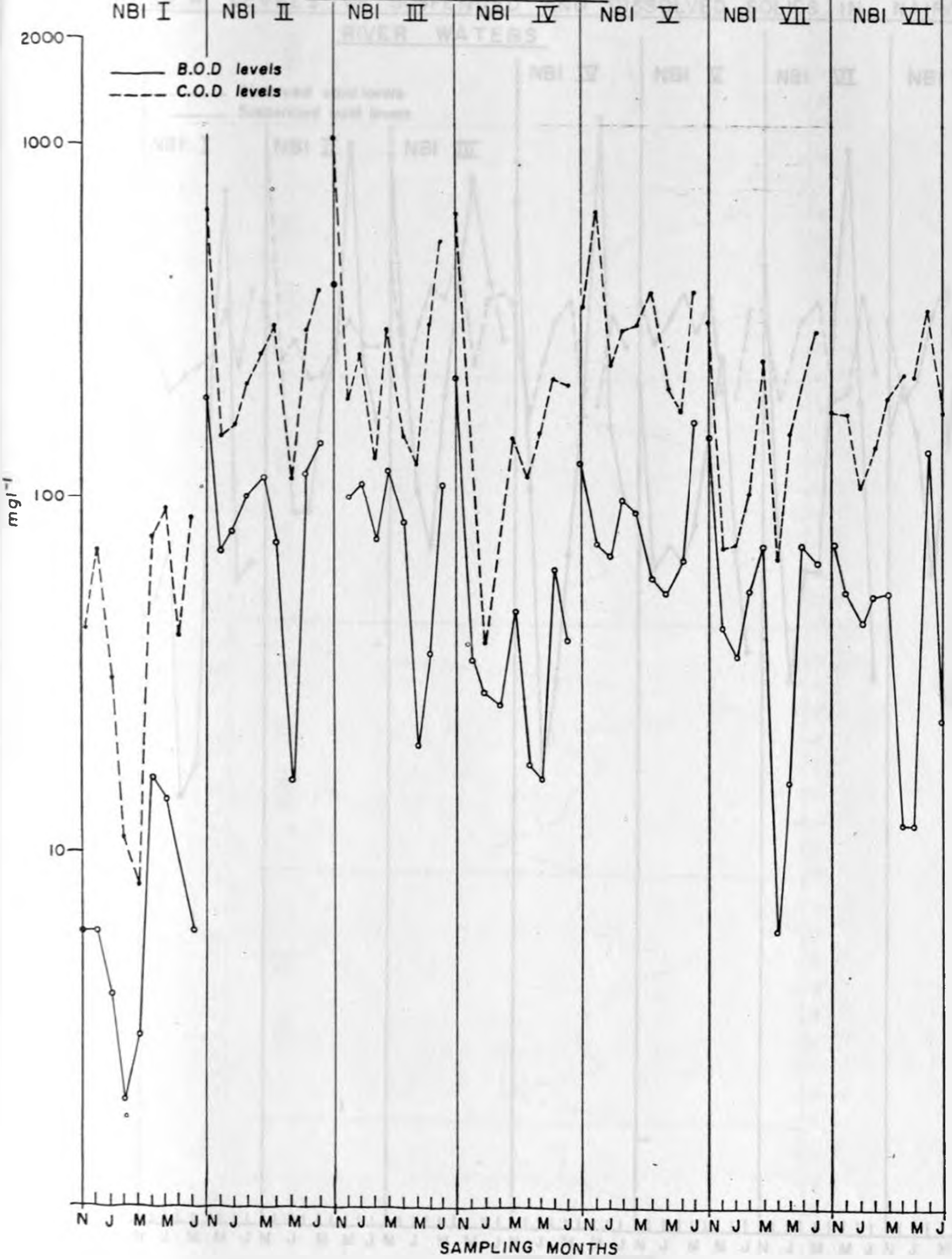


FIG. 3.2.4 LEVELS OF SUSPENDED AND DISSOLVED SOLIDS IN NAIROBI RIVER WATERS

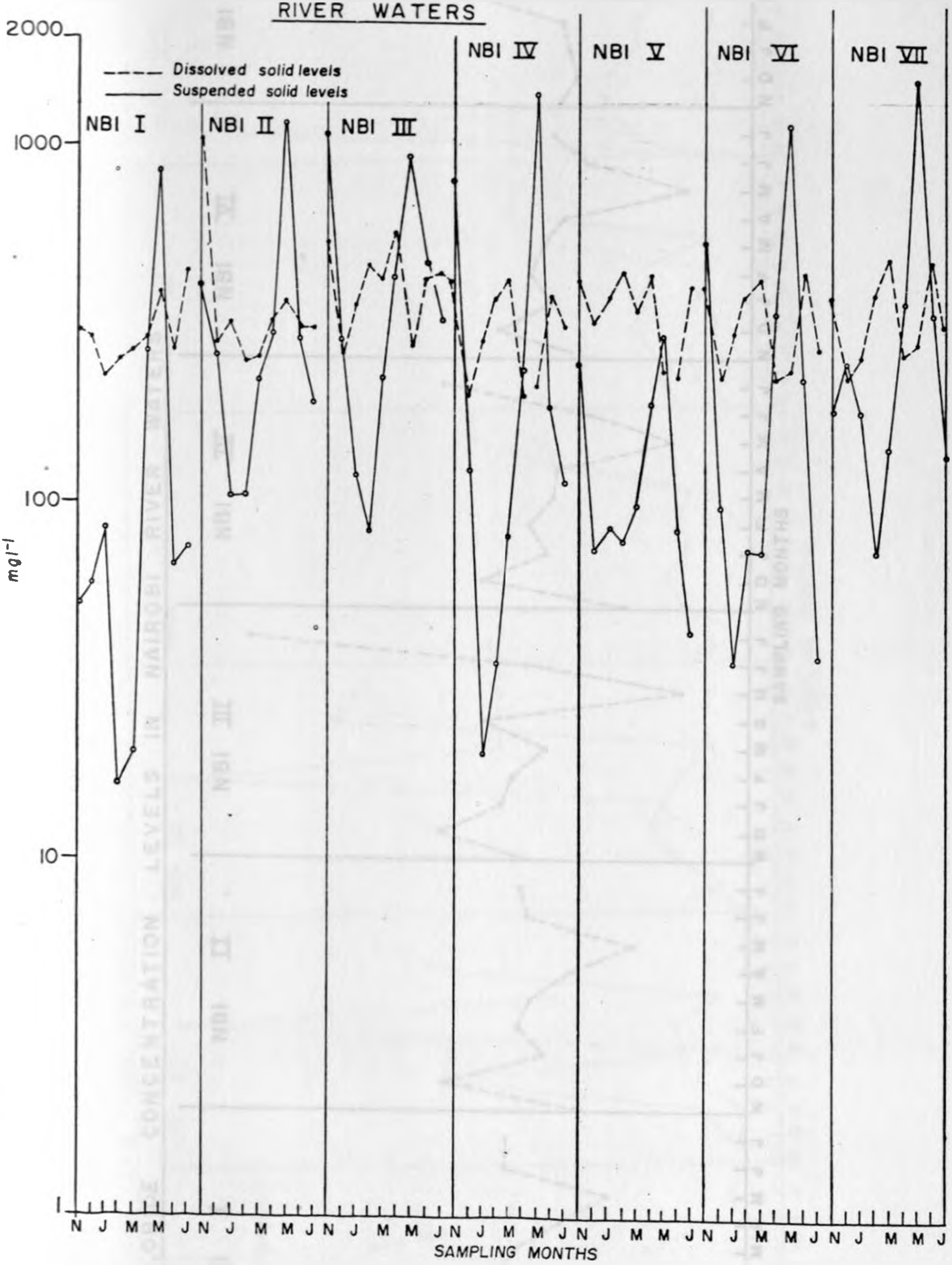


FIG. 3.2.5 CHLORIDE CONCENTRATION LEVELS IN NAIROBI RIVER WATERS

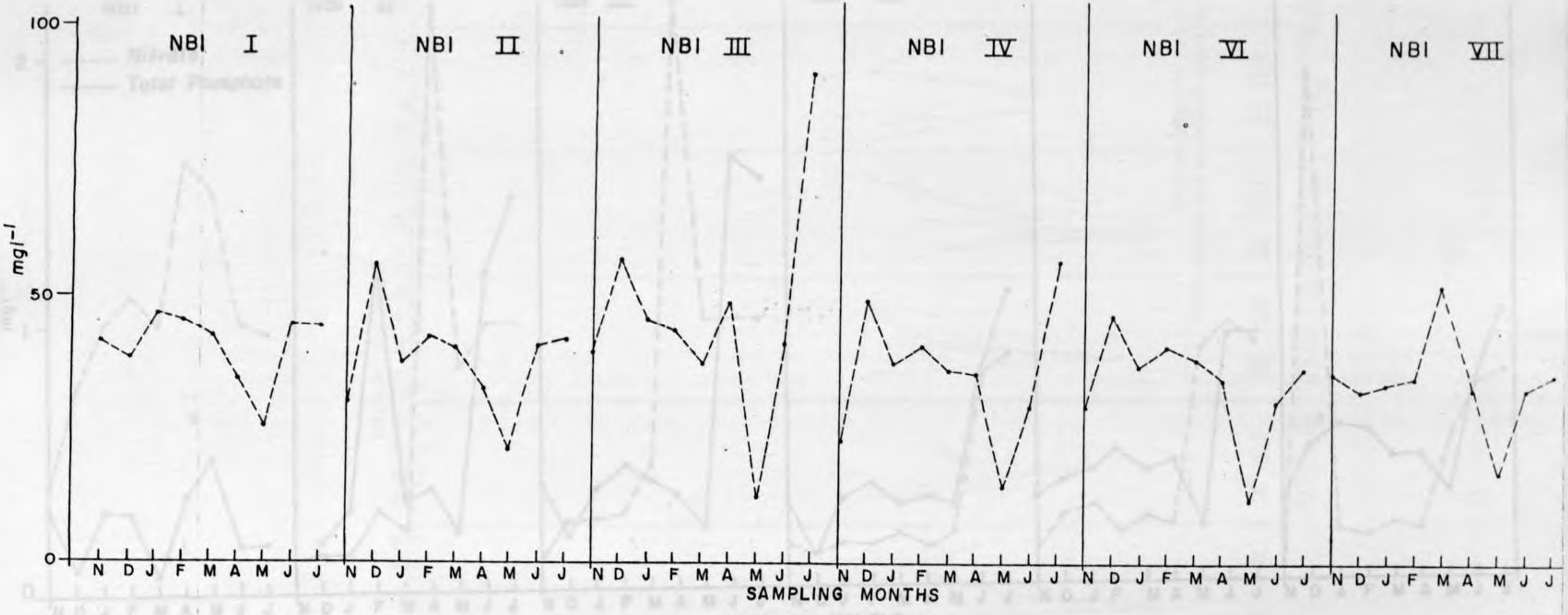


FIG. 3.2.6 NITRATE AND TOTAL PHOSPHATE LEVELS IN NAIROBI RIVER WATERS

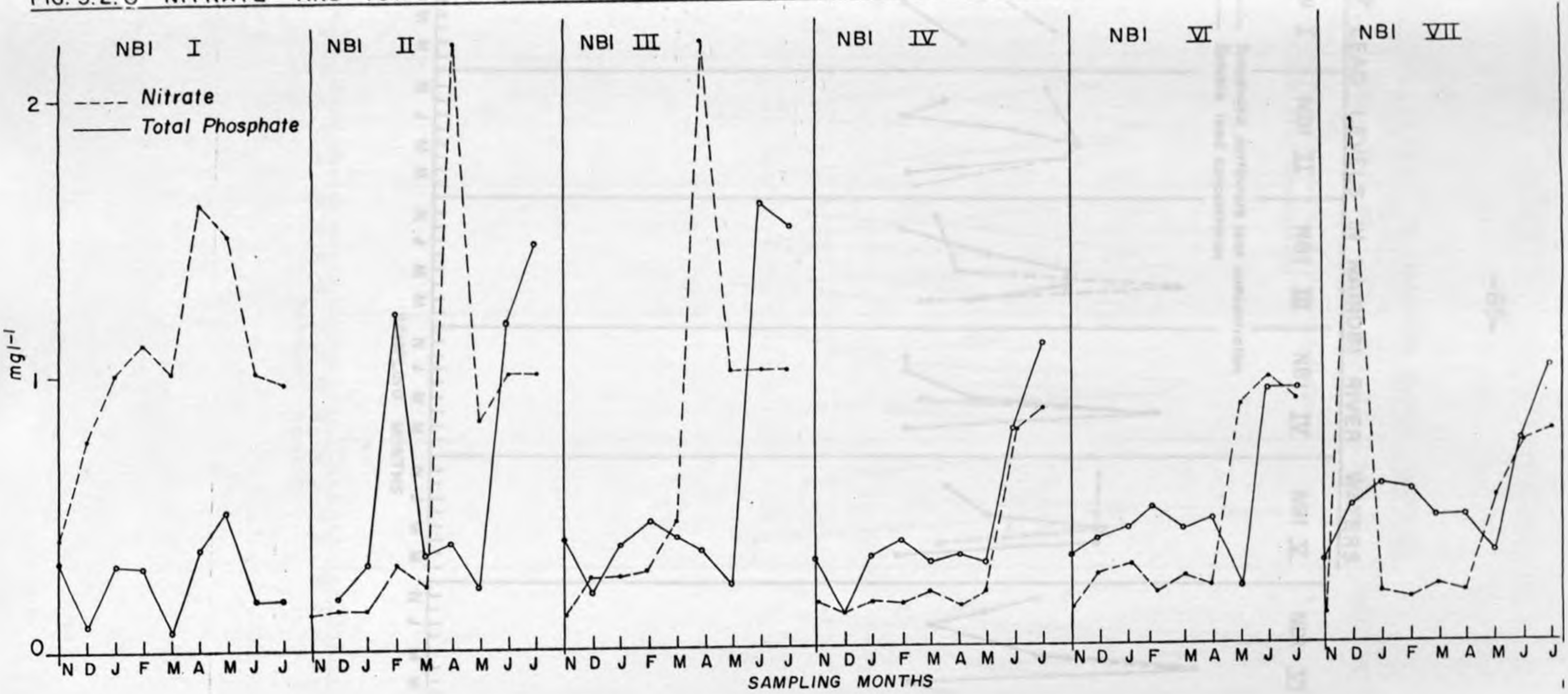


FIG. 3.2.7 LEAD LEVELS IN NAIROBI RIVER WATERS

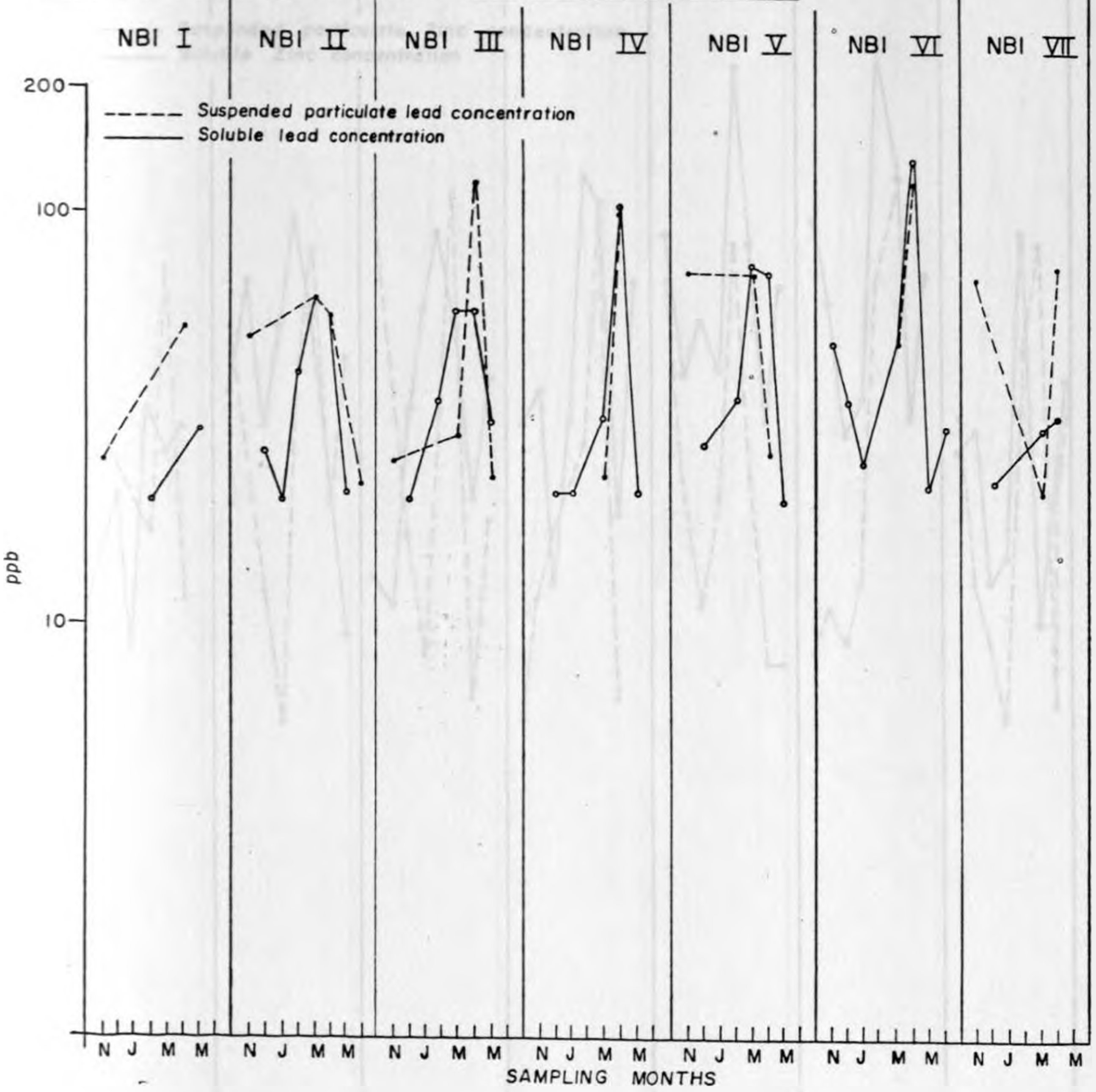


FIG. 3.2.8 ZINC LEVELS IN NAIROBI RIVER WATERS

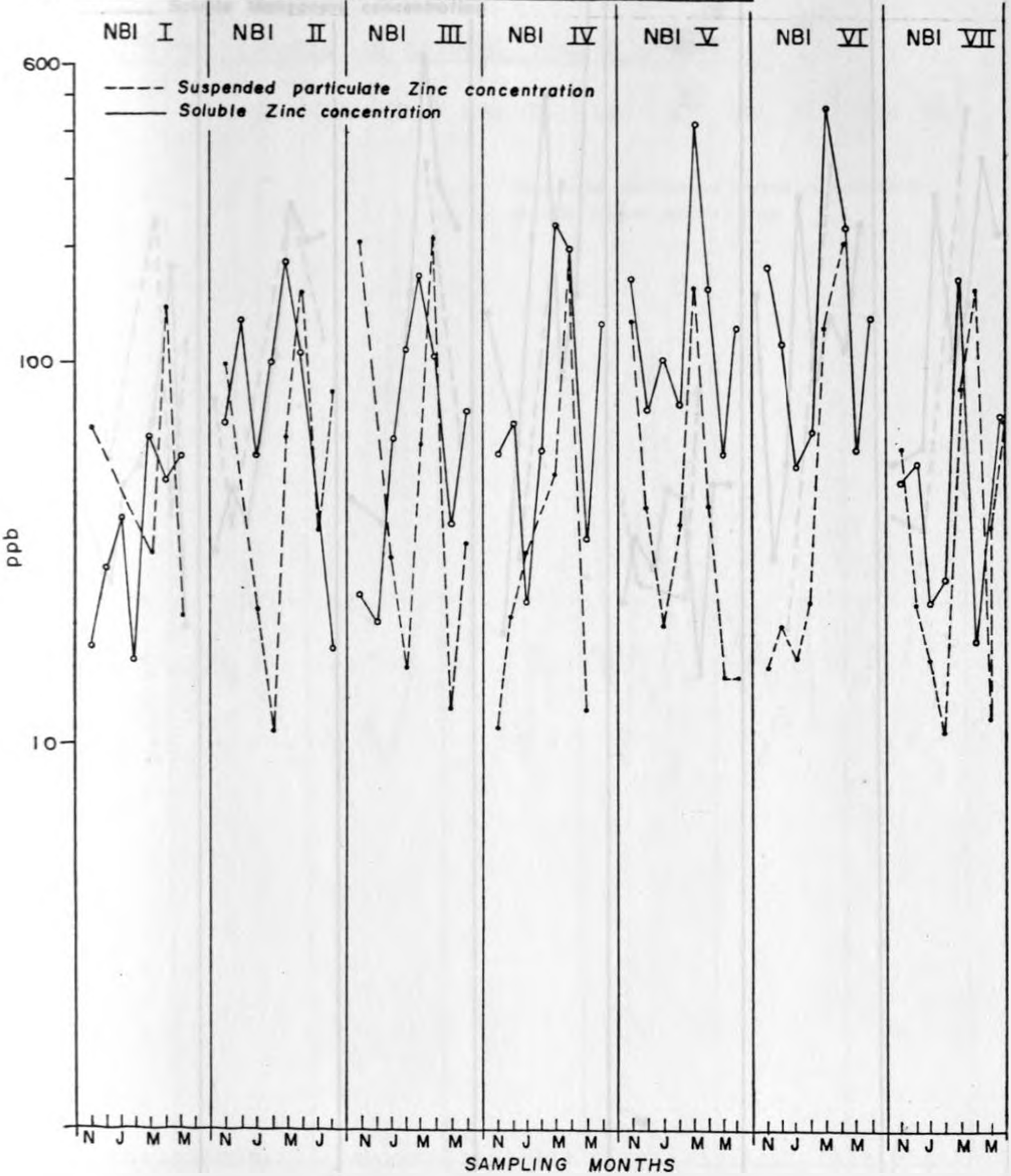


FIG. 3.2. 9 MANGANESE LEVELS IN NAIROBI RIVER WATERS

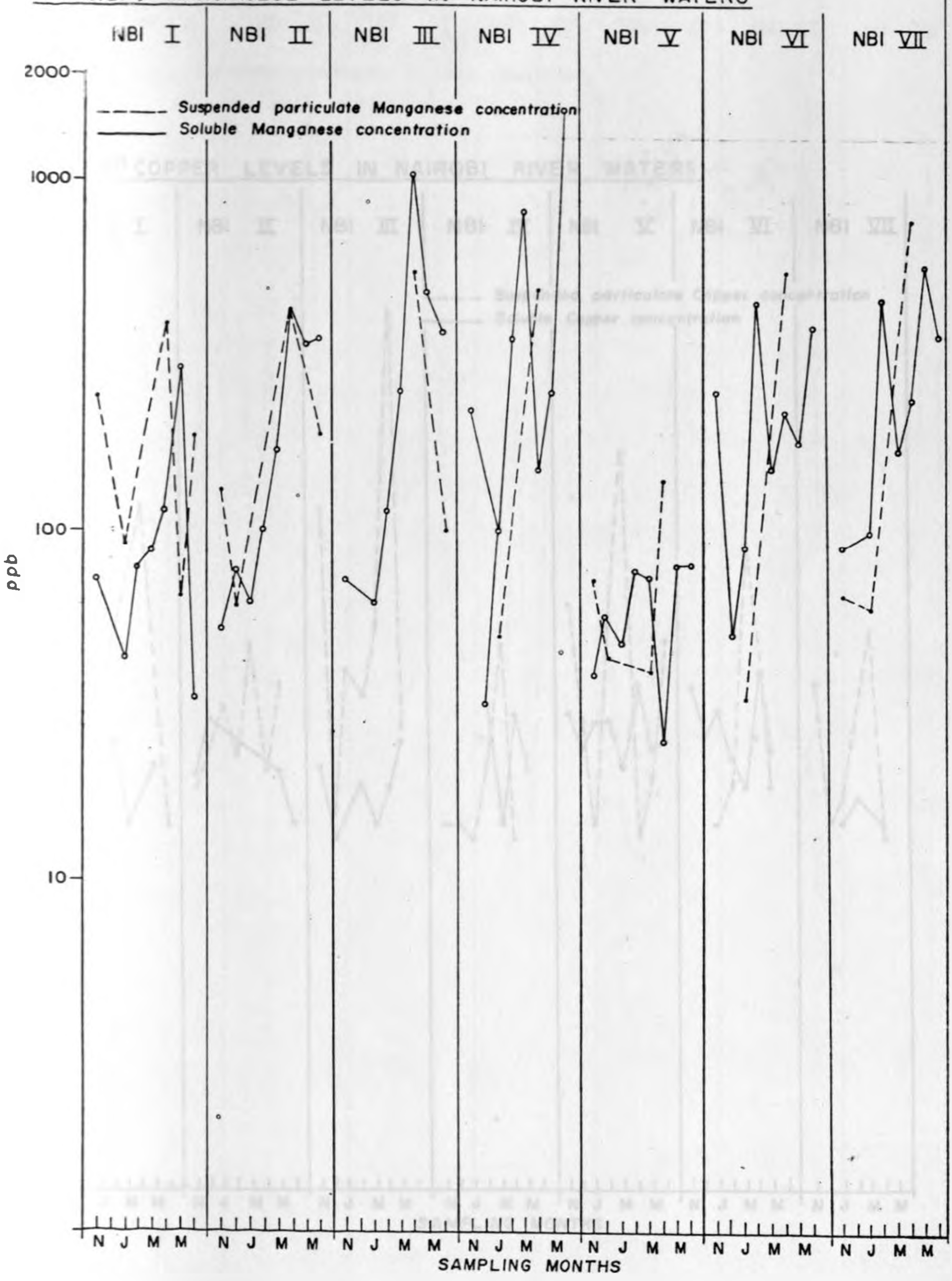


FIG. 3.2.10 COPPER LEVELS IN NAIROBI RIVER WATERS

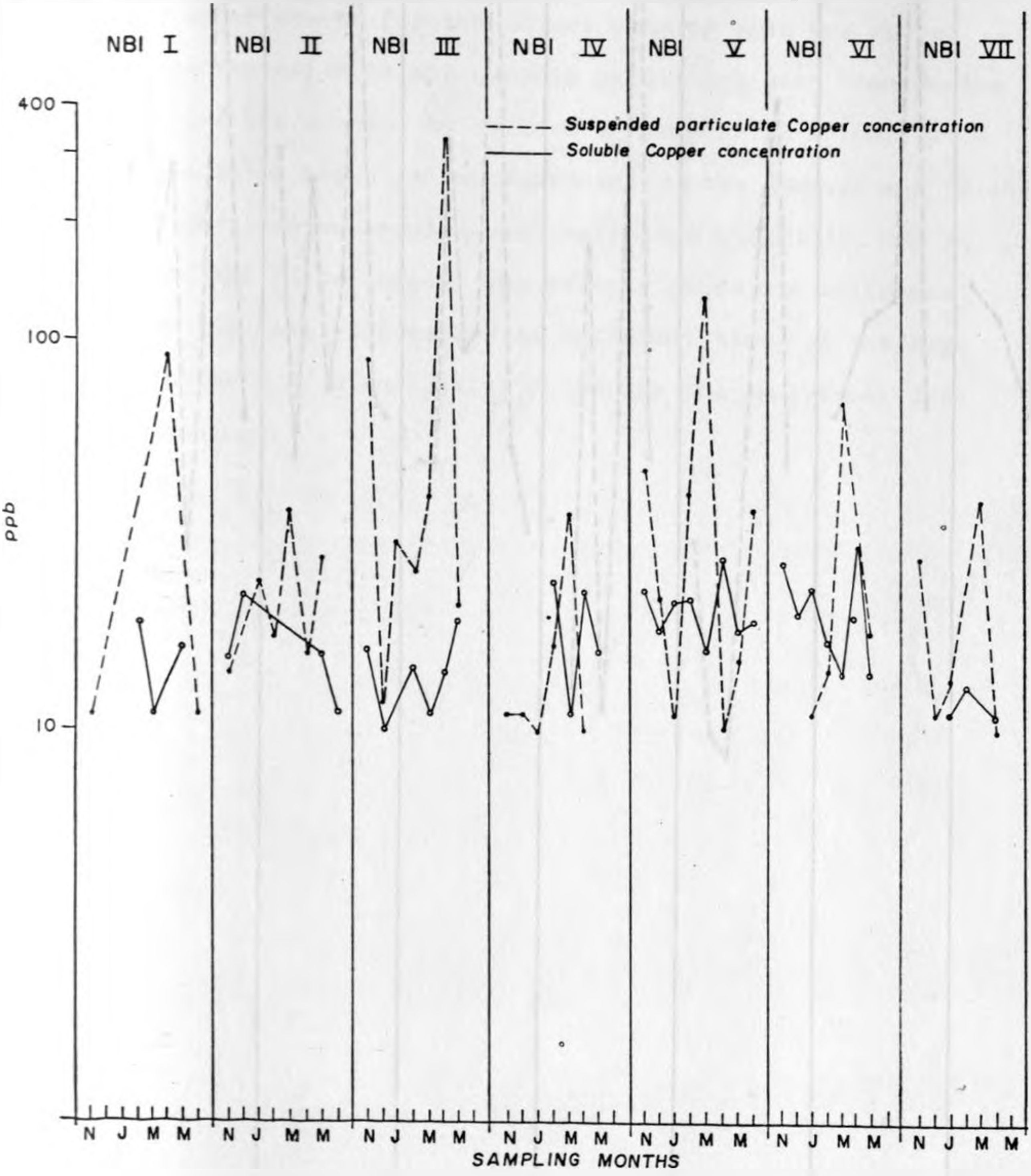
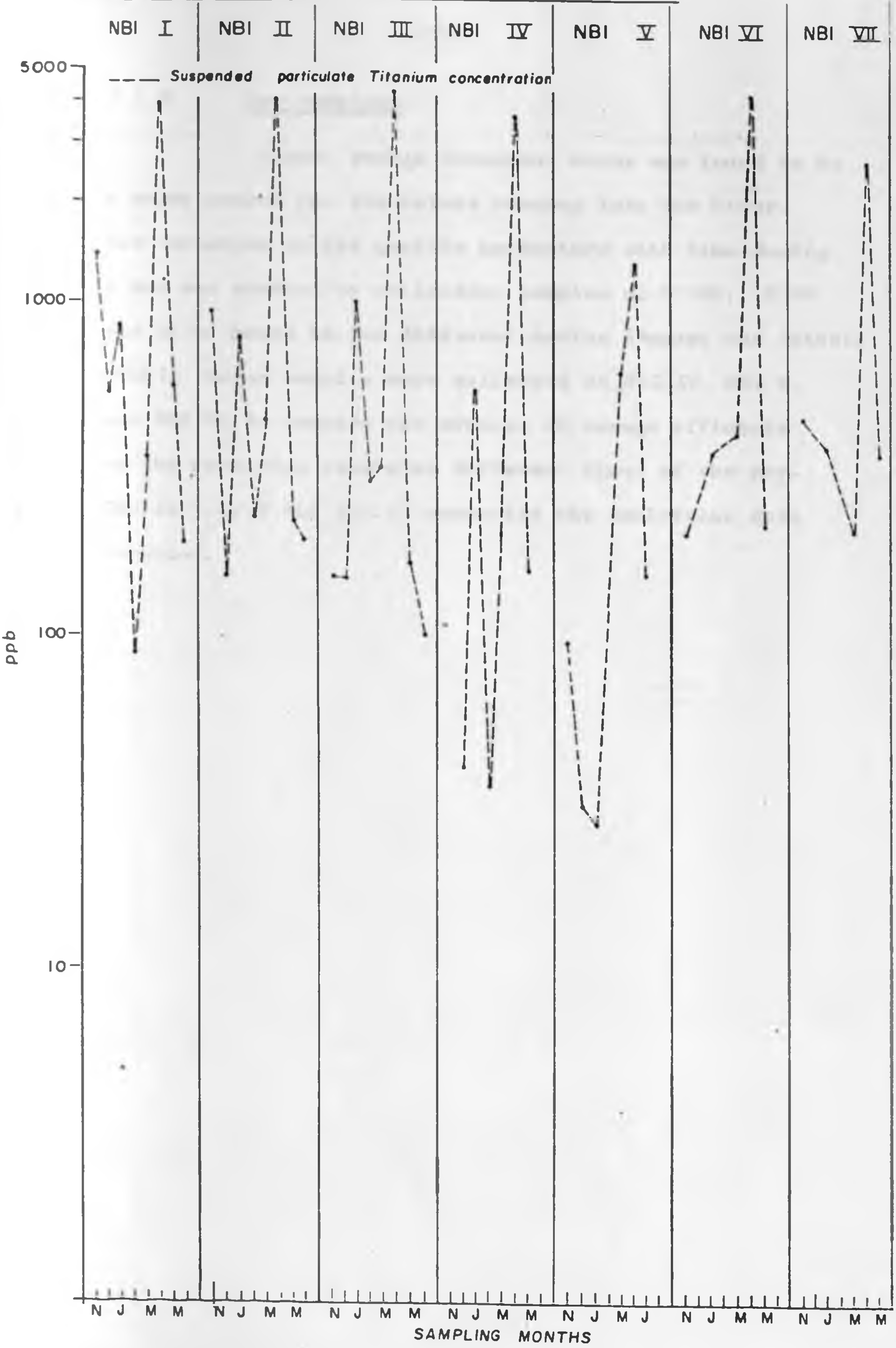


FIG. 3.2.11 TITANIUM LEVELS IN NAIROBI RIVER WATERS



3.2.2 Day sampling:

Since, sewage treatment works was found to be a major source for the waters running into the river, the variation in the quality parameters with time during a day was studied by collecting samples at 07:00, 12:00 and 16:00 hours in two different months (August and October 1986). Water samples were collected at NBI IV, NBI V, and NBI VI to compare the effects of sewage effluents on the receiving waters at different times of the day. Tables 3.2.10 and 3.2.11 summarise the analytical data obtained.

Table 3.2.10' - Quality parameters of Nairobi waters sampled on 4th August, 1986.

SAMPLING POINTS

	IV			V			VI		
	SAMPLING TIME								
PARAMATERS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Temperature (^{o}C)	19.0	20.9	21.4	21.7	23.4	23.8	20.8	22.0	22.9
pH	7.3	7.4	7.5	7.6	7.5	7.5	7.4	7.5	7.6
Conductivity (μscm^{-1})	496	412	410	544	589	658	499	456	485
BOD (mg/l)	12	15	32	70	104	120	56	24	66
COD (mg/l)	95	144	198	163	289	359	189	160	286
D.S. (mg/l)	288	176	216	248	268	264	300	212	220
S.S. (mg/l)	47	49	41	68	252	261	80	147	84

Table 3.2.11 - Quality parameters of Nairobi waters samples on 13th October, 1986.

SAMPLING POINTS

	IV			V			VI		
	SAMPLING TIME								
PARAMETERS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Temperature (^{o}C)	19.5	21.1	22.0	21.5	23.5	24.0	20.5	22.3	23.1
pH	7.6	7.6	7.7	7.7	7.6	7.4	7.7	7.5	7.3
Conductivity (μscm^{-1})	478	481	248	538	586	532	491	510	290
BOD (mg/l)	12	36	56	68	124	228	38	76	48
COD (mg/l)	99	180	189	179	340	518	107	240	142
D.S. (mg/l)	180	150	64	180	316	578	204	325	92
S.S. (mg/l)	42	24	1,312	57	219	456	42	79	1,122

3.3 Data analysis and discussion:-

3.3.1 Temperature:

The temperature of Nairobi river waters at NBI I varied between 18.3°C to 20.5°C depending on the season. Relatively high temperatures were recorded in the downstream sampling points with constant increase upto NBI IV. The temperature of the waters discharged from KSTW (NBI V) were always about 1 - 2°C higher than NBI IV, resulting in slight increase in temperature at NBI VI. The relative temperature at NBI VII was always lower by about 0.4 to 1.0°C than at NBI VI. Overall it is noted that the temperature at NBI VII were about 0.7°C to 1.4°C higher than those at NBI I. This increase caused could be attributed to changes in day temperature due to difference in sampling times (3 hours) and to the influx of various effluents into the stream in addition to the discharge from KSTW.

3.3.2 Hydrogen-ion concentration:

The pH values at the waters at NBI I varied mostly between 6.5 and 7.5 during the period of study, reaching the lower limit during the rainy season, an indication of probably acid rains. Consistently the pH at NBI II was relatively lower indicating the acidic nature of the effluents flowing in prior to this point. The pH then increase in all the samples at NBI III and was recorded in the range 6.7 to 9.0 indicating that prior to this point effluents which were basic in nature were entering the river waters.

The discharge at NBI V were also of the same pH range hence exerted little effect on pH of the downstream waters. Overall there was no definite trend in the pH variation in the stream.

3.3.3 Conductance (specific conductivity):

The conductance values of the waters at NBI I were in the range 175 - 357μs cm^{-1}. The low values in conductance were observed in the rainy season. Compared to NBI I relatively much higher values were observed downstream, but with no definite trend, suggesting the influx of pollutants are of varied nature.

3.3.4 Biochemical oxygen demand(BOD):

Low BOD values were observed at NBI I and the values ranged between 2 to 16 mg l^{-1}. The lower values indicate the good quality of the waters passing through at NBI I. Relatively higher values were recorded downstream, reaching a maximum of 400 mg l^{-1} at NBI III in a typical sample. In a general trend higher BOD values were recorded at NBI II and NBI III. The samples at NBI V had relatively higher BOD values than at NBI IV thus increasing the BOD levels at NBI VI compared to NBI IV. During the rainy season all the waters had reasonably low BOD levels. At NBI VII, the BOD values recorded were relatively much lower than those observed at NBI VI was an indication of the occurence of self-purification in the stream in that 10 Km stretch. The occational higher values at NBI VII could be attributed to the effluents from the tributaries.

3.3.5 Chemical oxygen demand (COD):

The COD values at NBI I were found to vary between 12 and 93 mg l^{-1}, again the lower limit being in the rainy season. Relatively much higher values were recorded in the downstream , recording a maximum 1,040 mg l^{-1} in one sample at NBI III. The peak COD levels at NBI II and NBI III pinpoint that this region is the major pollution area. At NBI IV a decreasing trend was observed, but again at NBI VI the values were relatively higher than NBI IV due to the influx of treated sewage effluents having higher COD levels. At NBI VII the COD values were observed to be lower compared to those at NBI VI, exhibiting the same trend as BOD levels.

3.3.6 Dissolved solids (D.S.):

The dissolved solid concentration at NBI I ranged between 190 and 450 mg l^{-1}, with lower values being observed during the rains. High values in the vicinity of 1050 mg l^{-1} were recorded at NBI II and NBI III in particula samples, but the typical values were about 400 mg l^{-1}. These typical levels were maintained even at NBI VII. Occasionally high levels were observed at NBI VII as compared to NBI VI, which could be due to the waters from the tributaries joining the river.

3.3.7 Suspended solids (S.S.):

At NBI I S.S. concentrations ranged from 15 to 835 mg l^{-1}. The higher values were recorded during the rainy seasons, which could be possibly due to washing off of different materials of anthropogenic origin by rain waters. In general relative to NBI I higher values were recorded downstream. with a maximum at NBI III in all the samples. Again the increase observed at NBI VI was due to the higher levels of S.S. in NBI V, with exception in rainy season. The S.S. values recorded at NBI VII were generally higher compared to NBI VI, suggesting the Mathare and Ruiruaka tributaries possibly carry a higher load of S.S. in their waters.

3.3.8 Chloride (CL^{-1}):

Except that the levels were low in the rainy season and occasionally higher at NBI III generally the chloride ion concentrations at all points were found to vary in the range 23 to 57 mg l^{-1} with distinct trend.

3.3.9 Nitrate ($N-NO_3$) :

Nitrate concentration at NBI I ranged from 0.40 to 1.62 mg l^{-1}. Interestingly higher NO_3 levels were observed in the rainy season, which could be due to leaching of nitrate fertilizers into the river. Relativly much lower values were observed in the downstream upto NBI IV, suggesting that not much nitrate containing discharge entered into the river. The sewage work (NBI V) tended to increase the nitrate levels in the downstream (NBI VI). At NBI VII compared to NBI VI lower nitrate levels were observed.

3.3.10 Total phosphate ($P-PO_4$) :

Higher limit being in rainy seasons phosphate concentrations at NBI I varied over a wide range 0.03 to 0.48 mg l^{-1}. Except during rains, relatively higher values were recorded in the downstream and levels were maintained between 0.11 to 1.79 mg l^{-1} at different points with no distinct trend. KSTW effluents invariably increased the levels of phosphate levels further downstream, resulting in considerable levels of phosphate even at NBI VII. Occassional increase could be attributed to influx of pollutants from the tributaries joining the river.

3.3.11 Soluble elemental concentrations

A perusal of the data in tables 3.2.1 to 3.2.9 and the figures 3.2.5 to 3.2.9 indicate that concentrations of the soluble elements at NBI I were quite low (Zinc $<$ 60 ppb, Cu $<$ 20ppb and Pb $<$ 30ppb), except for Mn which reached concentrations as high as 298 ppb. The high concentrations at this point were recorded during the rains.

Relatively high concentrations of heavy metals in soluble form were observed in the downstream. Copper concentrations recorded slight increases but in general the levels were fairly below 30 ppb in all the samples analysed during the study. Zinc concentrations recorded significant increases in the downstream, reaching values as high as 490 ppb at NBI VI. The effluents from KSTW (NBI V) markedly increased the Zinc levels in the receiving waters. High lead concentrations were also recorded in the downstream, occasionally at NBI II to NBI IV. The maximum value of Pb recorded in one sample at NBI VI was 134 ppb and the final effluent from KSTW had some effect on increasing Pb level in the waters. Although background levels of Mn were high (NBI I), relatively Mn levels were found to increase in the downstream and peak concentrations were recorded at NBI IV points. The increase observed at NBI VI could be attributed to the effluent from the KSTW. Occasionally higher values of Mn were observed at NBI VII reaching a maximum of 558 ppb, possibly due to waters from the tributaries again.

3.3.12 Suspended matter elemental concentrations

Background concentration of titanium at NBI I were found to be higher than downstream which was lowered due to dilution effects. Noticeable increases were observed at all points in the rainy months, indicating the origin of the titanium in the waters was the soil. Suspended Cu level were very low at NBI I and fairly higher at sampling points downstream. Occasionally higher values were observed at NBI III and NBI V (final effluent) leading to increase in the downstream. The high value noted at NBI III could be due to release of copper into the water from the sediment (river bottom) as a result of the basic pH of the water. Zinc concentrations recorded at NBI I ranged from 20 to 140 ppb with the maximum value being observed in the rainy season. Relativley higher values were noticed downstream and the noticeable increase at NBI VI could be due to the effects of high Zn levels in effluents from KSTW (NBI V). Manganese concentrations at NBI I ranged between 48 and 386 ppb and values were dependant of the season. Relativley much lower values were observed in the downstream including the discharges from KSTW. Only in the rains was there a noticeable increase downstream and the effects of the tributaries is observed at NBI VII.

3.3.13 Changes in levels of pollutants and corresponding parameters during day sampling at NBI IV, NBI V and NBI VI:

A perusal of the data in table 3.2.10 and 3.2.11 shows that temperature of the aquatic samples at each point increase in temperature was in the range 2° to 2.5°C from 07:00 hours to 16:00 hours during the day.

The pH values of the waters remained fairly the same during the day with marginal increases or decreases of 0.1 to 0.2 units during the day.

The conductance value at NBI IV remained fairly the same while the values increased with progress of the day at NBI V which correspondingly effected the values at NBI VI.

The BOD levels at NBI IV recorded a marginal increase during the day but the magnitude was higher in the sewage effluents at NBI V. The effect was reflected at NBI VI to same extent but the trend is not distinct The trend similar to BOD levels is observed in COD levels also and the continous increase is noticeable at both NBI IV and NBI V with the progress of the day in both the analysis, but at NBI VI peak values were observed at Noon-time.

The trends in levels of D.S. and S.S. at NBI IV were different on the two different days. Samples were collected hence no conclusion can be drawn. But in both cases levels of both D.S. and S.S. increased with the progress of the day in the treated sewage, exerting their influence in the corresponding samples at NBI VI.

The overall day sampling of waters at point IV, V and VI show that the level of pollutants and their representative parameters had a distinct raising trend in the effluents from KSTW with progress of day while it is less marked at NBI IV and NBI VI.

3.4 PRINCIPAL FINDINGS AND RECOMENDATIONS:-

The perusal of all the data accumulated on the Nairobi river reflect the state and quality of it's waters. Nairobi river in all aspects is moderately polluted, due to influx of both treated and untreated effluents, carrying varius types of pollutants. The data obtained indicate that the catchment areas prior to NBI II and NBI III are the regions of major pollution due to influx of untreated effluents. The high levels of BOD, COD, D.S. and S.S. reflect that in this stretch the stream is over-burdened with pollutants. Most noticeable pH changes were observed at these points which is an index of adverse nature of the pollutants. Another entry point of pollutants is the sewage treatment works, which is handling the sewage waters beyond its capacity, resulting in discharge of partly untreated effluents. This is evident from the quality parameters of the aquatic samples at NBI V and . also comparison of the data with values obtained at NBI IV and NBI VI. Significant increases in levels of heavy metals were also observed in the river waters, soluble form of Zn reached a maximum of 486 ppb at NBI VI which is quite above the permitted level for hygenic in aquatic sample. The levels of suspended Ti was found to be quite high occasionally reaching 1,000 ppb in the river samples. Even at NBI VII considering the levels of BOD, COD, D.S. and S.S. and phosphates observed, the river can still be considered polluted although some self-purification through aerial oxidation process and sedimentation process is observable.

Cleansing the Nairobi River is not an easy task since pollution sources are numerous and disperseable along the banks of the stream. The self-purification progress are not adequate due to the sustained inflow of effluents into the river. Hence steps have to be taken to check the inflow and run off of the untreated effluents to the possible extent and additional facilities for complete treatment of the sewage have to be provided.

CHAPTER FOUR.

4.0 ANALYSIS OF QUALITY OF NGONG' RIVER WATERS:-

4.1 Introduction:-

Ngong' river acquired it's name from it's place of origin, the Ngong' hills and flows through about 28 kms within the city boundaries. After about 4 kms within the city boundaries the river runs into the Nairobi dam (occupying approximately 7.5 square kms). Before entering the dam, the river pases through some thinly populated residential areas and collects waters from small tributaries. Although the Nairobi dam is a place of various activities such as watersports, it is not surrounded by any industries that could cause pollution. After flowing about 4 kms downstream from the dam, the river enters into the country's main industrial belt covering a distance over 10 kms collecting numerous pollutants. The river then passes through unihabited land a distance of about 12 km and again entering residential areas. The industrial oxidation ponds also discharge their effluents into this river in the downstream.

For studying the effects of mainly industrial effluents on the quality of Ngong' waters, five sampling sites (points) were identified along the streams starting with a point upstream after the Nairobi dam where the waters are fairly free from industrial pollution.

Map figure 1 shows the five sampling points stretched over a distance of about 20 kms identified for the studies. The description of the sites are as follows:-

NGN I (Mombasa Road Bridge) - A point prior to the industrial belt. Waters flowing from the Nairobi dam and carrying low levels of pollutants.

NGN II (pedestrian bridge) - Approximately 2 kms from NGN I, centre of major industrial activities.

NGN III (Enterprise Road bridge) - About 3 kms from NGN II, location of major industrial activities.

NGN IV (Outering Road bridge) = About 3.5 kms from NGN III Located within the industrial belt but industrial activity slightly lower.

NGN V (Njiru) - About 12 kms from NGN IV. Location of minimum industrial activity. Pollutant mainly from the industrial oxidation ponds.

4.2 Results:

4.2.1 Monthly samplings

Water samples were collected at fairly monthly intervals over a period of about one year (1985/1986) and the quality parameter determined. The analytical data obtained are tabulated in tables 4.2.1 to 4.2.9 (series A and B are in the previous chapters). The data obtained is also shown in figures 4.2.1 to 4.2.11.

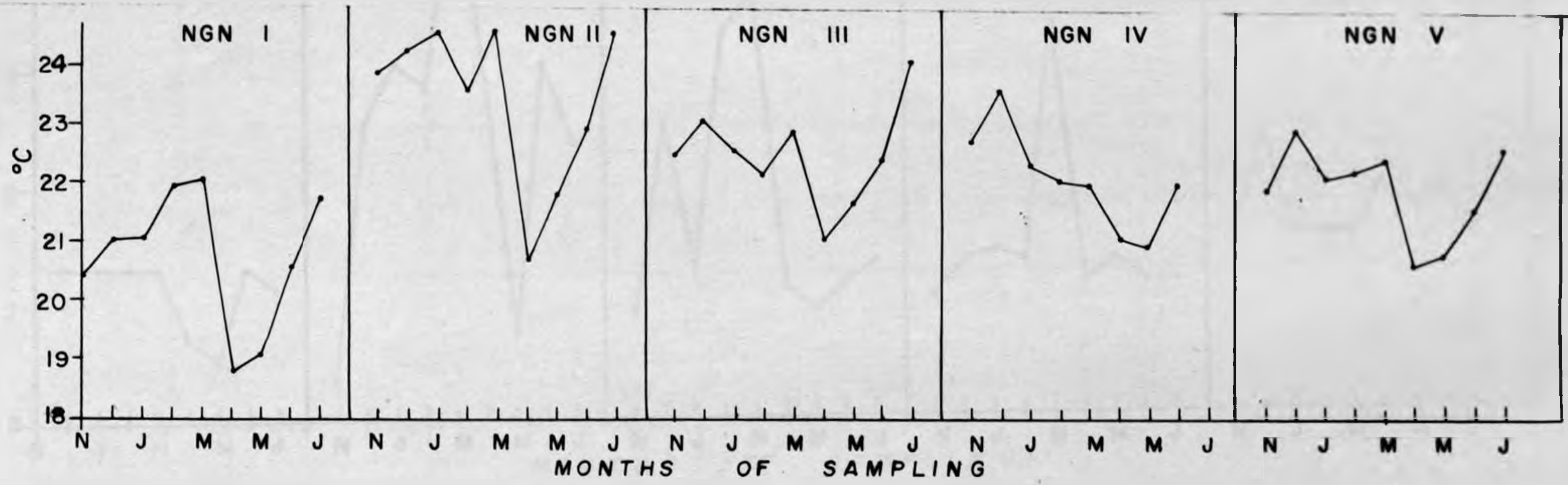


FIG. 4.2.1 TEMPERATURE PROFILE OF NGONG RIVER WATERS

FIG. 4.2.2 p.H PROFILE OF NGONG RIVER WATER

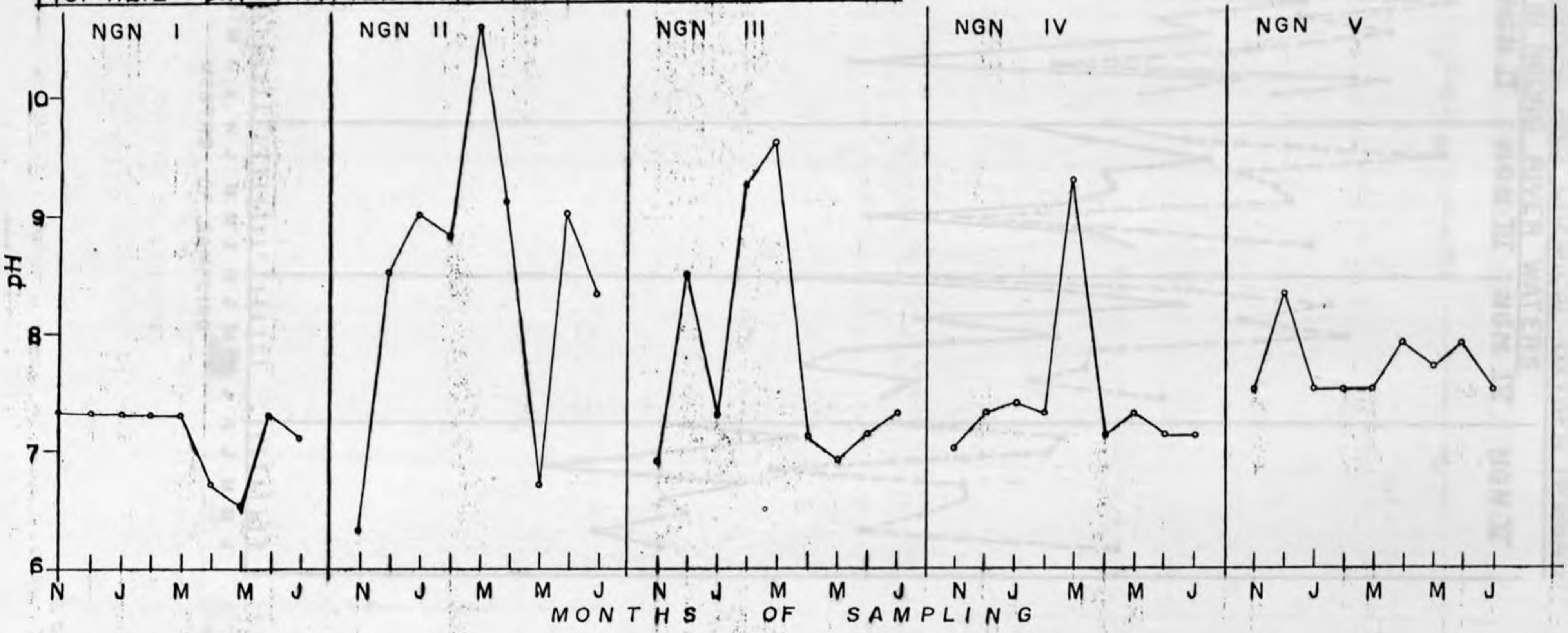


FIG. 4.2.3 BIOCHEMICAL AND CHEMICAL OXYGEN DEMAND LEVELS IN NGONG RIVER WATERS

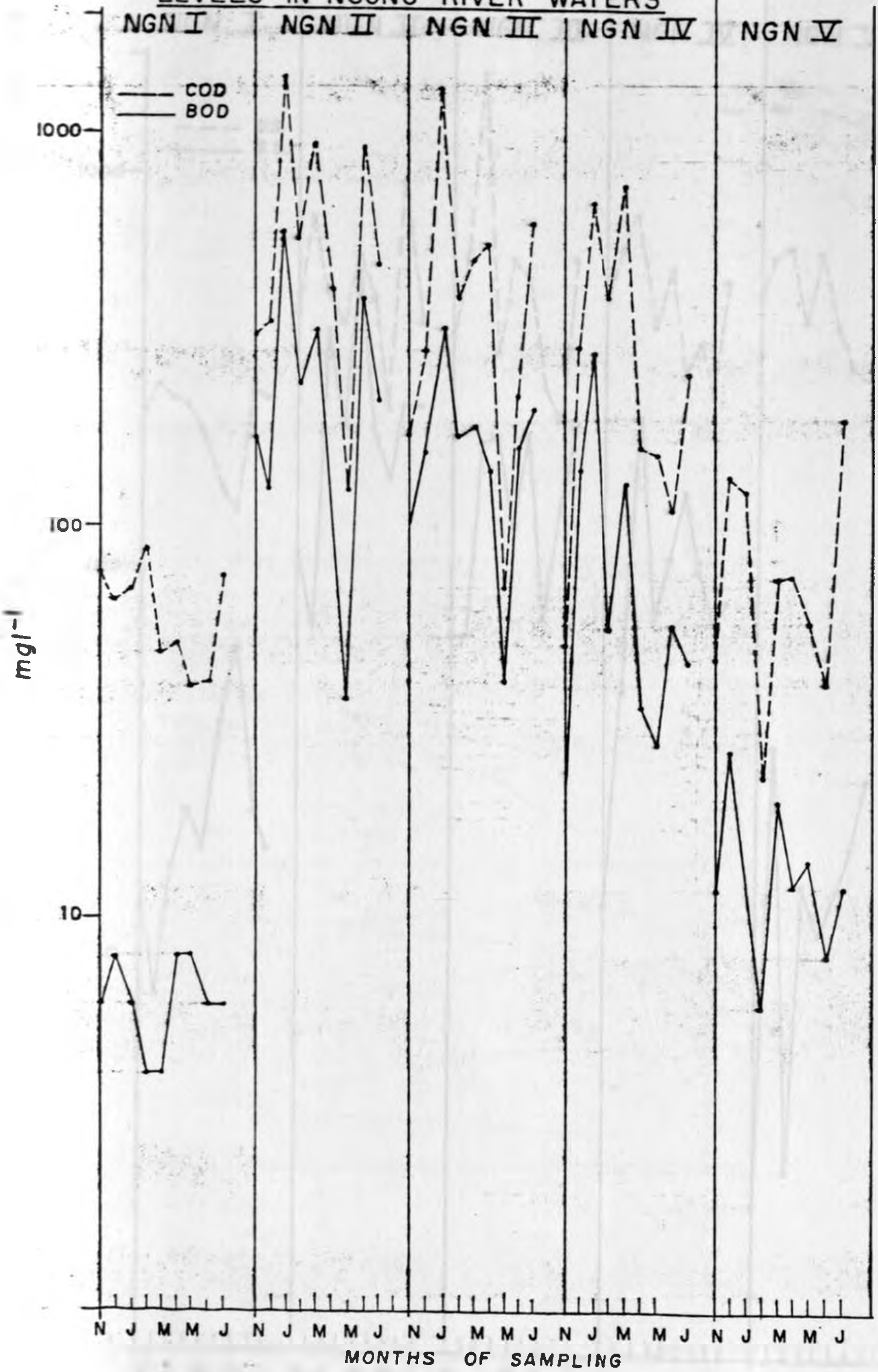


FIG. 4.2.4 DISSOLVED AND SUSPENDED SOLID LEVELS IN NGONG RIVER WATERS

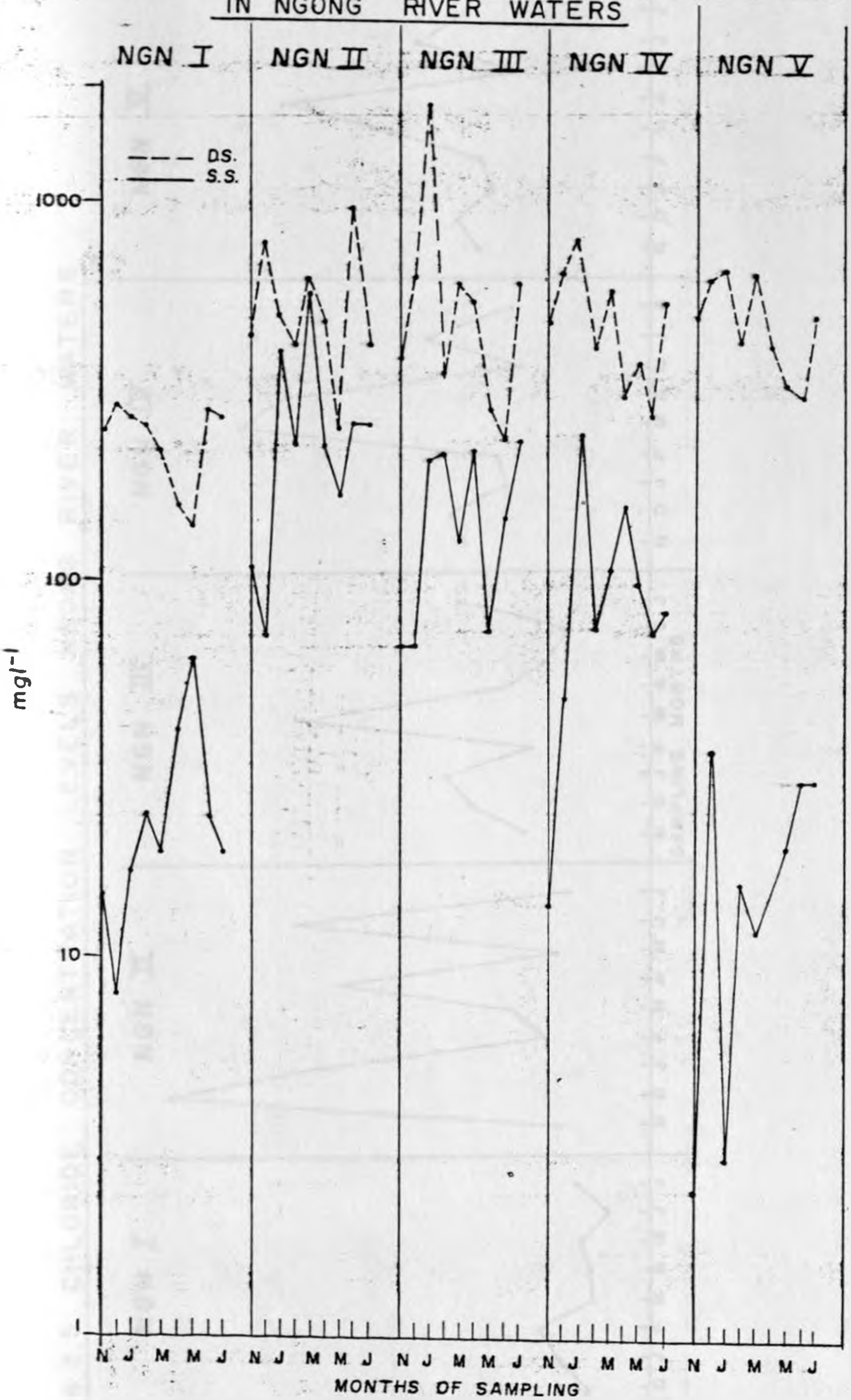
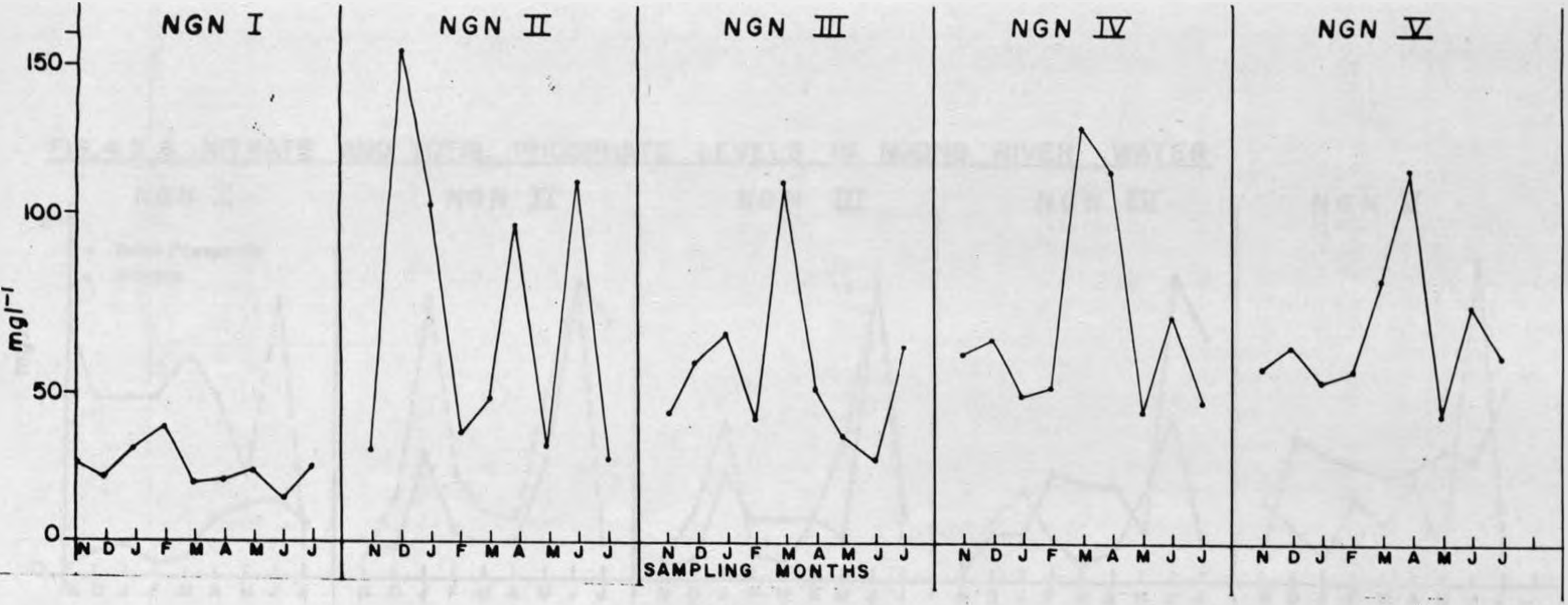


FIG. 4.2.5 CHLORIDE CONCENTRATION LEVELS NGONG RIVER WATERS



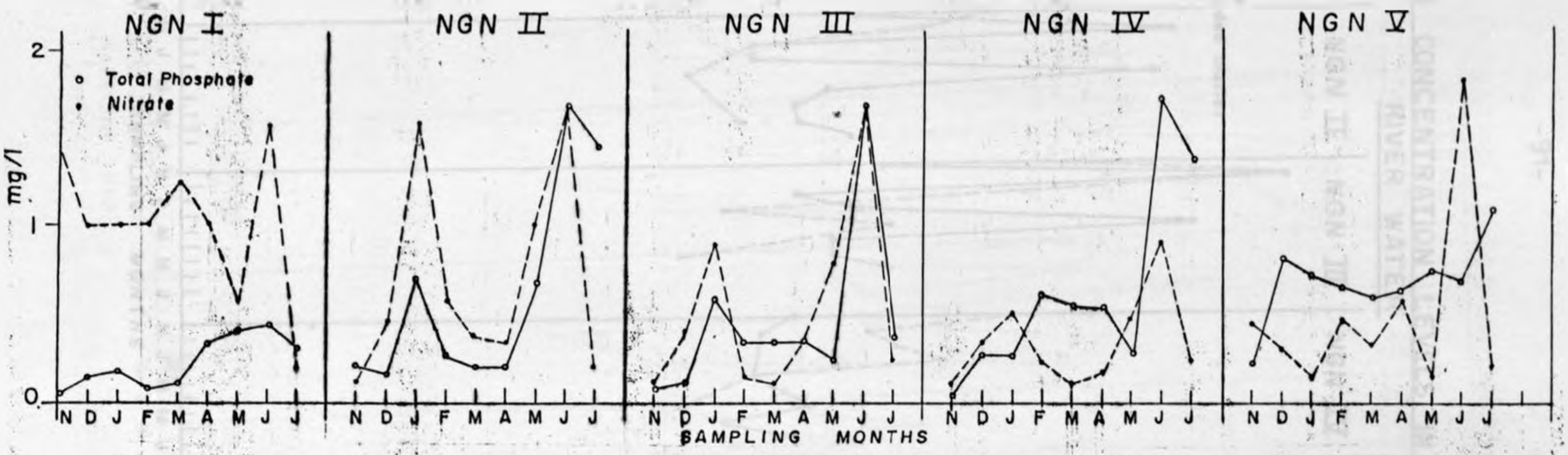


FIG. 4.2.6 NITRATE AND TOTAL PHOSPHATE LEVELS IN NGONG RIVER WATER

FIG. 4.2.7 LEAD CONCENTRATION LEVELS IN NGONG RIVER WATER

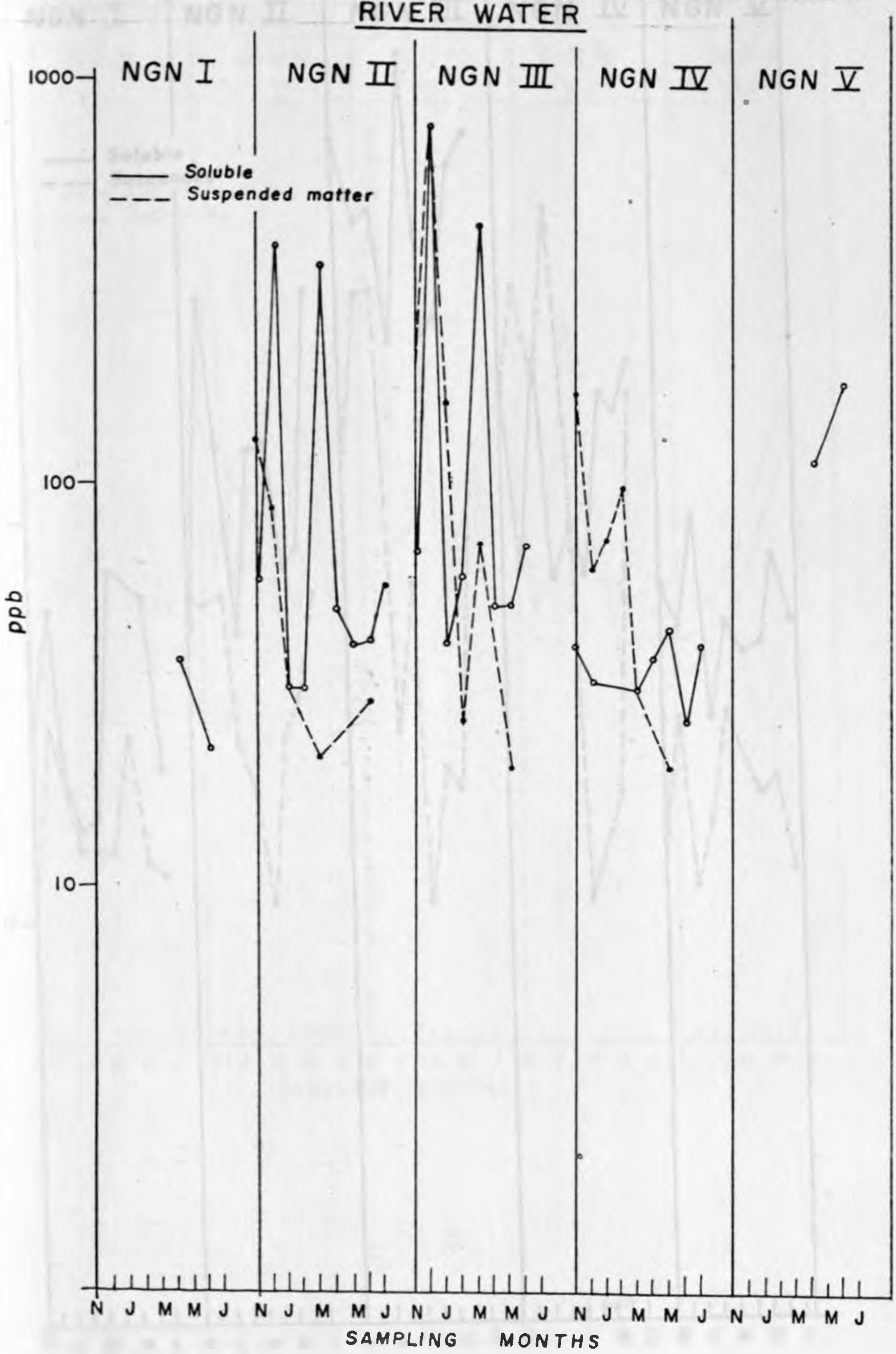


FIG. 4.2.8 ZINC CONCENTRATION LEVELS IN NGONG RIVER WATERS

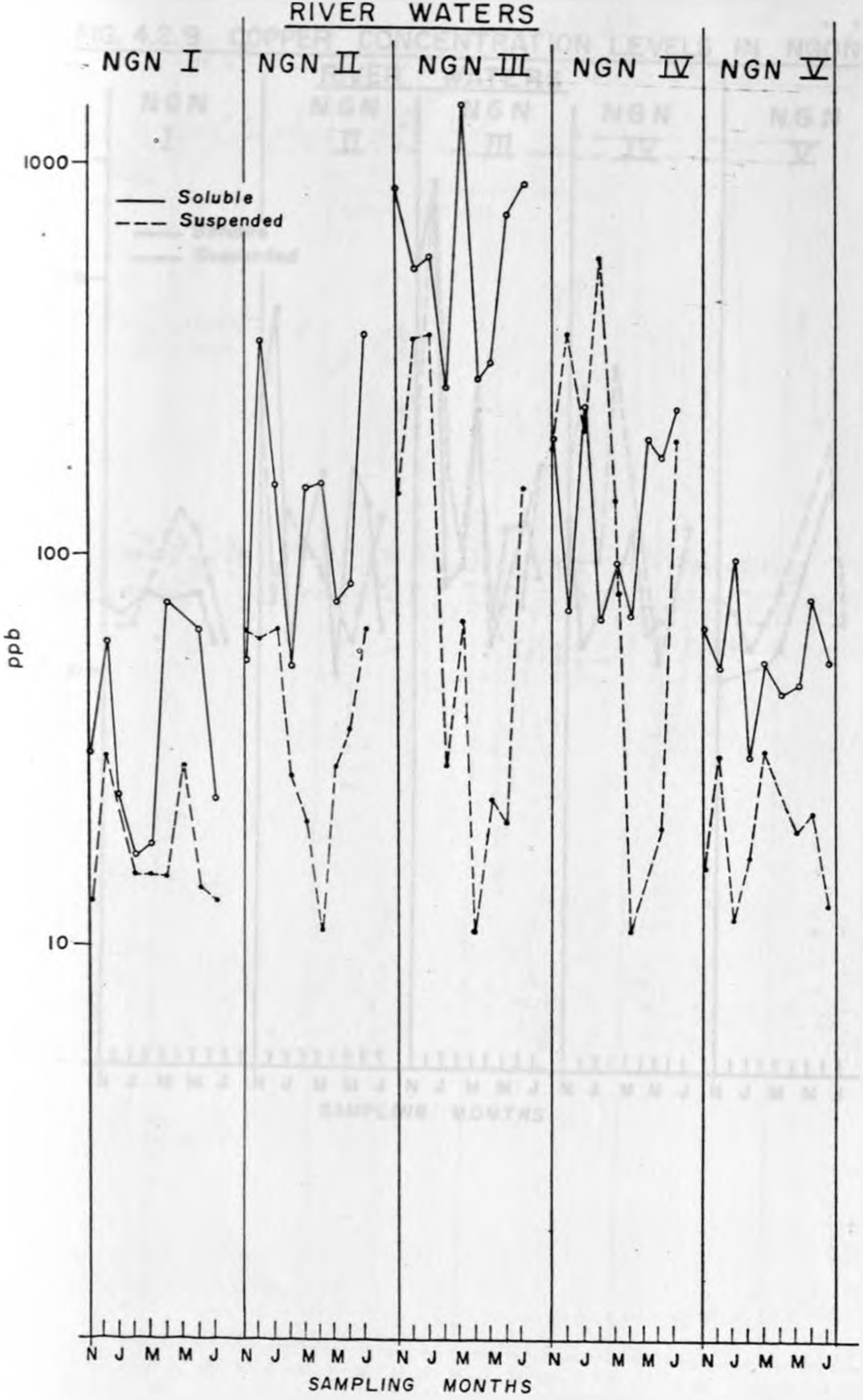


FIG. 4.2.9 COPPER CONCENTRATION LEVELS IN NGONG RIVER WATERS

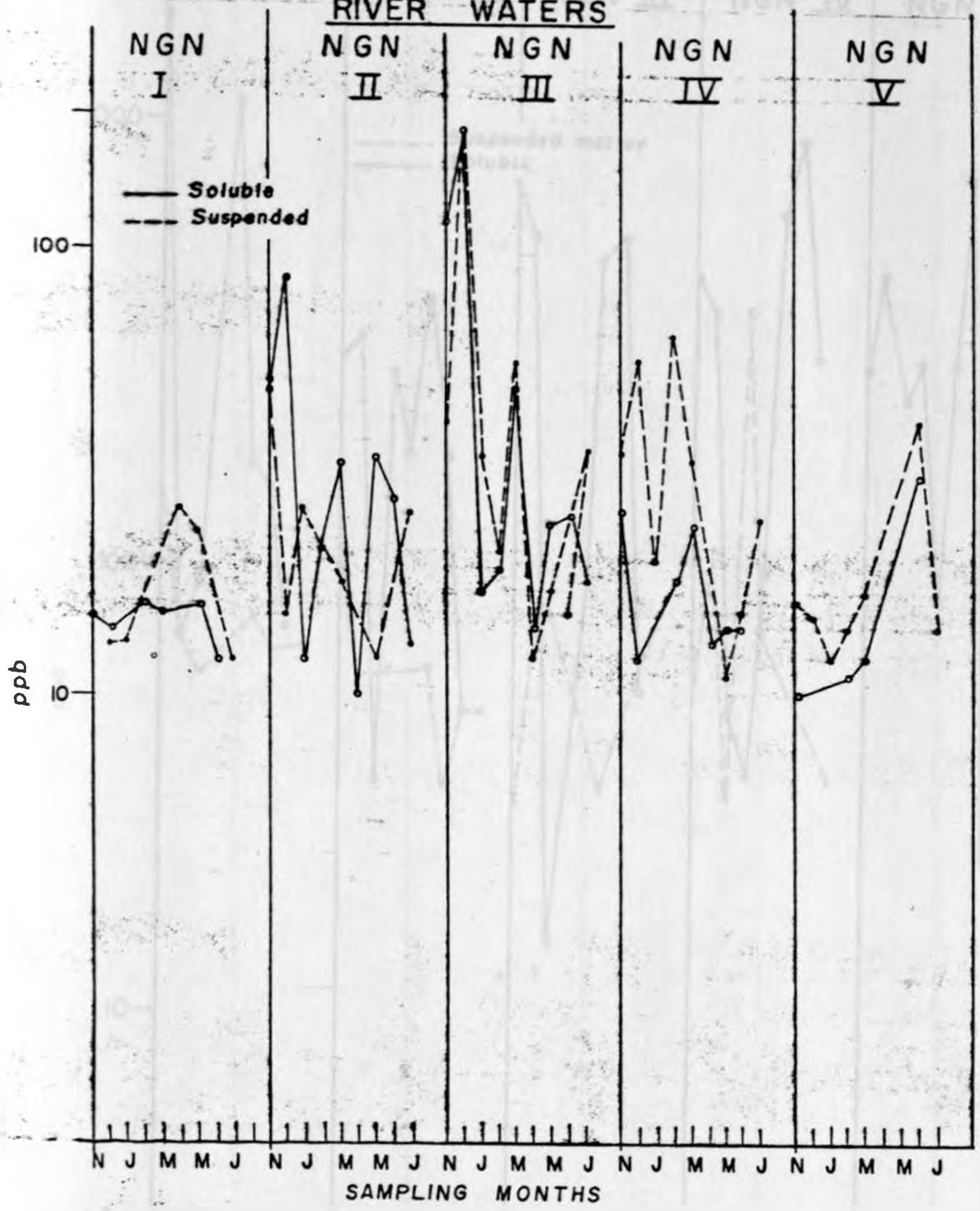


FIG. 4.2.10 MANGANESE CONCENTRATION LEVELS IN NGONG RIVER WATERS

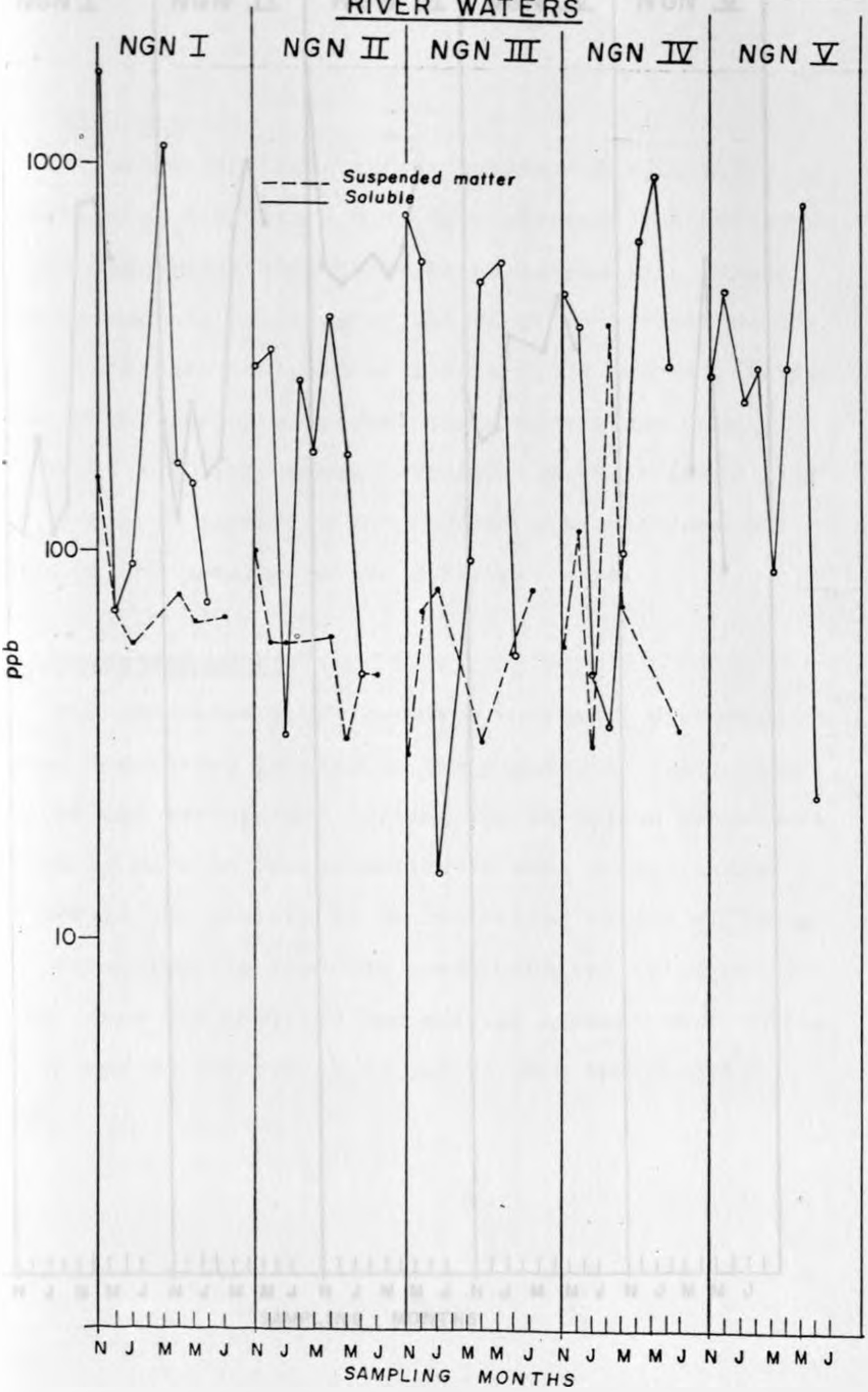
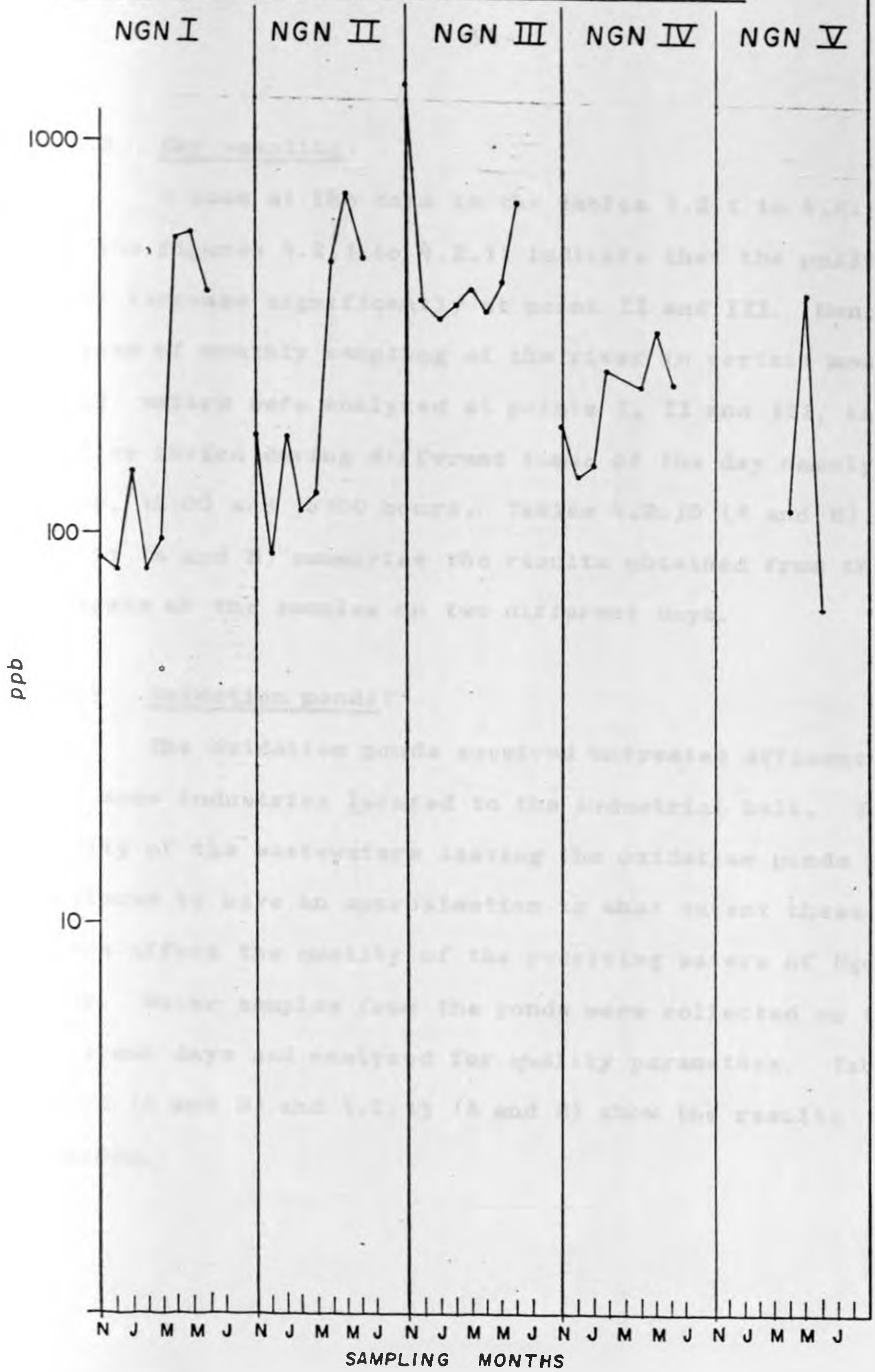


FIG. 4.2.11 SUSPENDED PARTICULATE TITANIUM CONCENTRATION LEVELS IN NGONG RIVER WATERS



4.2.2 Day sampling:

A look at the data in the tables 4.2.1 to 4.2.9 and the figures 4.2.1 to 4.2.11 indicate that the pollutant level increase significantly at point II and III. Hence, instead of monthly sampling of the river in certain months, Ngong' waters were analyzed at points I, II and III, taking samples thrice during different times of the day namely, 07:00, 12:00 and 16:00 hours. Tables 4.2.10 (A and B) and 4.2.11 (A and B) summarise the results obtained from the analysis of the samples on two different days.

4.2.3 Oxidation ponds:

The oxidation ponds received untreated effluents from some industries located in the industrial belt. The quality of the wastewaters leaving the oxidation ponds were monitored to have an approximation to what extent these waters affect the quality of the receiving waters of Ngong' river. Water samples from the ponds were collected on two different days and analysed for quality parameters. Tables 4.2.12 (A and B) and 4.2.13 (A and B) show the results obtained.

Table 4.2.10A - Quality parameters for day sampling on 7th September, 1986.

	SAMPLING POINTS								
	I			II			III		
	SAMPLING TIME								
PARAMETERS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
pH	7.90	7.40	7.35	10.15	9.15	8.95	11.15	11.00	10.95
Conudctivity (μS cm⁻¹)	276	296	286	397	728	694	2,110	1,859	2,571
BOD (mg/1)	4	4	6	140	560	320	100	400	330
COD (mg/1)	47	50	69	290	1,386	949	290	1,296	996
D.S. (mg/1)	224	174	179	352	672	480	1,596	1,754	1,324
S.S. (mg/1)	17.5	15	16	145.5	493.5	294.5	37.5	48	41

Table 4.2.10B - Soluble elemental concentrations

	SAMPLING POINTS								
	I			II			III		
	SAMPLING TIME								
ELEMENTS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Cu (ppb)	13 ± 2	16 ± 2	14 ± 2	30 ± 1	64 ± 4	197 ± 7	101 ± 5	584 ± 9	155 ± 4
Zn (ppb)	17 ± 2	24 ± 4	33 ± 4	99 ± 5	297 ± 4	228 ± 4	226 ± 5	1244 ± 11	450 ± 6
Pb (ppb)	•	•	•	112 ± 7	232 ± 5	158 ± 6	93 ± 6	903 ± 16	346 ± 7
Ti (ppb)	•	•	•	•	•	•	•	•	•
Mn (ppb)	2264 ± 34	2289 ± 59	2913 ± 60	295 ± 10	151 ± 17	215 ± 17	29 ± 5	42 ± 8	132 ± 8

Suspended matter elemental concentrations

	SAMPLING POINTS								
	I			II			III		
	SAMPLING TIME								
ELEMENTS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Cu (ppb)	•	•	•	•	25 ± 2	•	14 ± 1	32 ± 4	82 ± 5
Zn (ppb)	•	•	•	25 ± 3	28 ± 3	•	•	•	•
Pb (ppb)	•	•	•	•	23 ± 3	•	•	40 ± 3	•

• - below the minimum detactable limit

Table 4.2.11A - Quality parameter for clay sampling on 19th August, 1986

	SAMPLING POINTS								
	I			II			III		
	SAMPLING TIME								
PARAMETERS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
pH	7.15	7.20	7.15	8.90	7.20	7.15	8.90	8.00	8.50
Conductivity (µs/cm)	290	316	307	279	381	10,480	541	454	602
BOD (mg/l)	6	6	6	40	475	550	80	315	375
COD (mg/l)	76	77	84	124	1,540	2,500	220	1,680	1,400
D.S. (mg/l)	282	246	251	300	352	5,046	456	516	666
S.S. (mg/l)	17.3	16.4	16.8	39.2	60	367	29	38.4	61

Table 4.2.11B - Soluble elemental concentrations

SAMPLING POINTS

	I			II			III		
	SAMPLING TIME								
ELEMENTS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Cu (ppb)	13 ± 2	14 ± 3	12 ± 1	18 ± 3	46 ± 4	60 ± 4	27 ± 3	34 ± 4	421 ± 17
Zn (ppb)	53 ± 3	23 ± 3	25 ± 3	50 ± 3	87 ± 4	204 ± 5	173 ± 2	258 ± 7	6891 ± 48
Pb (ppb)	52 ± 3	24 ± 2	35 ± 3	89 ± 4	107 ± 3	558 ± 11	96 ± 4	136 ± 6	903 ± 11
Ti (ppb)	•	•	•	•	•	•	•	•	•

Suspended matter elemental concentration

SAMPLING POINTS

	I			II			III		
	SAMPLING TIME								
ELEMENTS	07:00	12:00	16:00	07:00	12:00	16:00	07:00	12:00	16:00
Cu (ppb)	•	•	•	•	•	•	•	30 ± 4	39 ± 3
Zn (ppb)	•	•	•	•	•	•	•	18 ± 2	17 ± 2
Pb (ppb)	•	•	•	•	•	•	•	22 ± 3	25 ± 4
Ti (ppb)	116 ± 9	66 ± 5	70 ± 6	49 ± 5	32 ± 3	•	17 ± 2	107 ± 14	891 ± 40

Table 4.2.12 - Quality parameter for oxidation pond (outlet). Samples on 20th August, 1986.

Parameters	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 (µS/cm)	633	639	635
BOD (mg/l)	13	16	14
COD (mg/l)	108	139	124
DS (mg/l)	508	528	516
SS (mg/l)	58	52	58
Chloride (mg/l)	73	75	77
Nitrate $N\text{-}NO_3$ (mg/l)	0.75	0.71	0.68
Phosphate $P\text{-}PO_4$ (mg/l)	5.02	4.57	4.63

Table 4.2.13A - Quality parameters for oxidation pond outlet sampled on 8th September, 1986.

Parameters	Time of the day		
	07:00	12:00	16:00
Temperature (°C)	20.1	22.4	23.3
pH	8.9	8.8	8.5
Conductivity (µS/cm)	673	677	675
BOD (mg/l^{-1})	35	41	32
COD (mg/l)	215	258	188
DS (mg/l)	501	512	544
SS (mg/l)	57	132	84
Chloride (mg/l)	80	79	81
Nitrate $N\text{-}NO_3$ (mg/l)	0.69	0.69	0.41
Total Phosphate $P\text{-}PO_4$ (mg/l)	2.65	1.93	2.62

Table 4.2.12B - Oxidation pond (outlet). Soluble elemental concentrations. Sampled on 20th August, 1986.

	Sampling time		
Elements	07:00	12:00	16:00
Cu (ppb)	15 ± 2	21 ± 2	12 ± 2
Zn (ppb)	60 ± 3	258 ± 13	69 ± 3
Pb (ppb)	21 ± 2	75 ± 5	31 ± 3
Mn (ppb)	1012 ± 26	1231 ± 23	2704 ± 67

Elemental concentration in suspended matter

	Sampling time		
Elements	07:00	12:00	16:00
Cu (ppb)	*	*	13 ± 3
Zn (ppb)	*	*	*
Pb (ppb)	*	20 ± 5	*

Table 4.2.13B - Oxidation pond (outlet). Soluble elemental concentrations. Sampled on 8th Sept., 1986.

	Sampling time		
Elements	07:00	12:00	16:00
Mn (ppb)	379 ± 12	754 ± 13	920 ± 20
Cu (ppb)	10 ± 2	10 ± 1	11 ± 1
Zn (ppb)	69 ± 3	87 ± 5	74 ± 3
Pb (ppb)	22 ± 2	27 ± 2	22 ± 2

* - below the minimum detactable limit

Elemental concentrations in suspended matter

Elements	Sampling time 07:00	12:00	16:00
Cu (ppb)	12 ±3	*	14 ±2
Zn (ppb)	*	15 ±3	*
Pb (ppb)	*	*	*

* = below the minimum detactable limit

4.3 Analysis of the data and dicussion:-

4.3.1 Temperature:

The temperature of the Ngong' waters at NGN I varied between 18.7°C to 22°C depending on the season. A relative temperature increase was observed in all the samples at NGN II. The maximum temperature recorded was 24.5°C. The temperature was found to be increased by about 1 or 2°C by NGN III and this was either maintained or slightly decreased in the downstream. In most of the samples the temperature of the stream at NGN V was at least 0.5°C to 1°C higher than at NGN I. This could be attributed either to the inflow of pollutants or to the increase in day temperature due to difference of about two hours duration between sampling point NGN I and NGN V. But the temperature profile clearly indicates that NGN II is the point where the thermal pollution occurs in addition to other pollutants entering the stream.

4.3.2 Hydrogen-ion concentration (pH):

A careful look into the pH data in tables 3.2.1 to 3.2.9A show that the pH of the water at NGN I remained constant about 7.3 except in the rainy season (April and May 1986) when it went down to 6.5. The pH levels at NGN II and NGN III recorded values over a wide range between 6.3 to 10.6 indicating that various types of industrial effluents flow into the stream and the pH has no clear trend. But the pH at point V stabilizes to about 7.5 to 7.9 in most of the samples. The occational increases observed at NGN V could be due to the influx of slightly alkaline effluents from the industrial oxidation ponds.

4.3.3 Conductance (specific conductivity):

The conducatance values of waters at NGN I were of the range 274 - 302$\mu S.cm^{-1}$ which show that the waters flowing through this point were fairly of the same composition during the summer months. The lower values (195 and 170$\mu S.cm^{-1}$) were observed during the rainy months of April and May respectively. But the conductance values reached a maximum value of 2,090$\mu S.cm^{-1}$ at NGN II. Values remain high even at NGN V, suggesting considerable levels of dissolved substance entering the stream stay in the waters between NGN II and NGN V.

4.3.4 Biochemical oxygen demand (BOD):

Low BOD level values at NGN I were observed and ranged between 4 and 8 mg l^{-1} over the period of study and this clearly indicates the good quality of waters in the stream. Relatively quite high values were recorded at NGN II (560 mg l^{-1}) and NGN III (320 mg l^{-1}). Showing the magnitude of pollutants entering the stream at these points. The relatively low value of BOD at NGN IV and fairly low values in the range 6 to 27 mg l^{-1} at NGN V, indicates the self-purification process going on in the downstream.

4.3.5 Chemical oxygen demand (COD):

The COD values at NGN I were found to vary between 39 to 88 mg l^{-1}. A look at the COD values in the tables and figures show that at NGN II, the values reach relative maximum having a 20 fold increase in the COD levels and a 5 fold increase being a common feature, pinpointing the location of pollutants entering the stream. The COD levels recorded a decreasing trend from NGN IV onwards and at NGN V, the values were fairly similar to the values at NGN I. The results support the purification trend observed in the BOD levels.

4.3.6 Dissolved solids (D.S.):

The dissolved solids concentration values at NGN I ranged from 220 to 288 mg l^{-1}. The values indicate that the waters flowing at this point were about the same composition during the summer months. The lower values (160 and 140 mg l^{-1}) were observed during the rains. Typical high values about 1,800 mg l^{-1} were observed at NGN II and NGN III. Values tended to then decrease at NGN V, and values at NGN V were found to be close to those recorded at point IV but occasional increases were observed. This could be due to effluents from the oxidation ponds.

4.3.7 Suspended solids (S.S.):

The suspended solids concentration ranged from 8 to 62 mg l^{-1} at NGN I over the period of study. High values were recorded in April and May. Relative to NGN I, high values were recorded at NGN II and NGN III, pinpointing the areas of points. The S.S. value then recorded a decreasing trend (NGN IV) and at NGN V the values were fairly low in the range 4 to 36 mg l^{-1}.

4.3.8 Chloride:

The chloride ion concentration at NGN I were recorded in the range 14 to 38 mg l^{-1} during this period. A look at the value in the tables and figure indicate that the values downstream tended to be much higher, with no distinct trend. The higher values at NGN V could be attributed in addition to pollutants entering the stream in the upstream also to the influx of effluents from the oxidation ponds.

4.3.9 Nitrates:

Nitrate concentration ranged from 0.10 to 1.61 mg/l N-NO_3 along the course of the river during the period of study. Relatively low concentration values were noticeable at NGN I in most of the samples.

4.3.10 Total phosphate:

Concentration values ranged from 0.04 to 0.40 mg/l P-PO_4 at NGN I. Relatively higher values were recorded donwstream. The increased occasional values observed at NGN V could be attributed to the effluents from the ponds.

4.3.11 Soluble elemental concentration:

The concentrations of the elements at NGN I were generally observed to be lower than those observed in the downstream except for MN.

Downstream Zinc concentration values were observed highest at NGN III and were in the range 260 to 1,400 ppb. Lead concentrations were observed high at NGN II and NGN III, reaching a high concentration of 780 ppb at point II. Copper concentrations also showed a similar trend and were recorded in the ranges 16 to 245 ppb at NGN III and 12 to 155 ppb at NGN II. Manganese concentrations were observed to remain high as in the upstream (NGN I) and the occasional increase observed at NGN V, could be due to effluents from the industrial oxidation ponds.

The concentrations of the elements (Cu, Zn and Pb) recorded at NGN V were relatvely lower than in the upstream.

4.3.12 Suspended matter elemental concentrations:

Titanium concentrations at NGN I were recorded in the range 80 to 580 ppb. Relatively higher values were observed at NGN III, in the range 350 to 1,400 ppb. High values in concentration of Ti were at all points during the rainy season (May and April).

Concentrations of Cu, Zn, Pb at NGN I waters were observed to be low ($<$ 30 ppb). Concentrations were noted to increase downstream. It was generally observed that the concentration of the elements in the suspended matter was lower than that observed in the dissloved (soluble) form, except at NGN IV where occasional high concentrations were observed. At NGN V the concentrations of most elements generally settle to the values observed at NGN I. The concentration profile tended to follow the trend observed for suspended solids.

4.3.13 Changes in parameters and levels of pollutants during the day cycle:

A look at the data (Tables and figures) show that the pH at NGN I remains fairly within a narrow range within the day sampling. The pH levels at NGN II and NGN III recorded values covering a range between 8.00 and 11.15 indicating that various types of industrial effluents enter the stream. The pollutants were observed to be fairly alkaline in nature.

The conductance value of the waters at NGN I were recorded in the range 286 to $316 \mu S cm^{-1}$ during this study and clearly supports the fact that the composition of the waters at NGN I remain basically of the same composition during the day. The conductance was higher at NGN III relative to NGN I and was observed to increase within the day reaching high values in the afternoon. This confirms the increased influx of different pollutants at these points.

Low BOD values were observed at NGN I ranging from 4 to 8 mg/l. Slight increases were observed in the later afternoon. Relatively higher values were observed at NGN II and NGN III, reaching about 566mg/l at NGN II and 400mg/l at NGN III by the afternoon.

The COD values at NGN I were found to vary between 47 and 84 mg/l with a slight increase in level with progress of the day. A perusal of the COD values in the tables and figures show that at NGN II and NGN III values recorded a relative 20 - 30 fold increase at any time of the day, pinpointing the location of pollution of the stream. Compared to NGN II at morning, noon and afternoon, relatively lower COD values were recorded at NGN III.

The dissolved solid concentration at NGN I ranged from 174 to 282 mg/l. Relatively higher values were recorded at NGN II reaching a maximum at NGN III.

The suspended solid concentrations ranged from 15 to 17.6 mg/l during the day at NGN I. Relatively higher values were observed at NGN II and NGN III. Highest values of suspended solids were observed at NGN II.

The concentration of trace elements observed at NGN I were generally low, in all the samples within the day. Relatively much higher values were observed at NGN II and NGN III. High concentrations were found at NGN III, between 12:00 and 16:00 hours.

4.3.14 Levels of pollutants in the oxidation pond outlet:

The temperature of the effluents leaving the ponds ranged from 18.9 to 23.5°C. High temperatures were observed in the later afternoons. The changes in temperature were mostly due to changes in the day temperatures.

The pH was observed to range from 8.5 to 9.2 during the study period and the values within the day of sampling did not show much change. The effluents discharged from the ponds are basically alkaline.

Conductance values ranged over a narrow range 633 to 677 $\mu S cm^{-1}$, during this period. This indicates the uniformity in composition of the effluents.

The BOD values were recorded in the range 13 to 14 mg/l. The values ranged from 13 to 16 mg/l during the first sampling day and 32 to 41 mg/l during the second, indicating the BOD levels do not change much withing the day and tended to remain low.

The COD values were found to vary from 108 to 139 mg/l during the first study and 188 to 258 mg/l during the second study.

Dissolved solids concentration levels were recorded in the range 501 to 544 mg/l, this confirms the conductance observations.

The suspended solid levels varied over a much wider range, 52 to 132 mg/l but in the effluents S.S. concentration was still low.

The effluents were observed to have a very high chloride ion concentration and ranged from 73 to 81 mg/l during the study.

Nitrates as $N-NO_3$, was observed to be in the range 0.41 to 0.75 mg l^{-1} during this period. Phosphate as $P-PO_4$, was observed to have a high concentration in the effluents, ranging from 1.93 to 5.02 mg l^{-1} during these samplings. Thus this could be responsible for the high contractions of total phosphate (as $P-PO_4$) observed in the Ngong' waters at NGN V.

The effluents from the ponds were also noted to have high concentrations of trace elements. The effluent concentration of Mn and Zn were notably high and could be responsible for the occassional increases noted in elemental concentrations at NGN V.

4.4 PRINCIPAL FINDINGS AND RECOMMENDATIONS:-

Thus Ngong' river is observed to be a river generally polluted by industrial effluents. The pollution of the water is concentrated around basically points II and III. This is supported by the strikingly high values and levels in parameters measured during this study period at these points. Temperature as high as 24.5°C was observed at NGN II and extremely high pH also were observed at these points. Conductance values reached a high value of 10,480 $\mu S cm^{-1}$ and it adopted a generally increasing trend during the day sampling, a clear indication of increased influx of pollutants. Levels of BOD and COD also adopted a similar trend during a day circle sampling and levels as high as 566 and 1,386 mg l^{-1} respectively were achieved. Dissolved and suspended solids also reached high values at these two points and within the day increased with the progress of the day. Chloride ion concentrations observed at these points were higher than at NGN I and clearly indicated inflow of industrial pollutants. Nitrate and phosphates levels were also high at these points relative to NGN I.

The pollution of the river further downstream, outside the industrial belt, by the oxidation ponds was observed to be not as bad. Noticeable increases were observed in the levels of Nitrates, phosphates, manganese and Dissolved Solids.

Levels of elemental concentrations also support the fact that NGN II and NGN III are the areas of maximum pollution. Zinc concentration as high as 6,891 ppb were recorded. Lead concentrations were also recorded at 903 ppb and copper at 421 ppb. It was observed that relatively high concentrations were recorded at NGN III. Elemental concentration increased during the day sampling, a clear indication of the increased influx of pollutants into the waters.

Thus though the levels of pollutions might seem not alarming, measures need to be taken so as to treat the industrial effluents before being discharged into the waterways. The treatment of industrial effluents at the oxidation ponds seem adequate and thus checks should be done to ensure that industrial wastes are channeled to the oxidation ponds rather than being discharged directly into the river.

Sufficient treatment should also be given to the industrial waste before being discharged from the industries.

CHAPTER FIVE

5.0 ANALYSIS OF QUALITY OF RUIRUAKA RIVER WATERS:-

5.1 Introduction:-

Ruiruaka river which originates in the Kikuyu escarpments discends through coffee plantations and forest land in the Kiambu district, which neighbours Nairobi city. It runs through about 10 Kms within the city boundaries of Nairobi flowing through large coffee plantations, forest and residential areas and then entering Ruiruaka estate which is slowly developing as the second industrial area. Furtherdown the stream passes through sparcely populated areas with marginal or minimal industrial and farming activities finally joining the Nairobi river (Map figure 1)

For the study of the quality of the Ruiruaka river waters, the details of the sampling points identified are as follows:-

RUA I - (Kiambu Road Bridge) - At this point, the river carries water from its tributaries in the upstream and run-off waters from coffee plantations and forest lands.

RUA II (Behind General Service Unit -(G.S.U.) Baracks) - A location within Karura forest with minimum human activity and about 2.5 Kms from RUA I.

RUA III (Thika Road Bridge) - The river carries partly treated domestic sewage from G.S.U. leading into a swamp where it takes a small tributary from surrounding lands. About 1.5.Kms from RUA II.

RUA IV (Kenya Breweries) - A location about 500 metres from point of discharge of brewery effluents and about 1 Km from RUA III.

RUA V (Baba Dogo) - Downstream location with no industrial activity located about 3 Kms from RUA IV.

5.2 Results:-

5.2.1 Monthly sampling:

Aquatic samples were collected at fairly monthly intervals over a period of one year from all the five sampling points and were analyzed for different quality parameters to characterise the quality of the river waters. Analytical data obtained are presented in tables 5.2.1 to 5.2.9 and in figures 5.2.1 to 5.2.18. The values of temperature, pH and conductivity, levels of BOD, COD, Suspended and Dissolved solids, chlorides, nitrates and phosphates are shown in the tables series A. The concentration of heavy metal are shown in series B separately as the soluble and suspended species as they exist in the aquatic samples. Although the general profile of the elements present in the water samples were obtained using x-ray fluorescence, the data is presented only for the selected heavy metals of toxic nature and for few heavy metals which are present in appreciable concentrations. Elements present below detection limit at all the five points are not shown in the tables. Rainy season was during the months of April and May 1986.

FIG. 5.2.1 TEMPERATURE AND pH PROFILE OF RUIRUAKA RIVER WATERS

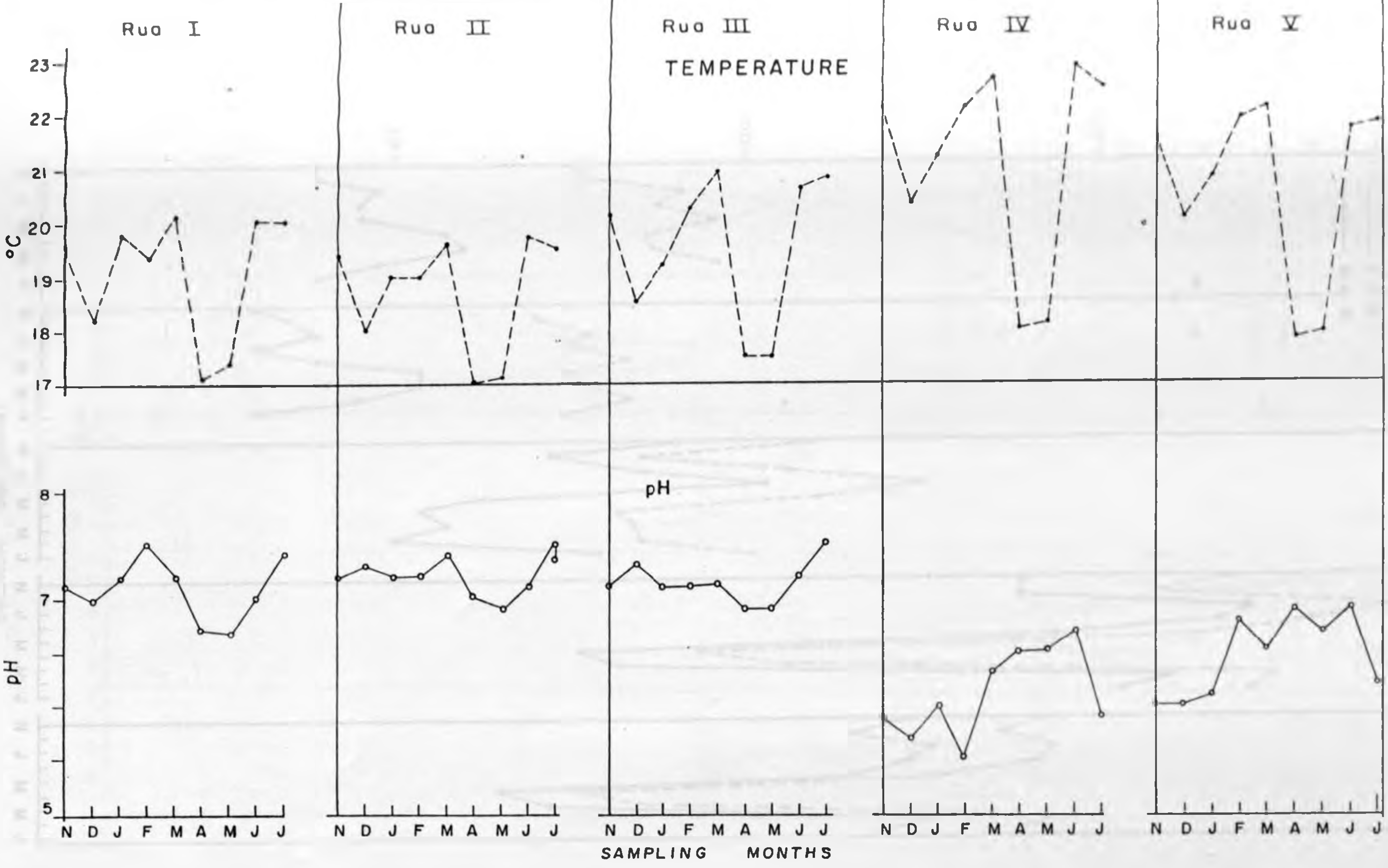


FIG. 5.2.2. BIOCHEMICAL AND CHEMICAL OXYGEN DEMAND OF RUIRUAKA RIVER WATERS

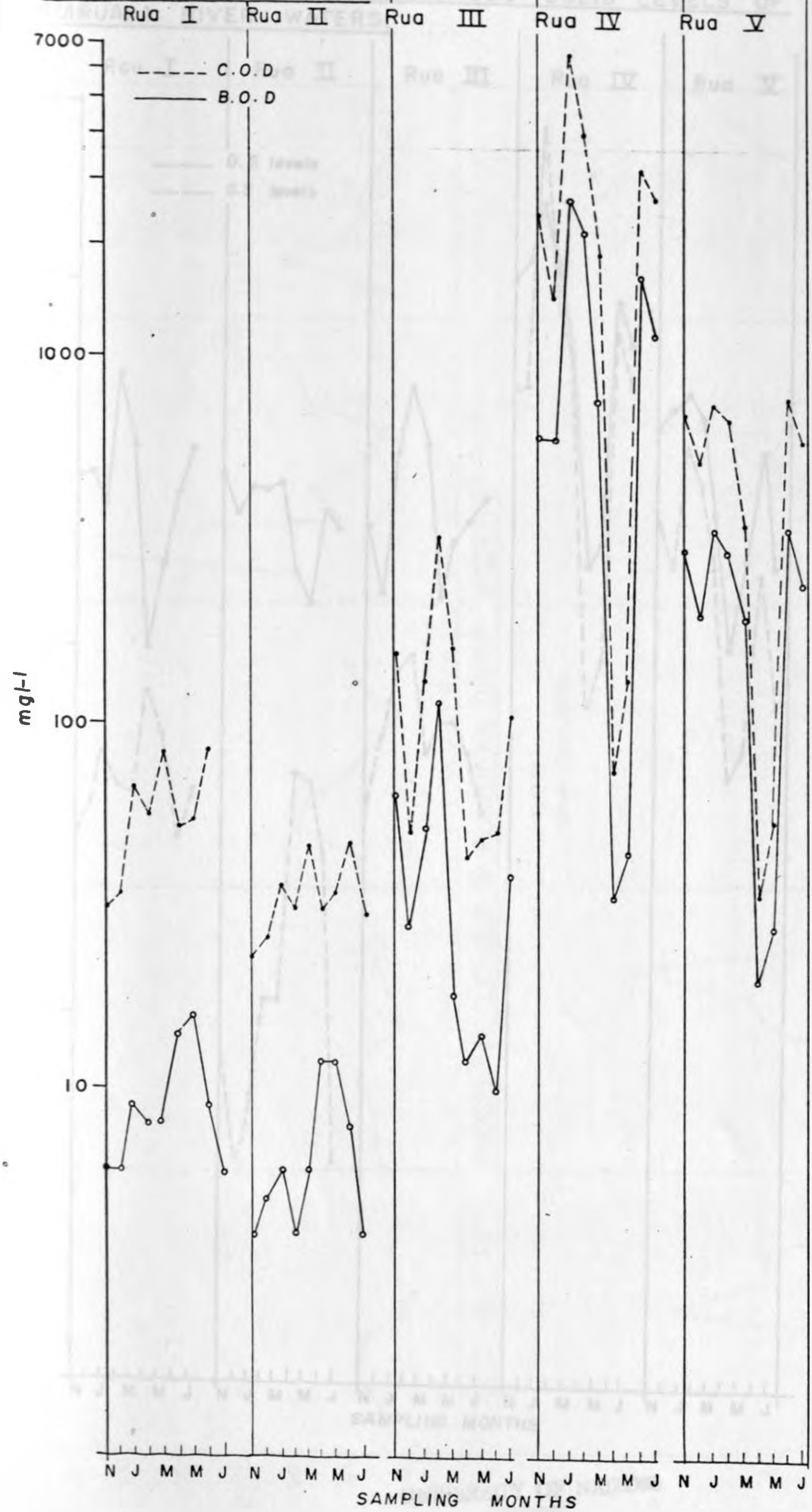


FIG. 5.2.3. DISSOLVED AND SUSPENDED SOLID LEVELS OF RUIRUAKA RIVER WATERS.

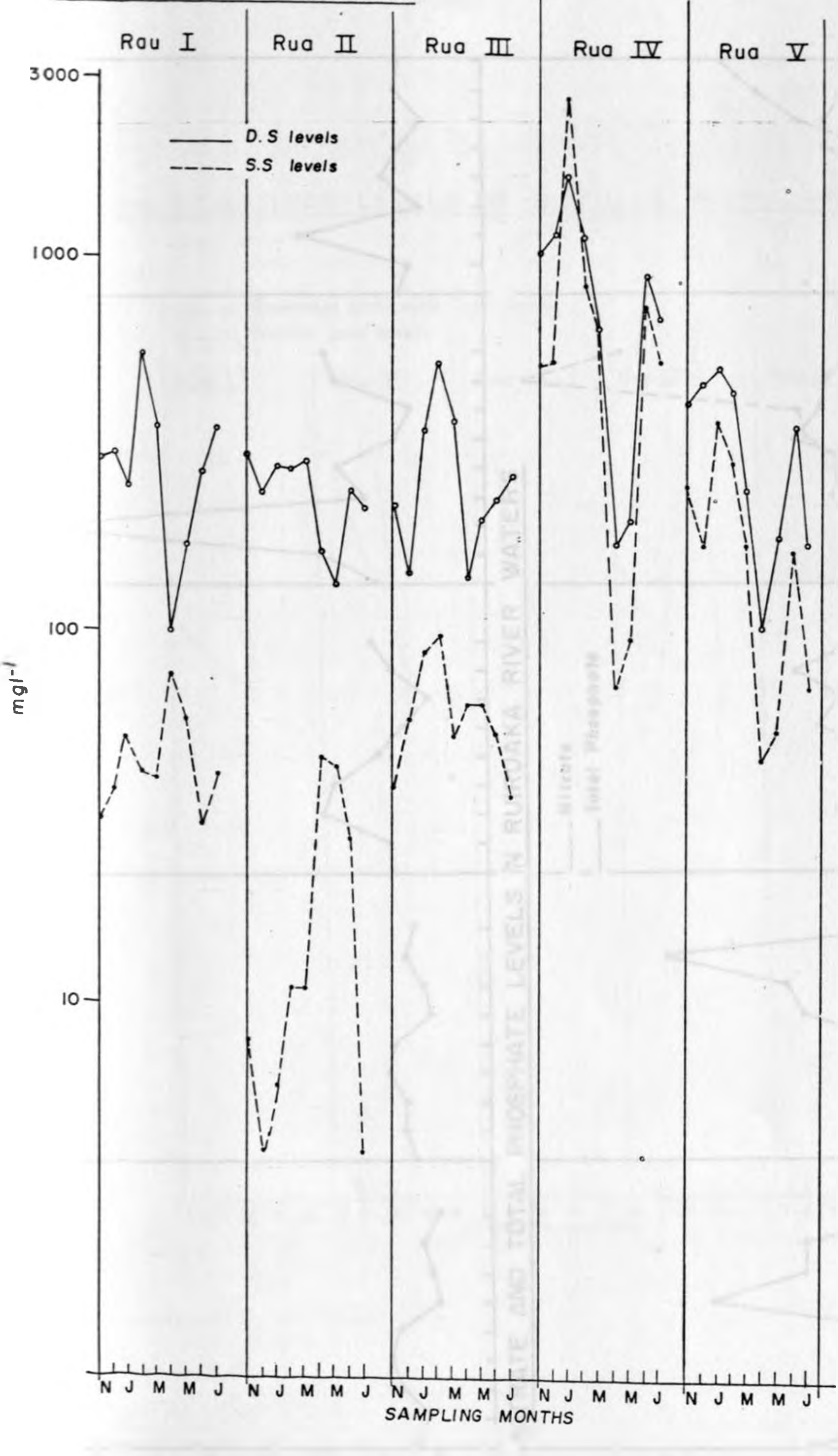
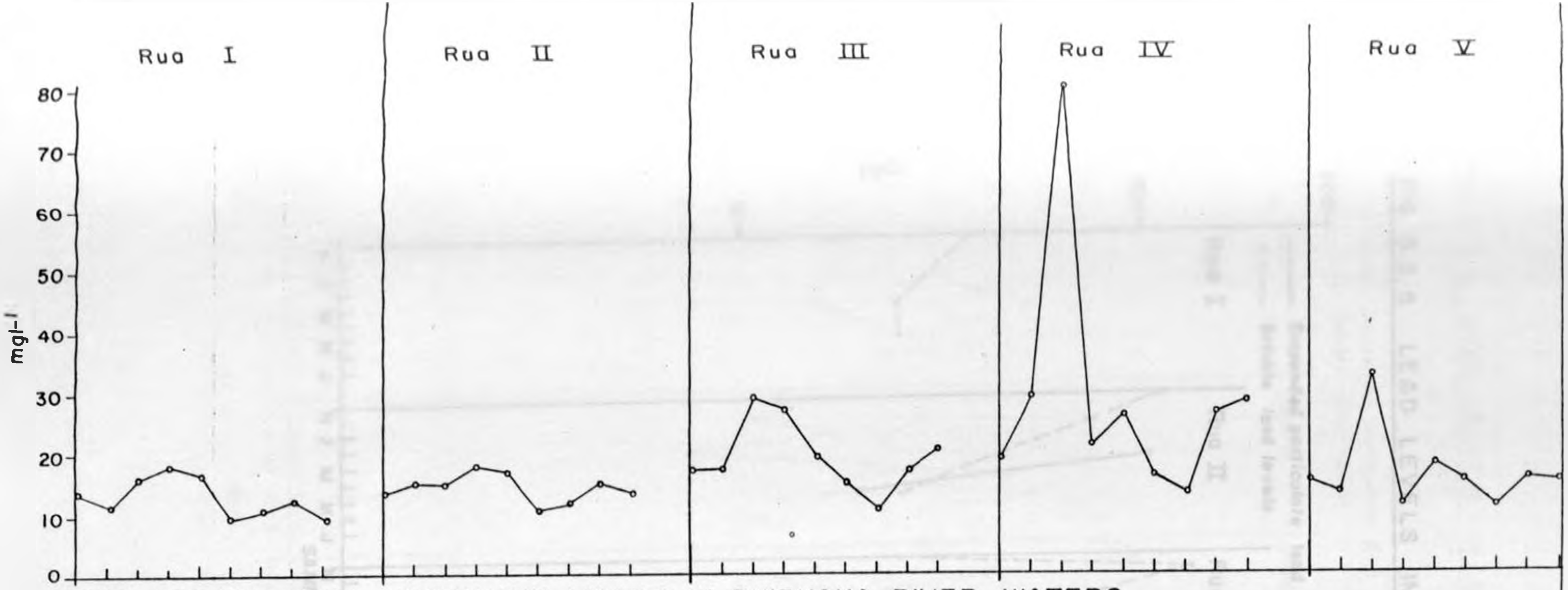


FIG 5.2.4 CHLORIDE CONCENTRATION LEVELS IN RUIRUAKA RIVER WATERS



NITRATE AND TOTAL PHOSPHATE LEVELS IN RUIRUAKA RIVER WATERS

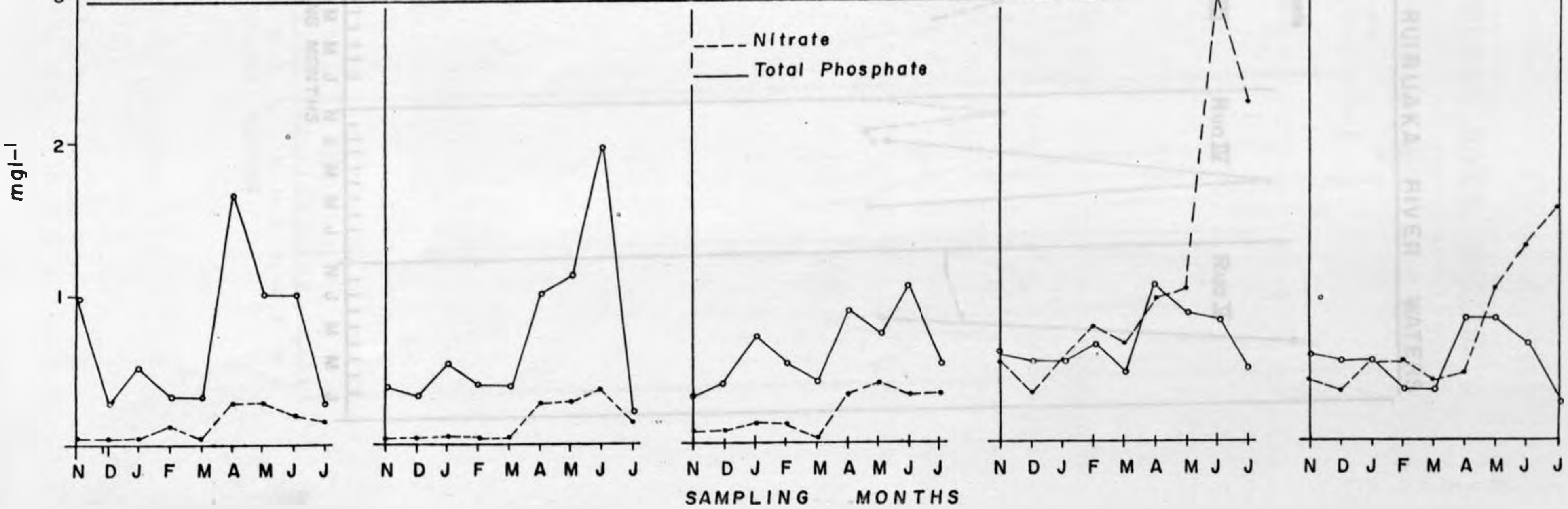


FIG. 5.2.5 LEAD LEVELS IN RUIRUAKA RIVER WATERS

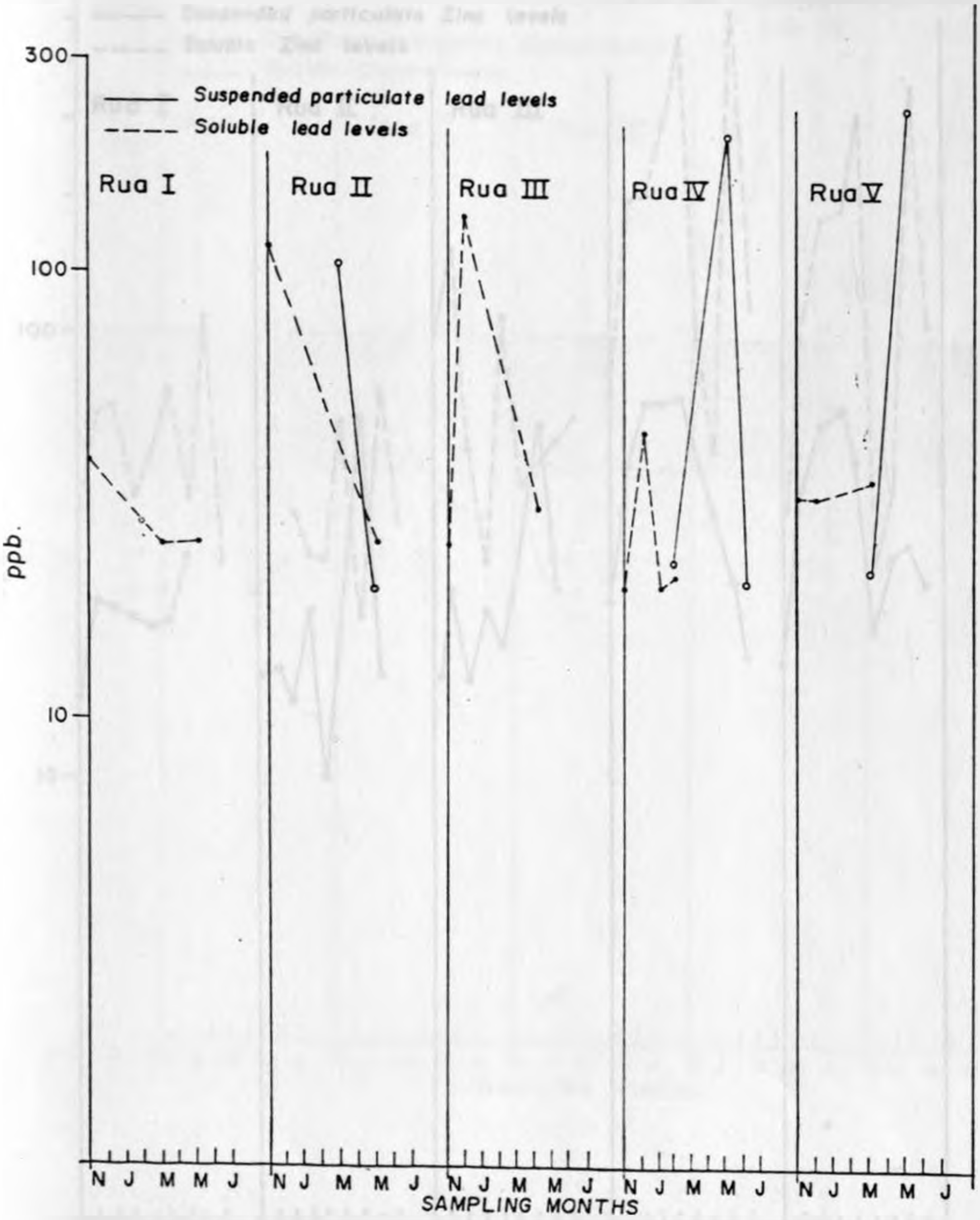


FIG. 5.2.6 ZINC LEVELS IN RUIRUAKA RIVER WATERS

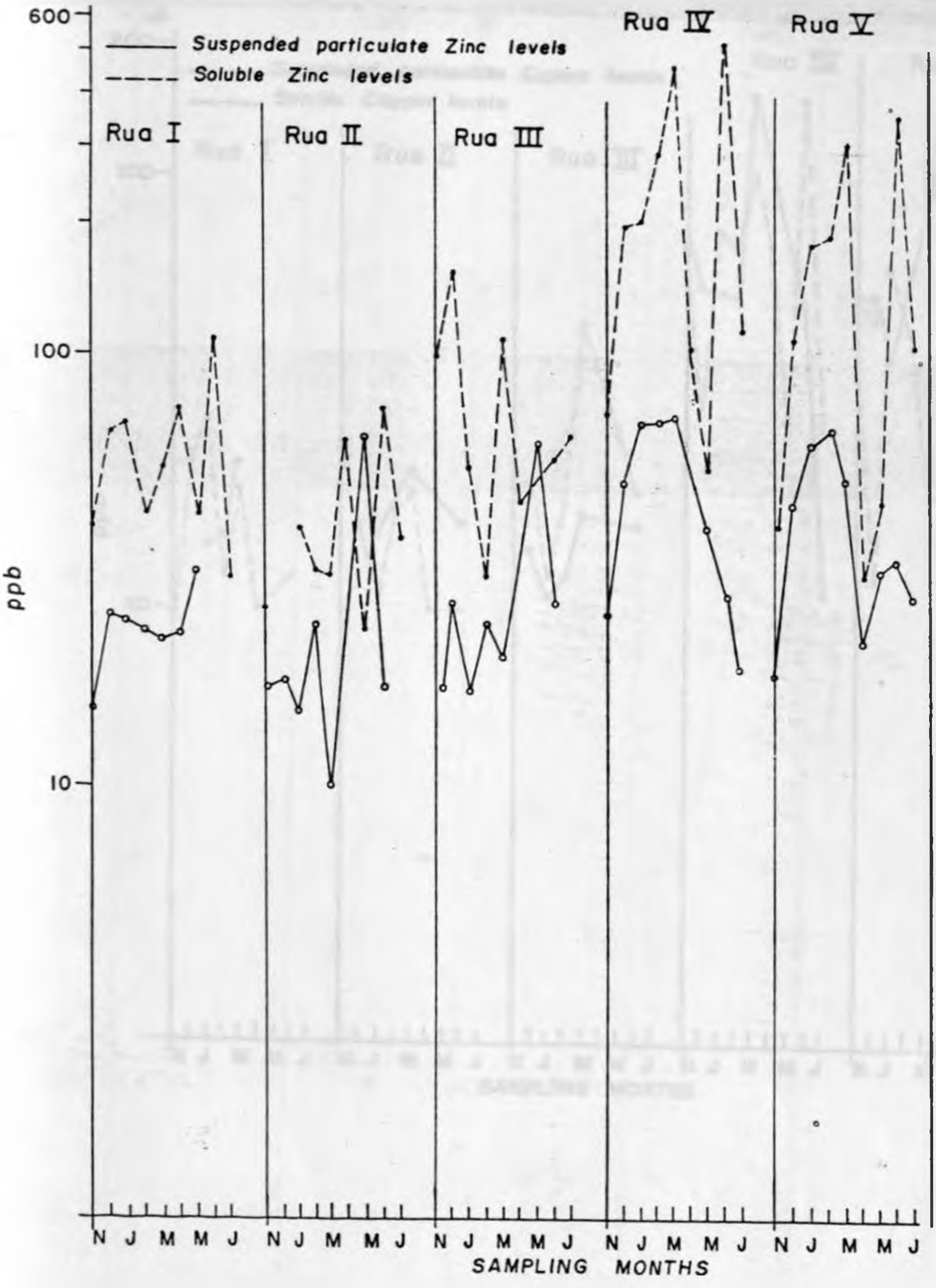


FIG. 5.2.7 COPPER LEVELS IN RUIRUAKA RIVER WATERS

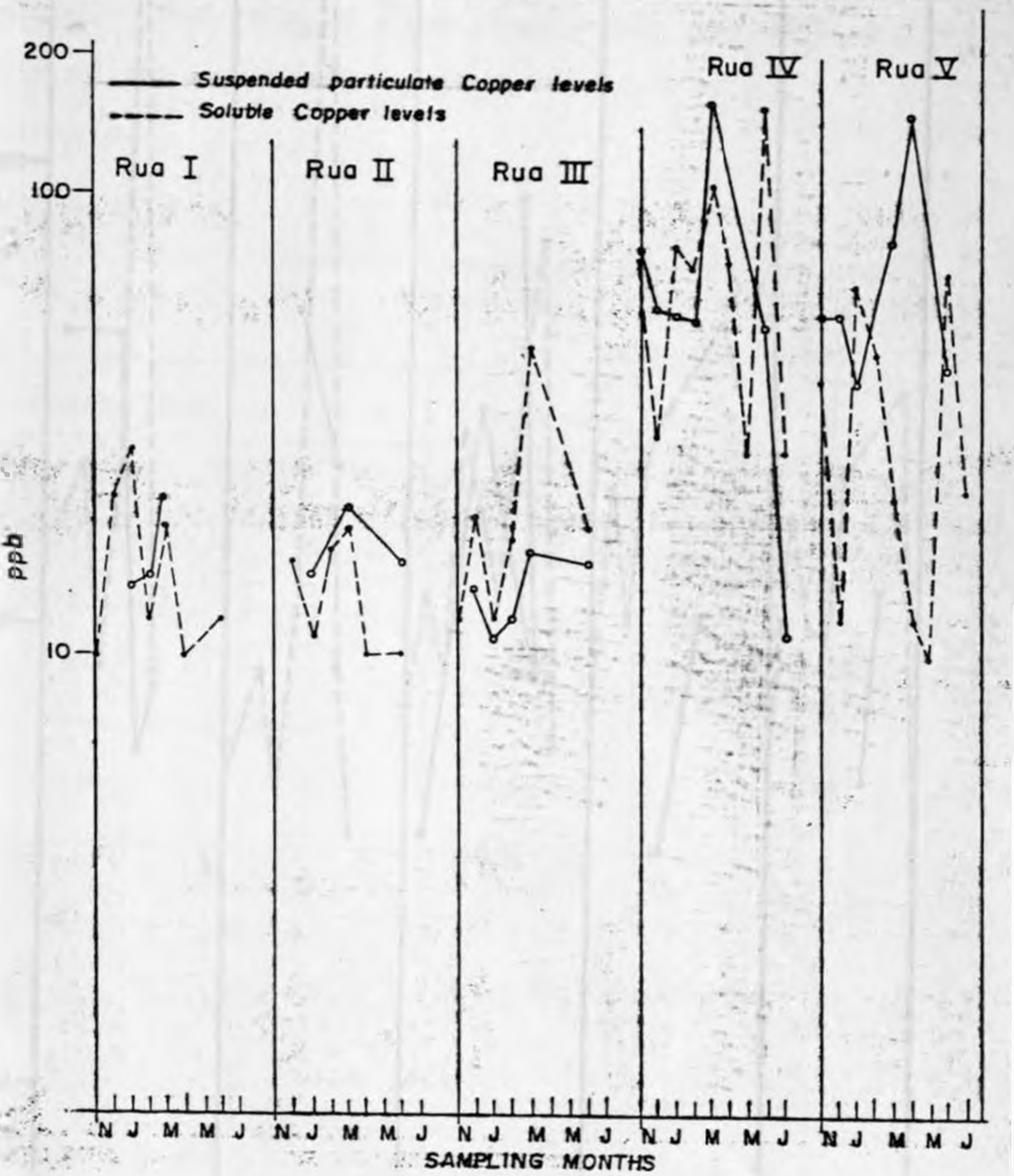
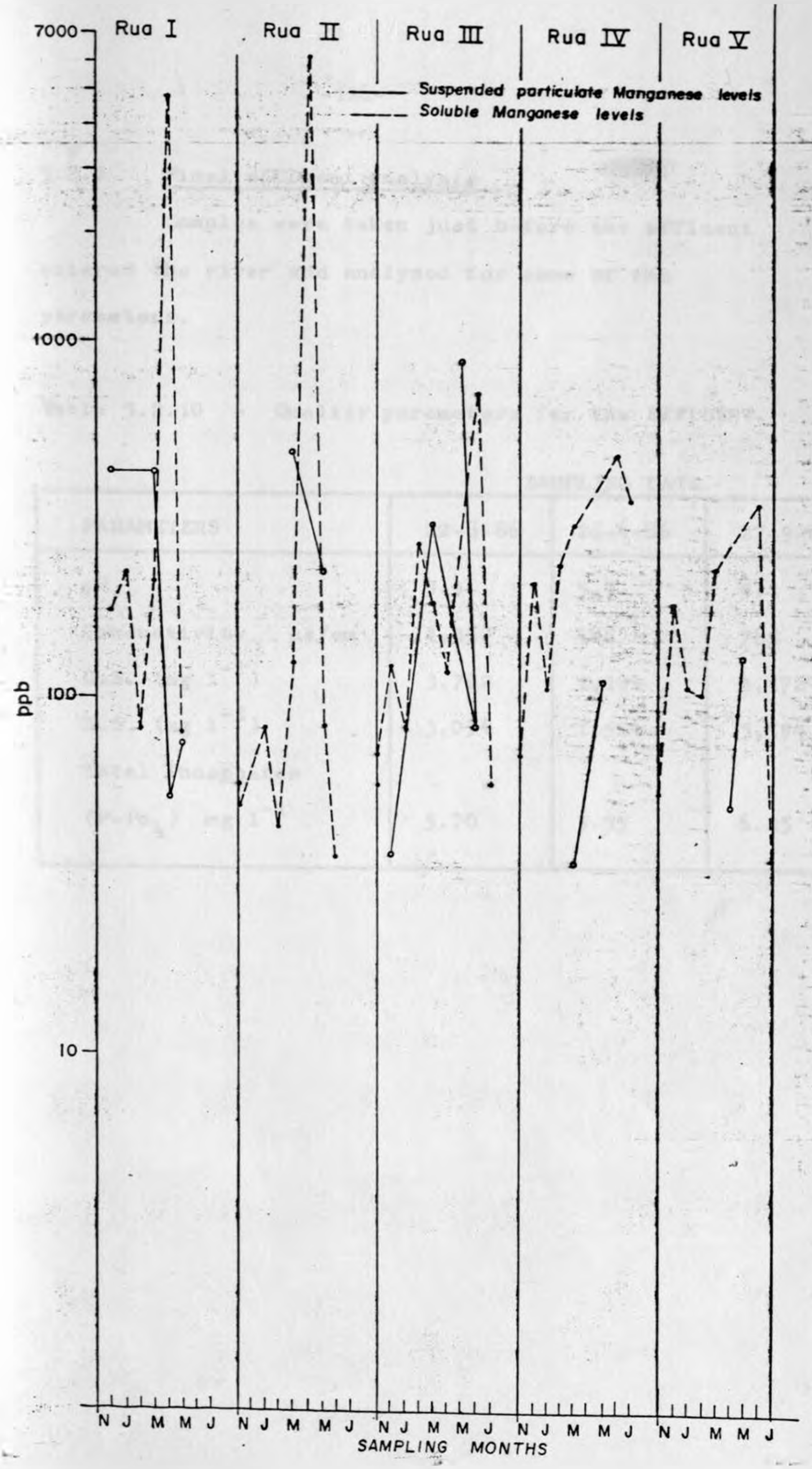


FIG. 5.2.8. MANGANESE LEVELS IN RUIRUAKA RIVER WATERS



5.2.2 <u>Final effluent analysis</u>

Samples were taken just before the effluent entered the river and analysed for some of the parameters.

Table 5.2.10 - Quality parameters for the EFFLUENT.

PARAMETERS	SAMPLING DATE 22-8-86	28-4-86	27-9-86
pH	5.4	5.9	5.4
Conductivity µs/cm	1,357	488	785
D.S. (mg l^{-1})	3,762	1,104	4,172
S.S. (mg l^{-1})	3,054	1,524	3,594
Total Phosphates ($P-Po_4$) mg l^{-1}	5.70	3.55	6.25

5.3 Data analysis and discussion:-

5.3.1 Temperature:

The temperature of Ruiruaka river waters at RUA I varied between 17.1°C and 20.1°C, touching the lower limit in the rainy seasons. Slight decrease in temperature about 0.5°C was recorded at RUA II, possibly due to slow flow through shaded forest. A relative increase was observed at RUA III in all the samples. A significant increase between 1 to 2°C was observed at RUA IV, due to the influx of the brewery effluents. At RUA V, relative to RUA IV a lower temperature was recorded possibly due to thermal exchange with the surroundings.

5.3.2 Hydrogen-ion concentration:

A perusal of the data in the tables 5.2.1 to 5.2.9 and figure 5.2.1 show that the pH of waters at RUA I, RUA II and RUA III had similar values. The values varies between 7.0 and 7.5 over the months, except in the rainy season, when the pH was about 6.5, this could be a result of acid rains. At RUA IV, the pH changes were significant reaching values as low as 5.5 in some samples due to the discharge of the acidic brewery effluents. The change was less pronounced in the rainy months, when the river carried high volume of relatively acidic waters. The pH increased at RUA V to some extent.

5.3.3 Conductance (Specific conductivity):

The conductance value at RUA I during the study period varied between 98 and 215 $\mu S\,cm^{-1}$. The lower values were recorded during the rains. The values remained fairly the same at RUA II and RUA III. Remarkably higher values were recorded at point IV due to inflow of brewery effluents. Relatively low values were observed at RUA V.

5.3.4 Biochemical oxygen demand (BOD):

BOD values were found to be quite low in all the aquatic samples at RUA I, RUA II and RUA III, ranging between 6 and 16 mg l^{-1} during the period of study, except for occasional increases at RUA III possibly due to effluents from the domestic sewage from the residential areas or the waters from the triburaty. The fairly low BOD values upto RUA III indicate the good state of the waters in the upstream. Higher BOD levels ranging between 34 to 2,700 mg l^{-1} were recorded at RUA IV. Higher BOD values were obtained during the dry months when the river flows was lean, while the lower limit was achieved in rainy months. The lower BOD levels in rainy season indicate that the river could sufficiently dilute the effect of effluents when the water flux was high. The levels of BOD at RUA V were found to be remarkedly low compared to values at IV pointing towards the rapid self-purification process occuring in the river, which could be due to the good quality of water prior to RUA IV.

5.3.5 Chemical Oxygen demand (COD):

The COD values at RUA I, RUA II and RUA III were not much affected by seasons and remained in the range 34 to 84 mg l^{-1} over the study period, except occasional higher values at RUA III. The COD values indicate that the waters are fairly clean upto this point. As can be anticipated COD levels were found to be significantly high at RUA IV reaching as high as 6,520 mg l^{-1} in the dry months of January, but the values were reasonably low in the rainy months of April and May due to the high volume of waters in the river. Relative to RUA IV, lower values were observed at RUA V, the levels almost dropping down to 10% supporting the healthy conditions of river to withstand the pollution a trend observed also in BOD levels at this point.

5.3.6 Dissolved solids (D.S.):

The dissolved solids at RUA I varied over a wide range of 104 to 548 mg l^{-1} during the duration of study. The low values were recorded during the rains. The same levels were maintained at RUA II and RUA III within the limit of estimations. Significant increases were observed at RUA IV, reaching a maximum value of 1,692 mg l^{-1} in the dry season and recording 176 mg l^{-1} on the lower limit in the rainy season. But the levels of D.S. dropped to 500 mg l^{-1} and 100 mg l^{-1} respectively in the corresponding samples at RUA V, showing a considerable fall in the values.

5.3.7. Suspended solids (S.S.):

The suspended solids concentrations at RUA I, RUA II and RUA III ranged from 30 to 76 mg l^{-1}, occasionally higher levels were observed at RUA III. The levels of S.S. were observed higher during the rainy season than in the dry months, this was as a result of run-off of the top soil by the rain waters. At RUA II and RUA III, the level decreased and occasionally increased respectively. In all seasons relatively high values of S.S. were observed at RUA IV. Reversing the seasonal effect on levels of S.S. observed at RUA I, the levels were low in the rainy seasons, possibly due to dilution of brewery effluents by high volume of waters. But in the dry months the S.S. level at RUA IV, were found to be quite high (2,760 mg l^{-1}). Significantly lower values were observed at RUA V, showing a good recovery of the stream from the pollution.

5.3.8. Chloride:

During the investigation period chloride concentrations in the Ruiruaka river waters, between RUA I, RUA II and RUA III were observed to be in the range 10 and 20 mg l^{-1} increase in chloride levels were observed at RUA IV resulting a 5 fold relative increase in the same samples. The maximum concentration of chloride at RUA IV recorded was 80 mg l^{-1} which is obviously from the brewery discharges.

5.3.9 Nitrates:

The nitrate concentration as $N\text{-}NO_3$ recorded at RUA I was in the range 0.26 to 1.62 mg l^{-1}. The higher concentrations were observed during the rainy seasons, which could be as a result of washing off of the nitrate containing fertilizers from the surrounding farmlands into river waters. The minimum and maximum concentrations recorded at RUA II and RUA III were (0.21 to 1.96 mg l^{-1}) and (0.30 to 1.02 mg l^{-1}) respectively, which were fairly in the same range as RUA I, in particular set of samples. No appreciable increase in nitrate levels were observed at RUA IV due to the brewery effluents. This suggests that the brewery discharges also contain approximately the same levels as in the receiving waters. Although not substantial, nitrate concentration tended to reduce at RUA V.

5.3.10 Phosphates:

The total phosphate concentrations as P-PO_4 recorded at RUA I were found to be in the range of 0.01 to 0.28 mg l^{-1}. Similar to nitrate levels, higher values were observed in the rainy months of April and May 1986. Concentrations recorded at RUA II and RUA III tended to be within the same range as RUA I, but occasional increase were noted at RUA III, marked increases were recorded at RUA IV, due to brewery effluents which contained high concentration of phosphate. At RUA IV phosphate concentrations as high as 2.90 mg l^{-1} (June 1986) were noticed. The levels were lower at RUA V, varying in the range 0.31 to 1.57 mg l^{-1}, which were considerably high compared to corresponding levels at RUA I.

5.3.11 Soluble elemental concentrations:

Soluble copper concentrations at RUA I, RUA II and RUA III were found to vary in the range 10 to 28 ppb during the investigation period. In the rainy seasons the levels of Cu were below the minimum detectable limit. Increase in concentrations were recorded at RUA IV and the levels ranged between 28 ppb in the rainy season and 155 ppb in the dry months. Relatively lower values were observed at RUA V.

Zinc concentrations at RUA I, RUA II and RUA III were in the range 31 to 110 ppb, with minimal variation between RUA I and RUA II, but with occasional rises in levels at RUA III, which reached a value 154 ppb in one sample. Significantly high values were observed at RUA IV, with the rainy seasons recording lower values. Values ranged between 55 ppb and 531 ppb which points towards the high concentration of Zn, the brewery effluents carry with it. Relatively lower values of Zn were recorded at RUA V.

During the study period, quite low lead levels were observed at RUA I and RUA II. But occasionally noticeable lead levels were noticed at RUA III reaching a maximum of 134 ppb. No noticeable increase was detected at RUA IV due to influx of effluents.

Manganese concentration at RUA I were recorded in the range of 80 to 4,808 ppb. The high concentration was observed during the April rains. Concentrations downstream were recorded within this range, with a pronounced increased being noted at RUA II, reaching a value of 6,356 ppb during the April rains. Increase in concentration due to influx of the brewery effleunts was not very significant, as noted at RUA IV.

5.3.12 Suspended matter elemental concentration:

Concentration of suspended form of titanium was generally high at RUA I and ranged from 170 to 965 ppb. High concentrations were observed in the rainy seasons, when the S.S. concentrations in river waters was high. A slight decrease at RUA II and again an increase at RUA III were generally observed in the samples. Increase in Ti levels at RUA IV were moderate and no steep increases were noticed. Relatively lower values were observed at RUA V.

Suspended copper concentrations at points RUA I, RUA II and RUA III were fairly low and were in the range 10 to 22 ppb. While presence of copper during the rainy seasons was not detectable at RUA IV, in the dry seasons the levels reached upto about 160 ppb. Relatively lower levels were noticed at RUA V.

Suspended Zn concentrations at RUA I were found to be in the range 15 to 32 ppb during the investigations period. Concentrations of Zn recorded at RUA II and III were within the same range as observed at RUA I. Concentrations of Zn at RUA IV were higher and maximum recorded was 72 ppb, while at RUA V the values were lower compared to RUA IV.

The suspended lead concentrations in water samples at RUA I, RUA II and RUA III were below the detection limit and quite low.

Only in few samples was lead observed at RUA IV, indicating occasional washing of trace concentrations of suspended lead into the receiving water.

Suspended manganese concentrations were quite low in dry seasons with occasional high concentration noted at RUA I. Levels increased in the rainy season including at RUA I, indicating sources of suspended Mn are prior to the first sampling point. Increase in concentrations of suspended manganese due to influx of the brewery effluents was not significant, as noticed by concentration recorded at RUA IV.

5.4 Principal findings and recommendations:-

After a perusal of the data in tables and figures and after a careful analysis, the quality of the Ruiruaka waters can be classified as good at point RUA I, and RUA II and fair upto RUA III, which can be seen from the quality parameters obtained at these points. Further downstream the quality of the water deteriorates and get extremely polluted by RUA IV due to the influx of the brewery effluents. It is evident from the pH values reaching as low as 5.5, BOD values as high as 2,700 mg l^{-1} and COD reaching a maximum of 6,520 mg l^{-1} in some aquatic samples at RUA IV. The peak D.S. and S.S. values observed, respectivley reaching about 1,690 mg l^{-1} and 2,760 mg l^{-1} explicitly show the heavy burden carried by the river in the summer months of the year. The water at RUA IV were also enriched with substantial concentrations of nitrate and phosphate also which facilitate the glow of biomass which in turn enhance the BOD values downstream. But a sign of recovery of the stream to some extent in observable in the 2 Km stretch from RUA IV to RUA V. The self purification process is slow. In the rainy months the quality parameter at RUA IV and RUA V clearly show that the river effectively dilutes the pollutants and fast recovers to a class of moderately clean river.

The elemental concentrations within the river more or less range within acceptable level of drinking water between point I, II and III. Increases due to the influx of the brewery effluents at RUA IV were observed to the not very pronounced, but noticeable increases were observed in the concentration levels of Ti, Cu, Zn and Mn during the dry seasons. Concentration of lead remain low. Thus to some extent the brewery effluents affect elemental concentrations in the waters.

Overall the analytical data accumulated and compiled on Ruiruaka river waters clearly pinpoint breweries discharges as the main source of pollution of the river, which drastically impairs the quality of the waters in the dry seasons. This can be quite effectively controlled by too much extent by retaining the effluents in oxidation ponds over a period of 1 to 2 days to let the suspended and dissolved solids settle down. The retention of oxidation process also bring down the BOD and COD levels of the effluents before effluents are discharged into the river. Although at this stage the river looks fairly less polluted, considering the fast growth of industrial activity and increase in settlements, in the rain catchment areas, Ruiruaka river also will in no time turn into a heavily polluted drain leading to other hygenic problems.

RESEARCH RECOMMENDATIONS:-

In order to ascertain the degree of pollution and acceptability of water for drinking purposes, it is necessary to:-

(1) carry out bacteriological and virological examination of the water in the three rivers

(2) establish the type of metal species in the three rivers, so as to convenience a control measure should pollution level be attained in these rivers

(3) establish the other sources of pollution.

1. Klein Louis. River Pollution: Causes and effects. London Butterworths. (1959).

2. Welch P.S. Limnology. 2nd Edition. New York, McGraw-Hill, 1952.

3. Arthur H. Benedict. Temperature effects on BOD Stoichiometry and oxygen uptake rate. J. Wat. Pollut Control fed. 49(5) 864 - 867

4. Ruby S.M. Aczel J. and Graig C.R. (1978). The effect of depressed pH on spermatogenis in flagfish. Jordanella floridae, Water Research 12: 621 - 626

5. Ciaccioi L.L. Water and Water Pollution. Handbook New York, Dekker 1971.

6. John E. Vogt. Impact of wastewater discharge on surface water sources, Journal AWWA (American water works Assn.) February 1972.

7. Ouana E.A.R., Lohani B.N. and Thanh N.C. (1978) Water pollution in developing countries.

8. Velz C.J. Applied stream sanitation. New York, Wiley.(1970)

9. Sawyer C.N. Chemistry for sanitary engineers. 2nd Edition. New York. McGraw - Hill (1967).

10. WHO (1977). Enviromental Health Criteria. World Health Organization, Geneva.

11. Henryk Manczak and Halina Flarczyk (1971). Interpretation of result from the studies of pollution of surface flowing water, Water Research 5: 575 - 584

12. Duncan P.H. Laxen and Roy M. Harrison (1981). The physicochemical speciation of Cd, Pb, Cu, Fe and Mn in the final effluents of a sewage treatment works and it's impact on specification in the receiving river, Water Research 15: 1053 - 1065.

13. Velz C.J. and Gannon J.J. Stream pollution, J. Wat. Pollut. Control Fed. 32 (1960), 392 - 417.

14. M. Katz, G.L. Pederson, M. Yoshinaka and D. Sjolseth (1969). Effect of pollution on fish life. J. of Water Pollut. fed 41(6). 994 - 1007.

15. Malberg J.W., Savage E.P. and Osteryoung J. (1978). Nitrates in drinking water and the early onset of hypertension, Enviromental pollution, Ser. A, 15: 155, - 160.

16. Reid George K. Ecology of inland waters and estuaries.

17. Brown L. and Bellinger E.G. (1978). Nitrate determination in fresh and some estuaries water by Ultra Violet light absorption, Water Research 12(4): 223 - 229.

18. Sridharan N. and Lee G.F. Phosphorous studies in lower Gree Bay, Lake Michigan, J. Water Pollut. Control Fed. 46(4) 1974: 684 - 696.

19. Hammer M.J. Water and wastewater technology. New York. Wiley, 1975.

20. Champman G. and Dunlop S. Detoxication of Zn and Cd by freshwater protozoan. "Tetrahymene pyriformis", Enviromental Res, 26, 1- 21, 1981.

21. World Health Organization (1973). Trace element in Human nutrition, WHO Technical Report No. 532 WHO, Geneva.

22. Burt K. Shepkard, Alan W. Mc Intosh, Gary J. Atchison and Darrel W. Nelson. "Aspects of the aquatic chemistry of Cadmium and Zinc in a heavy metal contaminated lake", Water Research 14 (1980): 1061 - 1066.

23. Ndiokwere C.L. An investigation of heavy metal content of sediment and algae from river Niger and Nigerian Atlantic coastal waters, Environ. Pollut. Serv. B 7 (1984), 247 - 254.

24. Waldichuk M. Health effect of Pb in the enviroment, Marine Pollution Bulletin, 11(9) 1980: 241.

25. John G. Shiber and Bryon Ramsay. Lead in concentration in Beirut waters, Marine pollution Bulletin, 3(11) 1972: 169-171

26. Marc Report No. 20
Enviromental hazard of Heavy metal: Summary Evaluation of lead, Cadmium and Mercury. Prep. by Global enviromental monitoring centre, UNEP, Nairobi.
Monitoring and Assessment Research centre, Chelsea College, London.

27. Goyer R.A., Mehiam M.A. (1977). Toxicology of trace element, Advances in modern toxicology Vol. 2, p. 303, John Wiley and Son, New York.

28. Parisi A.F., Valee B.L. (1969). Zinc metalloenzymes: Characteristic and signifance in Biology and medicine, Am. J. Clin. Nutr. 22: 1222-1239

29. Joyce Weber. Mercury. A hazardous waste problem J. Enviro. Health, 45(6) May/June 1983: 284-287

30. Lu, F, E, et al. The toxicity of Mercury in man and animals.
In "Mercury contamination in man and his enviroment."

31. Varma, M.M., Steven G. Serdahely and Hebert M. Katz. Physiological effects of trace elements and chemical in water, J. of Enviro, Health, 39(2): 90-97

32. WHO (1981). Chromium, Enviromental Health Criteria 17. 110pp, UNEP.

33. Wandiga S.O., Molepo J.M., Alala L.N. (1983): Concentration of heavy metal in water, sediment and plant of Kenyan lakes, Kenya Journal of Science and Technology series A (1983), 4(2): 89 - 94.

34. Onyari J.M. (1984) M.Sc. Thesis. Concentration of Manganese, Iron, Copper, Zinc, Cadmium and Lead in sediment and fish from Winam Gulf of Lake Victoria and fish bought in Mombasa town markets.

35. Nanzi S.A.M. M.Sc. Thesis. Determination of nitrates and nitirtes content in portable water and baby food in Kenya. 1985.

36. Bathey G.E. and Gardner D. (1977). Sampling and storage of Natural waters for trace metal analysis, Water Research, 11(9): 745 - 756.

37. Standard method for examination of water and waste water. 14th Edition 1975. American Public Health Association.

38. R. Van Grienken. Preconcentration methods for analysis of water by x-ray spectrometric techniques, Analytica chimica Acta, 143 (1982): 3 - 34.

39. C.J. Spark Jr. X-ray fluorescent Analysis.

40. Robert D. Giaugue and Joseph M. Jacklene. "Rapid quantitative analysis by X-ray spectrometry", in K.F.J.. Heinrich et al, Editors, Advances in X-ray Analysis, 15, pp 164 - 174, plenum press (1971).

41. W. Bambynek and D. Reher. "X-ray fluorescence yields, Auger and Coster-Krong transition probabilities". Rev. modern phys., 44 (1972) 716.

42. Storm E. and Israel H.I. Nuclear data tables. A7 (1970)

43. A.H. Pradzynski, R.E. Henry, J.S. Stewart. Concentration of transition metals by radioisotope excited energy dispersive x-ray spectrometry, Journal of Radio analytical Chemistry, 32 (1976): 219 - 228.

44. B. Holyska, K. Bisinlek. Determination of trace amount of metal in saline water by EDXRF using NaDDTC preconcentration, J. Radianal. Chem., 31 (1976): 159 - 166.

APPENDIX I

Existing WHO European standard and proposed EEC Standard for chemicals in drinking water.

CONSTITUENT	WHO EUROPEAN	GUIDE LEVEL	EEC PROPOSED MAXIMUM ADMISSIBLE CONCENTRATION
Chronium	0.05 (Hexavalent)		0.05
Lead	0.1		0.05
Cadmium	0.01		0.005
Nitrate	50 - 100 ppm		50 (as No_3) ppm
Copper	0.05		0.050
Iron	0.1	0.1	0.03
Manganese	0.05	0.02	0.05
Zinc	5		0.1
Mercury			0.001
Conductivity	400 µs/cm		1,250 μScm^{-1}
pH	6.5 - 8.5		9.5
D.O.		5 (as O_2) ppm	
BOD		50% of initial D.O.	
Temperature			25 (^oC)

(Elemental concentration in ppm)

APPENDIX II

Table: 3.2.1A - Quality parameters of Nairobi waters sampled on 12th November, 1985.

	SAMPLING POINTS						
PARAMETERS	I	II	III	IV	V	VI	VII
Temperature (^{o}C)	19.1	20.2	21.0	21.4	23.5	22.4	21.0
pH	7.4	6.9	7.1	7.3	7.3	7.4	7.5
Conductivity (μscm^{-1})	357	967	597	501	550	518	398
BOD (mg l^{-1})	6	196	400	220	124	150	76
COD (mg l^{-1})	43.5	656.1	1,043.5	640.3	383.4	324.1	177.9
D.S. (mg l^{-1})	304	1,052	536	416	424	408	388
S.S. (mg l^{-1})	52	400	1,108	808	252	568	178
Chloride (mg l^{-1})	41	40	39	23	36	29	35
Nitrates ($N-No_3$)(mg l^{-1})	0.40	0.12	0.10	0.15	0.11	0.11	0.10
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.05	0.33	0.39	0.31	0.46	0.32	0.30

Table 3.2.1B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENT	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	73±9	51±5	72±6	222±11	39±4	252±12	92±9
Cu (ppb)	*	15±2	16±2	*	23±2	27±2	*
Zn (ppb)	18±1	71±3	25±2	58±2	173±3	179±3	51±2
Pb (ppb)	*	*	*	*	*	19±1	*

* - Below the minimum detectable limit

Table 3.2.1B

Elemental concentration in suspended matter

SAMPLING POINTS

ELEMENT	I	II	III	IV	V	VI	VII
Ti (ppb)	1,391±113	914±101	250±13	145±11	96±9	203±11	455±16
Mn (ppb)	242±25	127±12	*	*	72±9	*	66±9
Cu (ppb)	11±1	14±1	90±8	11±2	47±6	*	28±3
Zn (ppb)	67±2	103±5	209±7	11±1	129±5	16±1	61±2
Pb (ppb)	25±2	51±3	25±2	*	72±5	10±1	71±5

* - Below minimum detectable limit

Table: 3.2.2A - Quality parameters of Nairobi waters samples on 10th December, 1985.

PARAMETERS	SAMPLING POINTS I	II	III	IV	V	VI	VII
Temperature (°C)	19.8	19.9	20.6	20.4	22.5	21.5	21.1
pH	7.4	7.2	7.5	7.3	7.3	7.4	7.2
Conductivity (μScm^{-1})	296	301	286	281	401	296	298
BOD (mg l^{-1})	6	68.5	100	35	76	44	55
COD (mg l^{-1})	69.2	150	195.2	107.7	634.2	73.1	176.9
D.S. (mg l^{-1})	288	284	264	204	324	232	232
S.S. (mg l^{-1})	60	264	288	126	74	96	248
Chloride (mg l^{-1})	38	56	57	49	44	46	32
Nitrates (N-No_3)(mg l^{-1})	0.75	0.13	0.25	0.14	0.15	0.25	1.88
Total Phosphates (P-Po_4) (mg l^{-1})	0.07	0.17	0.20	0.11	0.66	0.38	0.50

Table 3.2.2B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	*	77±10	*	35±4	58±5	50±7	*
Cu (ppb)	*	22±2	*	*	18	20±2	*
Zn (ppb)	29±2	132±3	21±1	71±4	78	113±7	56±3
Pb (ppb)		26±3	*	21±2	27±3	35±3	22±2

Table 3.2.2B

Elemental concentration in suspended matter

SAMPLING POINTS.

ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	522±19	151±11	147±11	39±6	31±11	•	•
Mn (ppb)	48±18	•	•	•	45±7	•	•
Cu (ppb)	•	•	•	11±2	21±3	•	11±2
Zn (ppb)	20±2	24±2	20±2	22±2	43±4	21±2	24±3

Table: 3.2.3A - Quality parameters of Nairobi waters sampled on 7th January, 1986.

PARAMETERS	SAMPLING POINTS I	II	III	IV	V	VI	VII
Temperature (^{o}C)	20.0	20.5	21.3	21.5	22.3	22.8	21.1
pH	7.3	6.9	7.3	7.3	7.5	7.4	7.1
Conudctivity (μscm^{-1})	297	401	408	311	414	356	287
BOD (mg 1^{-1})	4	80	110	28	68	36	44
COD (mg 1^{-1})	31.5	161.4	263.8	39.4	236.2	75.4	110.2
D.S. (mg 1^{-1})	224	320	364	288	380	304	260
S.S. (mg 1^{-1})	84	160	124	20	88	36	186
Chloride (mg 1^{-1})	46	37	45	37	38	36	33
Nitrates (N-No$_3$)(mg 1^{-1})	1.00	0.20	0.25	0.15	0.20	0.27	0.17
Total Phosphates (P-Po$_4$) (mg 1^{-1})	0.30	0.30	0.37	0.31	0.75	0.42	0.58

Table 3.2.3B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	43±6	62±6	62±7	101±7	47±6	89±7	99±6
Cu (ppb)	*	10±2	10±2	*	21±2	24±3	11±2
Zn (ppb)	39±1	59±2	64±2	27±2	106±5	56±3	24±2
Pb (ppb)	*	21±2	20±2	21±2	*	25±3	*

Table: 3.2.3B

Elemental concentration in suspended matter

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	828±52	792±33	1,008±51	552±41	27±8	347±17	372±19
Mn (ppb)	92±25	59±24	*	47±21	*	34±13	59±24
Cu (ppb)	*	23±5	31±5	10±2	11±2	11±2	13±2
Zn (ppb)	47±3	42±3	54±4	32±2	21±2	17±2	17±2

Table: 3.2.4A - Quality parameters of Nairobi waters sampled on 4th February, 1986.

	SAMPLING POINTS						
PARAMETERS	I	II	III	IV	V	VI	VII
Temperature (°C)	20.0	20.2	20.5	20.3	22.2	21.3	21.0
pH	7.1	6.9	7.3	7.3	7.4	7.3	7.4
Conductivity (μscm^{-1})	201	394	396	417	496	437	411
BOD (mg l^{-1})	2	100	75	26	100	56	54
COD (mg l^{-1})	11	208	131	82	300	104	142
D.S. (mg l^{-1})	252	424	472	380	456	388	396
S.S. (mg l^{-1})	16	102	82	36	80	75	73
Chloride (mg l^{-1})	45	42	43	39	41	40	39
Nitrates(N-No$_3$)(mg l^{-1})	1.12	0.31	0.27	0.15	0.20	0.18	0.15
Total Phosphates (P-Po$_4$)	0.07	1.21	0.45	0.37	0.81	0.50	0.55

Table: 3.2.4B

Soluble elemental concentrations

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	77±9	102±9	112±9	350±11	78±7	455±17	464±18
Cu (ppb)	19±2	20±2	14±2	24±3	22±3	17±2	13±1
Zn (ppb)	16±3	102±4	110±3	60±3	79±3	68±3	28±2
Pb (ppb)	*	41±3	35±3	*	36±3	*	*

Table: 3.2.4B

Elemental concentration in suspended matter

ELEMENTS	SAMPLING POINTS I	II	III	IV	V	VI	VII
Ti (ppb)	89±19	225±19	287±16	35±9	*	*	*
Mn (ppb)	*	*	*	*	*	*	*
Cu (ppb)	*	17±3	26±3	16±3	42±6	14±2	*
Zn (ppb)	*	11±2	16±2	*	38±5	24±2	11±2
Pb (ppb)							

Table: 3.2.5A - Quality parameters of Nairobi

PARAMETERS	I	II
Temperature (^{o}C)	19.9	20.4
pH	7.3	6.7
Conductivity (μScm^{-1})	301	396
BOD (mg l^{-1})	3	115
COD (mg l^{-1})	8	256
D.S. (mg l^{-1})	264	376
S.S. (mg l^{-1})	20	208
Chloride (mg l^{-1}),	42	40
Nitrates ($N-No_3$) (mg l^{-1})	1.00	0.21
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.03	0.33

waters sampled on 4th March, 1986.

SAMPLING POINTS

III	IV	V	VI	VII
21.1	21.2	23.5	22.3	21.4
6.9	7.5	7.3	7.3	7.3
401	414	425	417	427
120	48	92	76	55
310	151	308	248	194
428	424	352	432	496
224	80	96	76	144
37	36	40	38	52
0.26	0.14	0.20	0.20	0.18
0.40	0.29	0.67	0.42	0.45

Table: 3.2.5B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	88±6	171±11	251±14	810±21	74±9	154±13	172±12
Cu (ppb)	11±1	•	11±1	11±1	16±2	14±2	•
Zn (ppb)	64±2	185±4	178±4	234±6	433±8	486±8	167±4
Pb (ppb)	•	62±14	58±14	34±13	75±15	48±13	30±13

Table: 3.2.5B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	IV	V	VI	VII
Ti (ppb)	339±20	441±26	319±30	205±27	619±43	406±21	215±2
Mn (ppb)	31±11	33±15	•	•	39	22	•
Cu (ppb)	•	37±3	40±5	37±5	128±5	71±5	39±3
Zn (ppb)	32±3	66±3	63±5	52±3	153±6	126±5	67±5
Pb (ppb)	•	63±3	29±4	23±3	72±6	50±4	21±4

Table: 3.2.6A - Quality patameters of Nairobi waters sampled on 8th April, 1986.

	SAMPLING POINTS						
PARAMETERS	I	II	III	IV	V	VI	VII
Temperature (^{o}C)	18.5	19.0	19.5	19.9	22.0	20.6	20.0
pH	6.9	6.9	9.0	7.1	7.3	7.1	7.1
CONDUCTIVITY (μS cm^{-1})	200	220	496	286	444	300	296
BOD (mg l^{-1})	16	76	86	18	60	6	12
COD (mg l^{-1})	78	321	151	113	384	68	126
D.S. (mg l^{-1})	118	328	576	200	448	224	264
S.S. (mg l^{-1})	268	300	421	244	190	346	372
Chloride (mg l^{-1})	34	32	49	35	37	34	32
Nitrates (N-No$_3$)(mg l^{-1}	1.62	2.29	2.21	0.20	0.22	0.23	0.20
Total Phosphates (P-Po$_4$ (mg l^{-1})	0.35	0.37	0.34	0.32	0.75	0.45	0.45

Table: 3.2.6B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	115±10	433±11	1,063±14	151±21	25±5	220±16	233±
Cu (ppb)	*	*	14±3	230±4	28±3	30±4	11±2
Zn (ppb)	50±3	108±5	107±4	202±4	161±5	221±6	19±3
Pb (ppb)	*	57±3	57±3	103±3	73±3	134±3	

Table: 3.2.6B

Suspended matter elemental concentration

	SMAPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	3893±140	4020±161	4249±189	3689±107	1308±101	4096±190	2621±161
Mn (ppb)	386±122	435±131	563±151	495±140	141±43	551±154	778±113
Cu (ppb)	93±5	17±3	329±8	193±3	•	29±3	•
Zn (ppb)	140±6	154±5	215±9	202±6	43±3	208±6	162±8
Pb (ppb)	53±4	58±6	118±7	105±4	26±3	120±6	76±6

Table: 3.2.7A - Quality parameters of Nairobi waters sampled on 6th May, 1986

	SAMPLING POINTS						
PARAMETERS	I	II	III	IV	V	VI	VII
Temperature (°C)	18.3	18.5	18.7	18.9	22.4	19.9	19.0
pH	6.5	6.6	6.7	6.8	7.2	6.8	6.9
Conductivity (μscm^{-1})	175	203	240	232	383	244	206
BOD (mg l^{-1})	14	16	20	16	54	16	12
COD (mg l^{-1})	93	112	123	157	205	153	224
D.S. (mg l^{-1})	376	368	276	216	240	236	284
S.S. (mg l^{-1})	834	1,180	928	1,404	308	1,152	1,544
Chloride (mg l^{-1})	25	21	12	14	22	12	17
Nitrates (N-No$_3$) (mg l^{-1})	1.50	0.81	1.00	0.71	0.51	0.85	0.51
Total Phosphates (P-Po$_4$) (mg l^{-1})	0.48	0.21	0.22	0.19	0.60	0.20	0.32

Table: 3.2.7B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	298±12	345±12	480±9	252±10	25±1	179±10	558±13
Cu (ppb)	16±2	16±2	19±2	16±2	18±2	14±2	19±3
Zn (ppb)	30±2	43±2	38±2	35±3	59±2	60±2	38±2
Pb (ppb)	30±2	21±2	31±2	21±2	20±2	21±3	33±2

Table: 3.2.7B

Suspended matter elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	570±37	218±13	164±13	155±14	250±14	215±12	343±20
Mn (ppb)	65±20	*	*	*	*	*	*
Cu (ppb)	*	28±2	*	*	15±1	18±1	*
Zn (ppb)	22±3	11±2	13±2	13±1	15±2	13±2	12±2
Pb (ppb)	*	*	23±2	*	*	*	*

Table: 3.2.8A - Quality parameters of Nairobi

PARAMETERS	I	II
Temperature (^{o}C)	19.5	20.1
pH	7.3	7.0
Conductivity (μScm^{-1})	298	311
BOD (mg l^{-1})	10	112
COD (mg l^{-1})	39	283
D.S. (mg l^{-1})	268	308
S.S. (mg l^{-1})	67	292
Chloride (mg l^{-1})	44	40
Nitrates ($N-No_3$) (mg l^{-1})	1.00	0.99
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.38	1.18

waters sampled on 10th June, 1986.

SAMPLING POINTS				
III	IV	V	VI	VII
20.8	21.4	24.5	22.7	21.5
7.3	7.4	7.3	7.3	7.2
411	403	427	374	332
165	64	68	76	140
311	217	179	224	354
432	384	228	444	472
484	190	88	230	340
41	29	31	30	32
0.85	0.61	0.71	0.96	0.73
1.59	0.77	1.79	0.93	0.72

Table: 3.2.8B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	33±4	348±19	360±11	1,596±40	79±9	379±9	360±11
Cu (ppb)	•	11±3	•	•	19	•	•
Zn (ppb)	•	18±3	76±3	135±5	127±3	125±3	75±3
Pb (ppb)	•	•	•	29±3	20±3	•	•

Table: 3.2.8B

Suspended matter elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	237 ±12	•	66 ±9	25 ±4	•	•	•
Mn (ppb)	187 ±15	189 ±15	102 ±11	•	•	•	•
Cu (ppb)	11 ±2	•	•	•	37 ±5	•	•
Zn (ppb)	•	85 ±5	34 ±3	•	15 ±1	•	•
Pb (ppb)		22 ±5	•	•	•	•	•

Table: 3.2.9A - Quality parameters of Nairobi waters sampled on 8th July, 1986.

	SAMPLING POINTS						
PARAMETERS	I	II	III	IV	V	VI	VII
Temperature (^{o}C)	20.5	21	21.4	21.9	24.0	22.5	21.9
pH	7.5	7.1	7.2	7.3	7.5	7.4	7.9
Conductivity ($\mu S cm^{-1}$)	333	386	584	347	344	345	437
BOD (Mg l^{-1})	6	145	110	40	185	65	32
COD (mg l^{-1})	89	387	536	207	392	305	215
D.S. (mg l^{-1})	448	312	444	316	408	325	275
S.S. (mg l^{-1})	76	198	328	112	44	140	274
Chloride (mg l^{-1})	44	41	91	56	34	36	35
Nitrates ($N-No_3$) (mg l^{-1})	0.95	1.00	0.99	0.85	1.51	0.87	0.75
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.18	1.45	1.51	1.09	0.95	0.91	1.00

Table: 3.2.9B

Soluble elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)							
Mn (ppb)	73±7	50±6	71±8	351±12	74±8	456±17	470±16
Cu (ppb)	20±2	21±2	15±1	25±2	23±3	19±1	*
Zn (ppb)	17±1	100±3	112±3	59±2	80±2	70±2	*
Pb (ppb)	*	40±3	36±3	11±1	36±3	25±2	

Table: 3.2.9B

Suspended matter elemental concentration

	SAMPLING POINTS						
ELEMENTS	I	II	III	IV	V	VI	VII
Ti (ppb)	520	150	148	40	35	*	*
Mn (ppb)	92±19	60±17	*	48±15	*	35±13	*
Cu (ppb)	*	22±2	30±3	11±1	12±1	14±1	*
Zn (ppb)	24±2	25±2	26±3	28±3	43±3	32±5	*
Pb (ppb)							

APPENDIX III

Table: 4.2.1A - Quality parameters of Ngong' waters sampled on 15the November, 1985.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	20.4	23.8	22.4	22.6	21.8
pH	7.3	6.3	6.9	7.0	7.5
Conductivity ($\mu S cm^{-1}$)	302	507	451	575	550
BOD (mg l^{-1})	6	170	88	20	12
COD (mg l^{-1})	76.9	307.7	173.8	50.0	46.0
D.S. (mg l^{-1})	244	452	394	504	507
S.S. (mg l^{-1})	17	107	68	14	4
Chloride (mg l^{-1})	25	30	43	63	58
Nitrates (N-No$_3$) (mg l^{-1})	1.30	0.10	0.10	0.11	0.40
Total Phosphates (P-Po$_4$) (mg l^{-1})	0.04	0.18	0.05	0.04	0.16

Table: 4.2.1B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	1,660±28	301±27	740±33	477±13	287±7
Cu (ppb)	15±3	48±6	115±10	26±2	10±1
Zn (ppb)	31±2	54±7	891±59	200±6	67±2
Pb (ppb)	•	58±7	68±3	41±2	•

Table: 4.2.1B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	85±7	180±13	1,441±17	187±9	*
Mn (ppb)	154±9	100±17	30±7	58±7	*
Cu (ppb)	*	50±3	41±2	35±2	16±2
Zn (ppb)	13±1	64±2	146±2	188±6	16±1
Pb (ppb)	*	131±3	195±3	178±4	*

Table: 4.2.2A - Quality parameters of Ngong' waters sampled on 13th December, 1985.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	21.0	24.2	23.5	23.0	22.8
pH	7.3	8.5	8.5	7.3	8.3
Conductivity (μScm^{-1})	279	751	654	675	670
BOD (mg l^{-1})	8	125	156	140	27
COD (mg l^{-1})	64	323	279	287	136
D.S. (mg l^{-1})	288	792	640	668	648
S.S. (mg l^{-1})	8	72	68	50	36
Chloride (mg l^{-1})	21	155	59	68	66
Nitrates ($N-No_3$) (mg l^{-1})	0.90	0.41	0.37	0.31	0.28
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.12	0.15	0.08	0.24	0.72

Table: 4.2.2B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	138±9	*	36±4	*	*
Mn (ppb)	70±9	329±9	564±11	384±12	467±9
Cu (ppb)	14±1	87±3	186±5	12±1	*
Zn (ppb)	59±1	357±3	540±7	74±3	53±2
Pb (ppb)	*	393±6	790±6	35±1	17±1

Table: 4.2.2B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	81±1	87±2	138±11	391±13	*
Mn (ppb)	70±9	59±8	71±9	115±9	*
Cu (ppb)	13±1	55±1	185±6	15±1	15±1
Zn (ppb)	31±2	61±2	356±2	370±3	32±1
Pb (ppb)	*	87±3	788±4	63±2	*

Table: 4.2.3A - Quality parameters of Ngong' waters sampled on 9th January, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^oC)	21.0	24.5	22.5	22.1	22.0
pH	7.3	9.0	7.5	7.4	7.5
Conductivity ($\mu S cm^{-1}$)	278	2,175	1,571	1,201	981
BOD (mg l^{-1})	6	560	320	280	12
COD (mg l^{-1})	67	1,386	1,296	681	126
D.S. (mg l^{-1})	272	506	1,856	844	672
S.S. (mg l^{-1})	17	414	208	252	5
Chloride (mg l^{-1})	31	102	69	50	54
Nitrates ($N-No_3$) (mg l^{-1})	1.00	1.41	0.79	0.45	0.12
Phosphates ($P-Po_4$) (mg l^{-1})	0.15	0.60	0.52	0.24	0.65

Table: 4.2.3B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	93±4	34±3	*	49±2	245±9
Cu (ppb)	*	12±1	17±1	*	*
Zn (ppb)	24±1	120±2	579±13	239±1	97±2
Pb (ppb)	*	31±1	40±2	15±1	*

Table: 4.2.3B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)	146±1	178±11	351±12	149±7	•
Mn (ppb)	57±8	58±9	79±11	33±7	•
Cu (ppb)	13±1	26±1	34±2	20±1	12±1
Zn (ppb)	31±1	64±2	367±3	210±6	13±1
Pb (ppb)	26±2	73±3	162±5	30±2	•

Table: 4.2.4A - Quality parameters of Ngong' waters sampled on 6th February, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	21.9	23.5	22.1	22.0	22.1
pH	7.3	8.8	9.3	7.3	7.5
Conductivity (μScm^{-1})	254	2,134	401	464	451
BOD (mg l^{-1})	4	230	170	55	6
COD (mg l^{-1})	88	538	385	395	23
D.S. (mg l^{-1})	260	416	360	440	436
S.S. (mg l^{-1})	24	228	218	66	6
Chloride (mg l^{-1})	38	36	41	52	58
Nitrates ($N-No_3$) (mg l^{-1})	0.91	0.50	0.12	0.20	0.41
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.05	0.25	0.31	0.55	0.57

Table: 4.2.4B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	•	273±19	•	36±5	301±19
Cu (ppb)	16±2	22±3	19±2	18±2	11±2
Zn (ppb)	17±2	52±2	267±12	67±3	31±2
Pb (ppb)	•	31±3	59±5	•	•

Table: 4.2.4B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	80 ± 10	117 ± 13	375 ± 41	261 ± 10	16 ± 3
Mn (ppb)	*	*	*	393 ± 20	*
Cu (ppb)	*	22 ± 3	21 ± 3	63 ± 7	14 ± 1
Zn (ppb)	25 ± 2	27 ± 2	29 ± 3	578 ± 11	17 ± 1
Pb (ppb)	*	*	26 ± 3	102 ± 5	*

Table: 4.2.5A - Quality parameters of Ngong' waters sampled on 6th March, 1986

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	22.0	24.5	22.8	21.9	22.3
pH	7.3	10.6	9.6	9.3	7.5
Conductivity (μScm^{-1})	296	576	597	751	696
BOD (mg l^{-1})	4	320	180	130	20
COD (mg l^{-1})	47	949	482	759	75
D.S. (mg l^{-1})	220	640	612	888	676
S.S. (mg l^{-1})	19	580	131	108	12
Chloride (mg l^{-1})	18	47	110	130	88
Nitrates (N-No_3) (mg l^{-1})	1.10	0.32	0.10	0.10	0.31
Total Phosphates (P-Po_4) (mg l^{-1})	0.10	0.17	0.29	0.49	0.55

Table: 4.2.5B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	1,153±22	182±18	94±9	101±11	93±9
Cu (ppb)	15±2	33±3	49±3	24±2	12±2
Zn (ppb)	18±2	150±3	1,424±12	97±3	55±3
Pb (ppb)	•	347±7	435±6	32±5	•

Table: 4.2.5B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	96±18	127±15	418±25	*	*
Mn (ppb)	*	*	*	75±9	*
Cu (ppb)	*	17±2	55±3	36±5	17±2
Zn (ppb)	15±1	21±2	69±5	142±6	32±2
Pb (ppb)	*	21±3	72±6	31±6	*

Table: 4.2.6A - Quality parameters of Ngong' waters sampled on 3rd April, 1986

PARAMETERS	SAMPLING POINTS I	II	III	IV	V
Temperature (^{o}C)	18.7	20.6	21.0	21.1	20.5
pH	6.7	9.1	7.1	7.1	7.9
Conductivity (μScm^{-1})	195	411	476	418	428
BOD (mg l^{-1})	8	130	140	35	12
COD (mg l^{-1})	50	397	527	160	76
D.S. (mg l^{-1})	160	496	556	320	424
S.S. (mg l^{-1})	40	232	226	160	8
Chloride (mg l^{-1})	20	96	52	113	114
Nitrates (N-No_3) (mg l^{-1})	1.00	0.31	0.29	0.15	0.50
Total Phosphates (P-Po_4) (mg l^{-1})	0.31	0.19	0.31	0.47	0.57

Table: 4.2.6B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	171±9	403±17	501±9	646±17	299±12
Cu (ppb)	•	10±2	14±3	13±2	•
Zn (ppb)	76±5	154±4	286±5	72±3	45±3
Pb (ppb)	37±5	49±3	51±5	37±3	117±3

Table: 4.2.6B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	565±30	491±25	365±23	235±17	113±13
Mn (ppb)	77±25	61±21	33±17	•	•
Cu (ppb)	26±3	•	12±2	•	•
Zn (ppb)	15±3	12±3	11±2	10±1	•
Pb (ppb)					

Table: 4.2.7A - Quality parameters of Ngong' waters sampled on 1st May, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	19.0	21.7	21.6	20.9	20.7
pH	6.5	6.7	6.9	7.3	7.6
Conductivity (μscm^{-1})	170	301	311	400	397
BOD ($mg\ l^{-1}$)	8	36	40	28	14
COD ($mg\ l^{-1}$)	39	124	70	155	58
D.S. ($mg\ l^{-1}$)	140	256	292	388	336
S.S. ($mg\ l^{-1}$)	62	166	74	100	20
Chloride ($mg\ l^{-1}$)	24	32	36	43	41
Nitrates ($N\text{-}No_3$) ($mg\ l^{-1}$)	0.51	1.00	0.71	0.41	0.12
Total Phosphates ($P\text{-}Po_4$) ($mg\ l^{-1}$)	0.35	0.61	0.22	0.24	0.65

Table: 4.2.7B

Soluble elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	153±9	180±9	567±23	950±39	794±25
Cu (ppb)	16±2	35±3	24±3	14±3	*
Zn (ppb)	*	65±3	327±9	198±12	48±5
Pb (ppb)	*	40±3	50±3	44±5	*

Table: 4.2.7B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	578±20	740±35	438±19	331±21	413±20
Mn (ppb)	66±23	33±19	*	*	*
Cu (ppb)	23±3	13±2	17±3	11±2	*
Zn (ppb)	29±3	29±2	24±2	15±2	20±2
Pb (ppb)	23±3	*	22±2	*	*

Table: 4.2.8A - Quality parameters of Ngong' waters sampled on 5th June, 1986

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	20.5	22.8	22.3	21.9	21.5
pH	7.3	9.0	7.1	7.1	7.9
Conductivity (μscm^{-1})	293	2,090	396	461	418
BOD (mg l^{-1})	6	378	157	56	8
COD (mg l^{-1})	40	929	214	107	40
D.S. (mg l^{-1})	284	984	242	276	312
S.S. (mg l^{-1})	24	264	148	74	30
Chloride (mg l^{-1})	14	109	28	76	79
Nitrate (N-No_3) (Mg l^{-1})	1.40	1.50	1.50	0.82	1.61
Total Phosphates (P-Po_4) (mg l^{-1})	0.40	1.50	1.50	1.52	0.61

Table: 4.2.8B

Soluble elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	74±9	48±9	55±9	313±11	25±10
Cu (ppb)	12±2	28±3	25±3	14±3	37±2
Zn (ppb)	64±4	84±3	738±16	182±5	78±15
Pb (ppb)	22±3	40±3	70±3	26±5	179±2

Table: 4.2.8B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	•	51 ± 12	•	•	•
Cu (ppb)	•	•	10 ± 1	15 ± 2	41 ± 6
Zn (ppb)	14 ± 3	35 ± 4	21 ± 3	19 ± 2	43 ± 4
Pb (ppb)	•	29 ± 4	•	•	34 ± 6

Table: 4.2.9A - Quality parameters of Ngong' waters sampled on 3rd July, 1986

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (°C)	21.7	24.5	24.0	23.8	22.5
pH	7.1	8.3	7.3	7.1	7.5
Conductivity ($\mu S cm^{-1}$)	274	401	603	613	648
BOD (mg l^{-1})	6	210	200	45	12
COD (mg l^{-1})	75	457	598	252	193
D.S. (mg l^{-1})	272	416	628	564	512
S.S. (mg l^{-1})	19	262	280	83	30
Chloride (mg l^{-1})	25	28	66	48	62
Nitrates (N-No_3) (mg l^{-1})	0.18	0.17	0.20	0.20	0.18
Total Phosphates (P-Po_4) (mg l^{-1})	0.27	1.30	0.32	1.23	0.96

Table: 4.2.9B

Soluble elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	95±4	40±3	*	50±2	250±10
Cu (ppb)	*	13±1	18±2	*	*
Zn (ppb)	24±1	357±4	890±50	240±8	54±2
Pb (ppb)	*	56±4	70±4	40±2	*

Table: 4.2.9B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	58±7	57±7	80±8	35±5	*
Cu (ppb)	12±1	26±2	35±2	25±2	14±1
Zn (ppb)	13±1	65±2	150±2	200±5	13±1
Pb (ppb)	*	135±4	200±5	180±4	*

APPENDIX IV

Table: 5.2.1A - Quality parameters of Ruiruaka waters sampled on 19th November, 1985.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (°C)	19.6	19.4	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	705
D.S. (mg l^{-1})	289	296	220	1,050	424
S.S. (mg l^{-1})	31	8	38	516	252
Chloride (mg l^{-1})	14	14	17	19	15
Nitrates (N-No_3) (mg l^{-1})	1.00	0.40	0.30	0.60	0.54
Total Phosphates (P-Po_4) (mg l^{-1})	0.05	0.05	0.06	0.50	0.40.

Table: 5.2.1B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	*	50±4	57±7	70±5	55±3
Cu (ppb)	10±1	*	12±2	74±5	40±4
Zn (ppb)	40±2	26±1	100±6	73±3	40±2
Pb (ppb)	38±2	115±3	25±4	20±2	*

Table: 5.2.1B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	243±12	274±11	188±9	361±15	98±5
Mn (ppb)					
Cu (ppb)	*	*	*	76.0±3	55±2
Zn (ppb)	15±1	17±1	17±1	25±2	18±1
Pb (ppb)					

Table: 5.2.2A - Quality parameters of Ruiruaka waters sampled on 24th December, 1985.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (°C)	18.2	18.0	18.5	20.3	20.0
pH	7.0	7.3	7.3	5.7	6.0
Conductivity ($\mu S cm^{-1}$)	161	152	157	401	257
BOD (mg l^{-1})	6	5	28	600	201
COD (mg l^{-1})	34	26	50	1,454	522
D.S. (mg l^{-1})	296	236	145	1,108	476
S.S. (mg l^{-1})	37	4	58	536	175
Chloride (mg l^{-1})	12	15	17	29	13
Nitrates ($N-No_3$) (mg l^{-1})	0.26	0.32	0.39	0.53	0.52
Total Phosphates ($P-Po_4$) (mg l^{-1})	0.05	0.04	0.07	0.33	0.31

Table: 5.2.2B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	174±9	*	124±9	214±8	189±7
Cu (ppb)	22±2	16±2	20±3	30±2	12±1
Zn (ppb)	66±3	18±2	154±5	197±5	111±3
Pb (ppb)	*	*	134±5	45±2	32±2

Table: 5.2.2B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)	113±9	90±8	95±8	150±9	94±9
Mn (ppb)	433±16	•	37±7	•	•
Cu (ppb)	•	•	14±2	58±3	56±3
Zn (ppb)	25±3	18±1	27±2	51±5	47±3

Table: 5.2.3A - Quality parameters of Ruiruaka waters sampled on 28th January, 1986

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^oC)	19.8	19.0	19.2	21.2	20.8
pH	7.2	7.2	7.1	6.0	6.1
Conductivity ($\mu S\,cm^{-1}$)	171	181	201	417	311
BOD (mg l^{-1})	9	6	53	2,700	337
COD (mg l^{-1})	66	36	130	6,522	750
D.S. (mg l^{-1})	245	282	350	1,692	525
S.S. (mg l^{-1})	48	6	88	2,762	375
Chloride (mg l^{-1})	16	15	29	80	32
Nitrates ($N\text{-}No_3$) (mg l^{-1})	0.52	0.50	0.72	0.51	0.50
Total Phosphates ($P\text{-}Po_4$) (mg l^{-1})	0.05	0.05	0.10	0.51	0.50

Table: 5.2.3B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	224±9	84±6	82±9	109±13	111±9
Cu (ppb)	28±3	11±2	12±2	77±5	64±3
Zn (ppb)	70±3	40±3	55±3	206±6	183
Pb (ppb)	*	*	*	20±2	*

Table: 5.2.3B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	171±12	28±6	137±13	386±15	311±17
Mn (ppb)	•	•	•	38±15	•
Cu (ppb)	14±2	15±2	11±2	55±5	40±5
Zn (ppb)	24±2	15±2	17±2	70±5	63
Pb (ppb)					

Table: 5.2.4A - Quality parameters of Ruiruaka waters sampled on 18th February, 1986.

SAMPLING POINTS

PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	19.4	19	20.2	22.1	21.9
pH	7.5	7.2	7.1	5.5	6.8
Conductivity (μs cm^{-1})	215	171	211	407	289
BOD (mg l^{-1})	8	4	114	2,220	296
COD (mg l^{-1})	56	32	320	4,037	686
D.S. (mg l^{-1})	548	266	536	1,160	450
S.S. (mg l^{-1})	41	11	98	860	290
Chloride (mg l^{-1})	18	18	27	21	11
Nitrates (N-No$_3$) (mg l^{-1})	0.30	0.40	0.50	0.64	0.30
Total Phosphates (P-Po$_4$) (mg l^{-1})	0.10	0.05	0.11	0.75	0.50

Table: 5.2.4B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	82±2	44±6	279±17	245±13	106±9
Cu (ppb)	12±2	17±2	18±3	71±3	46±3
Zn (ppb)	44±2	32±3	31±2	277±7	192±7
Pb (ppb)	*	*	*	21±2	*

Table: 5.2.4B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	228±17	*	158±12	579±29	362±27
Mn (ppb)					
Cu (ppb)	15±2	*	12±2	54±3	46±3
Zn (ppb)	23±2	24±2	24±2	70±5	69±5
Pb (ppb)	*	*	*	23±2	*

Table: 5.2.5A - Quality parameters of Ruiruaka waters sampled on 18th March, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	20.1	19.6	20.9	22.7	22.1
pH	7.2	7.4	7.1	6.3	6.5
Conductivity (μs cm^{-1})	201	189	217	289	241
BOD (mg l^{-1})	8	6	18	760	195
COD (mg l^{-1})	83	46	160	1,890	352
D.S. (mg l^{-1})	350	286	370	674	244
S.S. (mg l^{-1})	40	11	52	660	176
Chloride (mg l^{-1})	17	17	19	26	18
Nitrates (N-No$_3$) (mg l^{-1})	0.31	0.35	0.40	0.45	0.30
Total Phosphates (P-Po$_4$) (mg l^{-1})	0.01	0.05	0.05	0.64	0.41

Table: 5.2.5B

Soluble elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	214±15	124±9	189±13	313±17	242±20
Cu (ppb)	19±1	19±1	47±3	104±5	22±3
Zn (ppb)	55±1	31±2	111±3	471±12	310±3
Pb (ppb)	25±2	•	•	45±4	35±5

Table: 5.2.5B

Suspended matter elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)	*	*	33±9	597±42	195±27
Mn (ppb)	432±23	497±21	317±12	400±21	*
Cu (ppb)	22±3	22±3	17±3	169±7	81±6
Zn (ppb)	22±2	10±1	20±2	72±5	52±7
Pb (ppb)	21±1	104±5	*	*	22±1

Table: 5.2.6A - Quality parameters of Ruiruaka waters sampled on 22rd April, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	17.1	17.0	17.5	18.0	17.8
pH	6.7	7.0	6.9	6.5	6.9
Conductivity ($\mu s\,cm^{-1}$)	98	182	209	302	320
BOD (mg l^{-1})	14	12	12	34	20
COD (mg l^{-1})	53	31	43	74	34
D.S. (mg l^{-1})	104	164	140	176	107
S.S. (mg l^{-1})	76	46	64	72	46
Chloride (mg l^{-1})	10	11	15	16	15
Nitrates ($N\text{-}No_3$) (mg l^{-1})	1.62	1.00	0.87	0.81	0.81
Total Phosphates ($P\text{-}Po_4$) (mg l^{-1})	0.28	0.27	0.33	0.90	0.46

Table: 5.2.6B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	4,808±40	6,356±70	121±12	*	*
Cu (ppb)	10±2	10±2	*	72±3	12±2
Zn (ppb)	76±2	64±3	46±5	103±3	31±2
Pb (ppb)	*	*	30±3	*	*

Table: 5.2.6B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	Iv	V
Ti (ppb)	683±26	170±15	398±12	239±17	626±23
Mn (ppb)	53±30	*	*	*	51±21
Cu (ppb)	10±1	*	*	*	148±28
Zn (ppb)	22±3	*	*	*	22±3

Table: 5.2.7A - Quality parameters of Ruiruaka waters sampled on 20th May, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	17.4	17.1	17.5	18.1	17.9
pH	6.7	6.9	6.9	6.5	6.7
Conductivity ($\mu s\,cm^{-1}$)	105	162	175	235	227
BOD (mg l^{-1})	16	12	14	45	28
COD (mg l^{-1})	54	34	48	131	54
D.S. (mg l^{-1})	172	136	201	200	184
S.S. (mg l^{-1})	58	43	64	98	55
Chloride (mg l^{-1})	11	12	11	13	11
Nitrates (N-No_3) (mg l^{-1})	1.00	1.10	0.71	0.85	0.81
Total Phosphates (P-Po_4) (mg l^{-1})	0.27	0.29	0.41	0.01	1.00

Table: 5.2.7B

Soluble elemental concentration

ELEMENTS	SAMPLING POINTS I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	80±9	84±7	*	*	*
Cu (ppb)	*	*	*	28±5	10±2
Zn (ppb)	43±3	23±3	*	55±3	46±3
Pb (ppb)	25±2	25±2	*	*	*

Table: 5.2.7B

Suspended matter elemental concentration

SAMPLING POINTS

ELEMENTS	I	II	III	IV	V
Ti (ppb)	963±29	1,815±40	1,142±24	1,377±38	943±34
Mn (ppb)	74±28	228±66	901±55	115±42	133±45
Cu (ppb)	10±2	*	11±2	*	*
Zn (ppb)	32	66±3	63±3	40±3	32±3
Pb (ppb)	*	30±3	32±4	*	*

Table: 5.2.8A - Quality parameters of Ruiruaka waters sampled on 24th June, 1986.

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (°C)	20.0	19.7	20.6	22.9	21.7
pH	7.0	7.1	7.2	6.7	6.9
Conductivity ($\mu S\,cm^{-1}$)	140	138	141	311	189
BOD (mg l^{-1})	9	8	10	1,680	338
COD (mg l^{-1})	84	47	50	3,200	780
D.S. (mg l^{-1})	272	240	232	920	368
S.S. (mg l^{-1})	30	28	53	760	168
Chlorides (mg l^{-1})	13	15	17	26	15
Nitrates ($N\text{-}No_3$) (mg l^{-1})	1.00	1.96	1.02	0.78	0.65
Total Phosphates ($P\text{-}Po_4$) (mg l^{-1})	0.20	0.34	0.30	2.90	1.26

Table: 5.2.8B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	•	36±5	728±13	492±14	365±17
Cu (ppb)	12±1	10±1	19±2	155±5	68±5
Zn (ppb)	111±4	76±3	58±2	531±7	362±5

Table: 5.2.8B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)	*	*	23±9	156±10	346±21
Mn (ppb)	*	*	84±11	*	*
Cu (ppb)	*	16±2	16±2	52±7	43±6
Zn (ppb)	*	17±2	27±3	28±5	34±6
Pb (ppb)	*	*	*	21±4	*

Table: 5.2.9A - Quality parameters of Ruiruaka waters sampled on 22nd July, 1986

	SAMPLING POINTS				
PARAMETERS	I	II	III	IV	V
Temperature (^{o}C)	19.9	19.5	20.8	22.5	21.8
pH	7.4	7.6	7.5	5.9	6.2
Conductivity ($\mu S\,cm^{-1}$)	113	101	107	207	141
BOD (mg l^{-1})	6	4	38	1,136	245
COD (mg l^{-1})	42	30	106	2,686	595
D.S. (mg l^{-1})	349	214	264	704	176
S.S. (mg l^{-1})	41	4	36	540	72
Chlorides (mg l^{-1})	10	14	20	28	15
Nitrates (N-No_3) (mg l^{-1})	0.26	0.21	0.49	0.54	0.25
Total Phosphates (P-Po_4) (mg l^{-1})	0.15	0.15	0.30	2.25	1.51

Table: 5.2.9B

Soluble elemental concentration

	SAMPLING POINTS				
ELEMENTS	I	II	III	IV	V
Ti (ppb)					
Mn (ppb)	*	*	57±9	377±19	36±7
Cu (ppb)	*	*	*	28±4	23±2
Zn (ppb)	31±3	38±3	65±3	116±5	104±5

Table: 5.2.9B

Suspended matter elemental concentration

ELEMENTS	SAMPLING POINTS				
	I	II	III	IV	V
Ti (ppb)	231±18	98±14	400±12	380±19	*
Mn (ppb)					
Cu (ppb)	*	*	*	11±2	*
Zn (ppb)	*	*	*	19±4	28±3