

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

THE DEGRADATION OF THE
ABO-KEBENA RIVER IN
ADDIS ABABA, ETHIOPIA

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ABO-KEBENA RIVER IN
ADDIS ABABA, ETHIOPIA

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Abstract

A study of biological and chemical characteristics was conducted on the Abo-Kebena River, a tropical, high altitude mountain river, in the vicinity of the city of Addis Ababa, Ethiopia. The study was carried out over a one year period - July 1984 to August 1985. Observations were made at 20 stations which had similar features of depth, substrate and velocity. The 20 stations covered the stream over its course from one side of the city to the other. Though the mountain river was free of pollution and the upper part reasonably clean, water quality of the lower part of the river deteriorated significantly, particularly during the dry season. Deterioration of water quality caused by organic pollution from domestic and municipal wastes was exacerbated by low flows and low dilution during the dry season. The biological determination of water quality was made using macroinvertebrates as indicators. Throughout the study period, 18,934 organisms of 52 taxa were collected. The chironomids were very important constituents comprising 54% of the benthic macroinvertebrate community. They occurred at all stations throughout the study. The study demonstrated the effects of organic pollutants upon stream communities. Plecoptera, Ephemeroptera, Trichoptera, and Coleoptera were restricted to the clean upper part of the river and suppressed in the lower part by water quality conditions. Other taxa which dominated the polluted part of the river were the Diptera; Chironomidae and the Oligochaeta; Tubifex spp. Limnodrilus spp. and Nais spp. Among the ephemeropterans, Baetis harrisoni was ubiquitous throughout the drainage. Simulium spp. were also abundant in both the clean and the polluted part of the river. Although represented by small numbers, Limnophora larvae were found to resist heavy organic pollution in the Abo-Kebena River. There was significant seasonal variation (Students t-test) in abundance of macroinvertebrates. Almost all of the benthic fauna was found to be affected by flows. Their numbers declined during the wet season. The Orthocladinae, Cricotopus spp. were an exception to this. They were very abundant and dominated the fauna during the wet season. Nitrate - nitrogen, orthophosphate and BOD₅ increased progressively downstream indicating enrichment of the river. A clear seasonal variation in the nutrient level of the river was also noted. Higher concentrations of nutrients were recorded during the dry season than the wet season. The effects of organic pollution on the river were much more severe during the dry season when the stream flow was low. Possible sites of pollution have been identified. The present condition of Abo-Kebena River is compared with other degraded streams and rivers in Africa. It is found that organic pollution has much the same effects in Ethiopia as in other countries. Recommendations have been made based on the present data.

I. INTRODUCTION

Throughout the world rapid population growth, urbanization and industrial development have adversely affected the environment and pollution has reached alarming proportions. The economic development of a country and its resultant environmental degradation are usually directly related. However, environmental pollution in general commands a low priority in terms of national investment, especially in the developing countries.

One of the principal consequences of man's activities is water pollution and the consequent deterioration of the aquatic environment. Traditionally, towns and cities are located on the banks of rivers and streams or in close proximity to them. These water courses serve the needs of town dwellers for domestic water supply as well as waste disposal.

Until recently, the deterioration of water courses by pollution was not a serious problem because fairly small human populations lived in scattered communities and the wastes dumped into rivers were subject to dilution and natural self-purification.

As human populations multiply and industrialization increases and diversifies, the problem of water pollution becomes more critical. Industrialization leads to urbanization, with people leaving the land to work in the new factories. Domestic wastes from the rapidly expanding towns and wastes from industrial processes are poured into the nearest river or stream. Such activities not only affect the beneficial use of the water but they also upset the natural balances within the stream ecosystem.

A rational approach to the conservation of our water courses would be to understand the nature and the impact of activities which cause water pollution; when such understanding is gained about pollution, whether from single or multiple sources, measures of prevention or abatement can be taken.

Information on water pollution in the tropics, including high elevation

tropical areas such as Addis Ababa, is scarce or absent (Hynes, personal communication). Moreover, the knowledge of pollution of African rivers which we do have comes mainly from studies done in South Africa, a subtropical to temperate area. In view of this, water pollution investigations similar to those published about the temperate zone, is very much needed for polluted aquatic systems in tropical Africa.

The development of water pollution in the city of Addis Ababa follows patterns that are evident elsewhere. There has been a rapid population growth, which is expected to continue to the point where there will be two million people by the turn of the century. Domestic and municipal wastes are dumped untreated into rivers and streams because the sewage transport system in the city is underdeveloped. Furthermore, there is no sewage treatment plant in the city so raw sewage that is collected is only partly treated. A treatment plant is, however, underconstruction and in the future sewage will receive primary and secondary treatment before disposal.

Industry, likewise, is no better provided for, nor are data available on the quality and quantity of its discharges to the receiving water. Monitoring of industrial effluents even on an intermittent basis is lacking. Thus wastes of unknown quality and quantity are being discharged into the aquatic environment. Unfortunately, we have no information on the magnitude of the problem.

This thesis is an attempt to make some contribution to the understanding of urban pollution effects of a river in a high elevation area of tropical Africa. The thesis will present results based on biological and chemical investigations in the Abo-Kebena River which runs through the city of Addis Ababa. The Kebena River and its tributaries are clean above the city but the river becomes heavily polluted as it flows through it. The aim of this paper, therefore, is to show chemical changes along the system, in nitrate, orthophosphate, and BOD₅; and to relate these to changes to species composition and density of macroinvertebrates.

A study on water pollution such as this should properly begin with a definition of the term. Unfortunately such a definition is not easily

formulated. Wilber (1969) defines water pollution as any influence, whether physical or chemical, that affects the natural conditions or the intended use of water. Similarly, Nara (1980) defines a river or stream as polluted when its quality has deteriorated to such a level that it is no longer suitable for its intended purpose.

From the above definitions, it is clear that perceptions of water pollution depend primarily on the ultimate use to which the water in question is to be put. Water which might be considered unpolluted or satisfactory for certain recreational uses might very well be considered polluted or unsatisfactory for drinking purposes. Such definitions are therefore subjective and probably too broad to be useful.

These definitions reflect social or user values. They do not reflect the source of pollution nor do they, in themselves, quantify changes that have occurred in the aquatic systems. It is also possible that sources of pollution may be non-anthropogenic. For instance, rivers and streams flowing through deciduous woodlands as reported by Oliff and King (1964) may become deoxygenated because so much natural organic matter is deposited into them. This results in decomposition, which is similar to heavy contamination with raw man-made sewage. These conditions result in an impoverishment of the fauna. The leaves are pollutants to somebody wishing to catch a fish; though the ecologist would consider deoxygenation as a normal seasonal feature in the dynamics of such streams.

Natural pollution may also bring about consequences which are very similar to addition of waste effluent to water. Huet (cited in Hynes, 1960) has reported that small trout streams in the Belgian Ardennes are adversely affected by afforestation with spruce and red cedar. The invertebrates and trout disappear from the little head streams in which they normally spawn. A fisherman who used to catch fishes during times previous to the establishment of spruce and cedar may consider the stream as polluted.

There is no doubt, however, that at present the most serious pollution is the direct result of human activity, i.e. direct discharges of effluent into rivers and streams. Therefore definitions of pollution are often

restricted to include only the effects of substances or energy released by man himself, avoiding the consideration of naturally stressed environments (Edwards et al., from Mason, 1981).

The definition of pollution followed in the present work is that of Holdgate (from Mason, 1981): "The introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structure or amenity, or interference with legitimate uses of the environment".

Organic pollution results when large quantities of organic compounds, which can act as substrates for micro-organisms, are released into water courses. Organic pollutants consist of proteins, carbohydrates, fats and nucleic acids. The main sources of organic pollutants from human activities are domestic sewage, urban runoff, industrial effluent and farm wastes.

Sewage effluent is one of the greatest sources of the organic materials which enter lakes, streams and rivers. A large proportion of it is organic in nature, since domestic sewage is waste originating from toilets, wash basins and kitchens (Mc Kinney, 1962). Imhoff and Fair (1956) estimate the average organic content of domestic to be approximately 300 mg l⁻¹.

Unlike industrial wastes, the characteristics of domestic sewage are relatively constant. According to McKinney (1962) the domestic sewage from one residential area is approximately of the same composition as from any other residential area because of the habits of the people within the region or community. James (1966) commented that despite changes brought about by changing technologies as a result of modern civilization, domestic sewage are more constant than those from industry.

However, domestic sewage in large urban North American cities is mixed with some industrial sewage and with storm water. These add a vast array of organic and inorganic compounds. In addition, flushed medical materials, pills, urine with birth control elements and other wastes in North America add many compounds that may not be found in such quantity in an African country such as Ethiopia.

Despite the worldwide significance of the problem, emphasis given and measures being undertaken to conserve water courses from the dumping of domestic wastes are quite different in different parts of the world. It appears that the level of treatment of wastes depends at least in part on the economic development of a country.

In some industrialized countries, virtually all of the waste water originating in urban communities is subjected to some degree of treatment (Okun and Ponghis, 1975). According to Mason (1981), sewage treatment process in England and Wales remove 77% of the overall polluting load, measured in terms of BOD, and this compares favorably with other European countries.

In developing countries, however, the considerable investment that will have to be made to provide the service to urban communities is still in an early stage (Lohani, 1980). Hence the release of untreated sewage into waterways is still a major problem. The cost of providing a sewage treatment plant capable of producing a satisfactory effluent is enormous (Mason, 1981). He estimates 10 million pounds for a population of 100,000 in Britain.

Almost all industries produce and discharge wastewater from some stage in their process. Many of these discharges contain organic pollutants which could find their way into a river, either directly or through a treatment plant.

However, not all industries release waste containing organic pollutants. Most of the organic matter from industry comes from manufacturing process (McKinney, 1962). The industries producing effluent containing substantial amounts of organic wastes are food processing and brewing, dairy, meat processing, tanning, textile and pulp and paper making industries (Mason, 1981).

The quality and quantity of industrial wastes depend on the type and quality of the industry. Some industrial effluents contain large amounts of organic matter. For instance, the effluent generated in the manufacture

of sauerkraut has a very high biochemical oxygen demand. It may be as high as $41,000\text{mg l}^{-1}$ (FAO, 1978). According to Gecaga (1980), water used for pulping and washing in the coffee industry in Kenya in 1975 was estimated to have an organic load (expressed as BOD_5) equivalent to that from a population of 120 million people, which is 10 times the population of the country.

Industrial wastes differ from domestic wastes in that the former is the principal source of controllable water borne wastes. This characteristic makes it more simpler to monitor and control the amount of waste discharged to the external environment.

In cities and towns, the runoff from garages, factories, fuel stations, laundries, offices, houses, and roads can result in severe pollution. Even if such urban runoff is routed through sewage works, these become severely overloaded during storm conditions resulting in a lower quality effluent discharge than under normal operating conditions (Mason, 1981).

This paper has already stressed that urbanization has long been recognized as a significant factor affecting the quality of aquatic systems. A mechanism for this impact involves land use change which appears to increase hydrologic and nutrient loading to receiving waters by increasing the amount of impervious area. A second mechanism involves increase in the concentration of nutrients in runoff water (Watson et al., 1981). In the survey of the Jukskei River system, South Africa, it was recognized that indiscriminate discharge of laundry and dry cleaning effluent, coupled with highly polluting substances carried by storm water drains during heavy rain, from densely built up areas was considerable. The effect upon the chemistry of the river measured in terms of BOD_5 was clearly seen, measured and documented (Allanson, 1961).

Despite the sparse information available on this subject, one can imagine how difficult it is to control pollution caused from urban-runoff. Whipple et al. (from Pratt et al., 1981) suggest that although it is easier to control point-source pollution, urban and rural storm water run-off would remain a major obstacle since we know very little about them.

Farm effluents are a further source of organic pollutants to receiving waters. The liquor from badly cited dumps of farmyard manure can cause serious pollution, especially when it is washed into drainage ditches after periods of rain (Mason, 1981). This is evident from the work of Allanson (1961). He reports the seepage from a poorly designed and very badly controlled compost installation as having a deleterious effect upon the Jukskei River, South Africa. Similar observations were made recently by Lemly (1982) from a livestock pasture.

Today animal rearing has become the activity of many people living in cities and towns. Mellanby (1980) describes that an increasing proportion of cattle, pigs, poultry and even sheep are confined to cities and buildings where there is no arable land on which to use their manure. Thus much of the excreta has become a source of pollution rather than a valuable resource. He estimates the potential contribution of the cattle, sheep, pigs and poultry in 1977 in Britain to be more than three times that of the human population.

At present, modern farming practices aimed at conserving grass and other crops in the form of silage for use at home and during severe environmental conditions are expanding. Although it is an excellent practice nutritionally, silage produces an effluent rich in organic substances. For instance, the effluent released from silos in which grass and other fodder crops are partially fermented, can be 220 times as strong in terms of BOD₅ as settled sewage (Klein, cited in Mason, 1981).

Removal of oxygen is one of the most biologically significant impacts of organic matter on receiving water. Dissolved oxygen content is known to decline in streams below sewage outfalls (Blum, 1957).

Pettet (1959) has pointed out that most organic matter both natural and synthetic can serve as food for micro-organisms. When such wastes are discharged to a river, the organic matter they contain is attacked by naturally occurring micro-organisms with oxidation of the material at the expense of oxygen dissolved in the river water.

Low values of dissolved oxygen are usually associated with high organic matter. This is evident from the works of Oliff (1960b), Allanson (1961), Khalaf and McDonald (1975) and Kondrateiff et al. (1984). Oxidation of organic matter causes the concentration of oxygen to fall below saturation level. In extreme cases the oxygen concentration may fall to zero for some distance along the stream below the point of effluent input (Hynes, 1959b). The decline in oxygen level may be accompanied by production of sulfides and methane.

The breakdown of organic effluent by bacteria is a slow process, and the amount of dissolved oxygen in the river water falls gradually (Hynes, 1960). The degree of deoxygenation depends on a number of factors (Klein, cited in Mason, 1981), such as the dilution that occurs when the effluent mixes with the stream, the BOD of the discharge and the receiving water, the nature of the organic material, the total organic load in the river, temperature, the extent to which reaeration occurs from the atmosphere, the dissolved oxygen in the stream and the number and types of bacteria in the effluent.

Temperature has a twofold effect on the oxidation of organic matter. Venkateswarlu (1969) suggests that when a rise in temperature occurs in a stream polluted by organic matter, there is not only disappearance of dissolved oxygen due to lower solubility of oxygen at the higher temperature, but also an increased rate of utilization of the dissolved oxygen by biochemical reaction which proceed much faster at higher temperatures. At higher temperatures, fish and invertebrates require more oxygen, this contributes to the depletion of oxygen.

Another indirect effect of organic matter on the dissolved oxygen concentration of a stream is through the stream community. In conditions where nutrient enrichment enhances the productivity of a stream, the higher plant community together with benthic and periphyton population are responsible for increased utilization of oxygen which in turn decrease the dissolved oxygen content, particularly at night (Wong et al., 1979; Moore, 1978). This is evident from the work of Khalaf and McDonald (1975) where

oxygen depletion was observed in ponds which contained rich faunas, and this was attributed to respiration of the community.

Rivers polluted by oxidizable organic effluent undergo self-purification, which is manifested by an increased mineralization of the organic matter.

The process of mineralization, particularly of nitrogen and phosphorus containing compounds, is discussed by Hynes (1959b). When organic matter decomposes, ammonia and phosphates are released from it and, as oxidation proceeds, the ammonia is transformed first into nitrite and then into nitrate. The mineralization of carbonaceous compounds in a stream is reviewed by Dahm (1981).

Many investigators including Lenhard (1965) and Venkateswarlu (1969) have reported that organic pollution tends to increase the nitrate and phosphate content of a stream. Lemly (1982) in a recent report has made similar observations, i.e. that rivers with high organic matter are rich in nitrate and phosphate.

In undisturbed, free-flowing streams the nitrate and phosphate levels are usually low. In a river where inputs are absent not only are nutrient levels low, but also their concentrations tend to decrease downstream (Moraitou - Apostolopoulou and Ignatiades, 1980; Casey and Farr, 1982; Silsbee & Larson, 1982) .

The direct effect of organic pollution on the nutrient level of a stream has been studied by Blum (1957). He recorded low concentrations of phosphate and nitrate in unpolluted portions of a stream, but with the entry of effluent from sewage and run-off, they increased approximately tenfold and remained high for a distance of 500 meters. He also recorded with progressive destruction of organic matter and the oxidation of ammonia and nitrites that nitrates slowly increased in quantity in the lower course of the stream.

Therefore, nitrate and phosphate concentrations along a stream are widely used in the determination of water pollution. They also give a clue as to

whether purification of the river takes place after a discharge of an effluent to the stream or a river.

Macroinvertebrates are among the stream biota which are affected by organic pollution in one way or another. There has been a great deal of work on the effects of organic pollution on macroinvertebrate communities in streams and rivers e.g. Maciorowski et al., 1977; Mohammed, 1980; Bronmark et al., 1984; Freeman and Wallace, 1984.

Pollution produces changes in the pattern of species distribution. Godfrey (1978) describes the impact of organic pollution as a reduction in the number of species and an accompanying increase in total abundance. Hynes (1960) comments that heavy pollution affects whole taxonomic groups of macroinvertebrates rather than individual species. Specific differences only become important in cases of mild pollution.

Several workers, after investigating the effect of organic pollution on the receiving streams or rivers, have reported that polluted rivers are characterized by higher density and lower diversity of macroinvertebrates than are unpolluted waters (Langford and Bray, 1969; Hendricks et al., 1974; Sala et al., 1977; Sinton, 1984). In his extensive survey of the Little Bushmans River, South Africa, Oliff (1960b) reported that the density of individuals was relatively low at stations in the unpolluted part of the river, and the number of different species was relatively high; while in the polluted part of the stream the opposite occurred. He recorded 6,241 individuals belonging to 45 different species from the unpolluted part of the river, whereas in the heavily polluted station, there were 27,738 individuals of 19 different species in his samples.

Macroinvertebrates display a longitudinal succession below a sewage outfall in response to the adverse conditions. Where the concentration of organic matter is high enough to produce total deoxygenation no normal river animals survive, but they may be replaced by the larvae of the moth fly Psychoda and the bee-fly Eristalis (Hynes, 1960). These larvae are both air breathers.

In heavily polluted waters, tubificid worms are frequently very abundant. Whitley (1968) noted the association of tubificid worms such as Tubifex and Limnodrilus hoffmeisteri with organically polluted environments. The presence of large number of worms on beds of stones or gravel from which they are normally absent or rare because they are mud dwellers, probably occur for two reasons (Brinkhurst, 1965). In the first instance the stones receive a fine layer of silt, which settles out from the suspended solids entering the river with each effluent. The second reason and the one of greater significance may be that the slimy coating of bacteria on the stones, growing readily in the nutritous environment, forms an ample and required food supply for the worms.

Change in riverine habitat is another effect of organic pollution which in turn affects the river fauna. Hynes (1960) comments that in polluted streams, where normally the amount of dissolved oxygen may be high because of good aeration and turbulent flow, the usual bottom organisms of eroding substrata, are absent because settled solids make conditions unsuitable for them. This certainly interferes with their holdfast mechanisms, which depend on the presence of smooth clean surfaces. Harrison and Elsworth (1958) also suggest that thick algal growth on stones may inhibit some clinging Baetidae and other forms.

In general, it can be stated that, there is always a change in the composition and density of the fauna when conditions are changed from the normal situation to that where the river or stream receives organic matter. The succession of macroinvertebrate communities in response to discharge of organic effluent to a river will be discussed later (4.2).

Organic pollution carries in organisms harmful to human health. The possible means of human exposure are through swimming, drinking or eating food such as vegetables irrigated by, or fish obtained from, polluted waters (Bachmann, 1980).

There are several pathogenic organisms which are commonly found in sewage. The most common of these have been listed by Hawkes (1971) as Vibrio, Salmonella, Shigella, Bacillus, Mycobacterium, and Entamoeba histolytica.

In addition to the diseases caused by these organisms, polluted water may spread poliomyelitis, hepatitis and parasitic worms, such as Ascaris and other round worms.

These organisms are highly infective and are responsible for many thousands of deaths each year. These dangers are far greater in developing countries than in industrialized ones because of the greater prevalence of disease organisms and the greater likelihood that people drink contaminated water (Bachmann, 1980).

A dramatic example of this is the spread of cholera (Vibrio cholera) through the tropics from south east Asia in 1961 to central Africa decade later (Mara, 1980). According to Arunga (1970), the 1970 outbreaks of cholera in Western Kenya were attributed to pollution of rivers in this area, e.g. Nyando River and its tributaries.

A water supply with a high nitrate level present yet another potential health risk. According to Mason (1981) infants under six months of age may develop methemoglobinemia, a disease involving nitrate which reduces the oxygen carrying capacity of the blood. The ailment usually occurs when the water may become critical on boiling and, furthermore, cow's milk itself may be the cause when the water drunk by the cow contains a high content of nitrate (Skeat, 1961).

The determination of water quality has gained considerable attention in recent times. There is an increasing need for a simple, rapid and reliable method of assessing the degree of purity or contamination of water. Although chemical methods have been used more widely than biological ones, the latter possess certain advantages not shared by the former (Harrison, 1960; Hynes, 1959a; 1960, Chandler, 1970; Cook, 1976).

Biological monitoring is a means of continuously assessing the quality of water and waste water using living organisms as indicators (Gruber and Cairns Jr, 1981). According to Economou-Amilli (1980), biological evaluations of water quality are rapid and give rough estimation of degree of pollution without the necessity of an accompanying chemical

investigation. The communities found also provide insight into lasting effects. Bass and Harrel (1981) also point out that physico-chemical data indicate water quality at the time of sampling, while biological data reflect both present and past conditions.

Hynes (1960) in his extensive review discusses the advantages of biological methods over chemical ones of assessing water quality. They take less time, because a single series of samples reveals the state of the animal and plant communities, which themselves represent the results of a summation of the prevailing conditions. The chemist has to make a long series of observations in order to obtain an average value, and even then his samples may all happen to be collected at times other than those of extreme conditions, which are often the most important. Furthermore he suggests that biological investigation shows up the effects of intermittent pollution or the result of a single discharge of a poisonous substance, which the chemist may miss altogether and it enables the investigator to pin point the source of the trouble.

However, the biological methods suffer from some shortcomings. Mason (1981) quoting others, states that the ecology and sensitivity to pollution of many of the organisms used in water quality assessments is still very inadequately known. Moreover, the key organisms in the fauna or flora of one particular watershed may be insignificant in another watershed with different geological conditions or flow regime. In addition different types of organic pollution produce slightly different effects, thus producing different ecological conditions in a river (Hynes, 1959a).

Another problem encountered in biological assessment of water pollution is communication of findings. According to Mason (1981), a biologist in the water industry has the task of explaining his findings to managers, who are usually not biologists. In order to be able to explain his findings, the biologist frequently resorts to deriving indices of water quality, i.e. single numbers which may help in communication but which result in a considerable loss of biological information. Moreover, biological study can reveal only the general type of the pollution; it does not indicate the exact substance involved (Bick, 1963). It remains for chemical methods to

identify the particular poison or condition which is causing damage.

Despite the many difficulties, biological assessment of water quality has proven successful and even low levels of intermittent pollution, frequently missed by routine chemical sampling, have been detected (Mason, 1981). Hynes (1965), stressing the value of biological methods in water quality studies, states that there is no type of pollution that would make water unsuitable for industrial, domestic, agricultural, or fishery purposes without having some detectable effects on the fauna and flora.

The previous sections have given evidence that environmental disturbances such as pollution induce changes in the structure and function of biological systems in natural waters.

As a result many investigators (e.g. Balloch et al., 1976; Cushman, 1984; Waterhouse and Farrel, 1985; Pinder et al., 1987) have attempted to judge the degree and severity of pollution by analyzing changes in the biological systems. Although biological changes occur at all levels of organization from the molecular to the community level, the early use of biological indicators involved using species composition as an index of pollution (Whitton, 1975).

The major groups of organisms that have been used as biological indicators are: algae (Hancock, 1973; Armitage, 1980; Gray and Ward, 1982), bacteria (Dresscher and van der Mark; 1976; Bass and Harrel 1981), protozoa (Nuland and Meis, 1980; Sladeck, 1981), macroinvertebrates (Mills et al., 1981; Holdich and Tolba, 1981; Harrel, 1985; Victor and Ogbeibu, 1986) and fish (Cairns et al., 1973; Birrell et al., 1993).

Early studies concentrated on micro-organisms, which are difficult to identify and usually have to be examined alive. Therefore, they are subject to very rapid changes in population density (Brinkhurst, 1965). Furthermore they require good laboratory facilities (Bick, 1963). However, for severe organic pollution, given that one has suitable laboratory facilities near at hand, micro-organisms are useful (Hynes, 1960), but for indicator organisms to be useful, they must help in the detection of

subtle, rather than gross and obvious, effects of pollution (Mason, 1981).

Benthic algae have frequently been used to demonstrate the effects of pollution. Among algae, diatoms have been used commonly for various reasons. Fjerdingstad (1964) stresses the use of diatoms which do not suffer from the disadvantages of other small organisms. Stevenson (1984) recently evaluated the hypothesis, that changes in species diversity of diatoms can be used as an indicator of changes in water quality. However, it is risky to confine a study to just one group of organisms when dealing with a whole range of pollutants. (Hynes, 1965).

In recent years macrophytes have been used in the assessment of water quality. Vrhovsek et al. (1981) discusses the advantage of using macrophytes. Macrophytes are immobile, i.e., they are permanently and directly exposed to pollutants. The advantage of working with them lies in the fact that most of their species can be determined on the field. The composition and abundance of macrophytes thereby gives an immediate and rough estimation of the extent of water pollution. However, Wiegleb (1981) noted different drainage areas showing a very different composition of the macrophyte vegetation. Similarly, Mason (1981), quoting others, states that macrophytes are strongly influenced by geology, soil type and management practices.

Use of fish faunas in situ have gained little attention in their uses as indicator of pollution for various reasons. They are too motile and they can potentially avoid pollution incidents or they can move in and out of polluted zone as conditions fluctuate (Chandler, 1970; Mason, 1981). In addition they are difficult to sample (Brinkhurst, 1965).

The most convenient organisms for the study are the bottom dwelling invertebrates. Macroinvertebrates are easily caught, inhabit the whole spectrum of aquatic habitats under all conditions of water quality, and are not very mobile when subjected to adverse changes (Chandler, 1970).

From my assessment of literature and discussions it is evident that the macroinvertebrate fauna of a stream is the best first line of evaluation of

water quality change, particularly where organic pollution is involved. This does not detract from the view that any ideal surveillance system may involve different kinds of biological monitoring and careful chemical analysis of water.

Analysis of community structure of benthic macroinvertebrates have been used more frequently to evaluate water quality in aquatic ecosystems than any other method. There are several reasons why macroinvertebrate community structure has been used for this purpose.

When conditions become adverse, the invertebrates of running water are unable to travel far or fast, and are thus subjected to the full rigours of local conditions at all times. Fishes on the other hand are motile and can move out of a polluted stretch of river. Hynes (1959a) concludes that because of this difference, macroinvertebrates are better indicators of pollution. They may in fact indicate the worst extreme conditions. Cook (1976) also comments that macroinvertebrates are differentially sensitive to pollutants of various types and react to them immediately.

Moreover, macroinvertebrates have several advantages over others. Hellowell (1977) lists a number of reasons for preferring benthic macroinvertebrates. The sampling procedures are relatively well developed, they can be operated by someone working alone, and there are identification keys for most groups. Macroinvertebrates are reasonably sedentary, with comparatively long lives, so that they can be used to assess water quality at a single site over a long period of time.

Many studies have been carried out in an attempt to develop biological criteria for evaluating the importance and degree of organic pollution. Oliff (1960b) suggests that the communities associated with different types and grades of organic pollution can be arranged in a series grading from those of light, to those of heavy pollution.

A summary of the invertebrate taxa associated with different degrees of organic enrichment has been given by Wilber (1969). Accordingly, in heavily polluted areas the aquatic animal consists almost entirely of

tubificid worms with occasional naidid worms and particular chironomid larvae. In areas that are less polluted, mollusks, are found. As the pollution becomes less severe, caddis-flies and numerous other organisms thrive. Finally in the clean waters, mayfly and stonefly larvae are found.

The idea of the ecological aspect of aquatic organisms as indicators of the purity or pollution of a water body appeared in the system of saprobic organisms by Kolkwitz and Marsson (cited in Sladeczek, 1965). In his review of biological methods of determining water quality, Bick (1963) explains that a slow and evenly flowing stream or river shows distinct zone of decreasing pollution. These zones are termed polysaprobic, (gross pollution), alphamesosaprobic, betamesosaprobic, and oligosaprobic. Their sequence reflects the process of self-purification. Biologically each zone affords optimal conditions for certain species and communities of organisms, so called indicator-organisms.

In general, those organisms associated with the silted regions of rivers are the most tolerant of organic pollution, while species associated with eroding substrata and swiftly flowing water are the most sensitive (Maciorowski et al., 1977).

Among invertebrates, oligochaetes are good indicators of pollution. Tubificidae such as Limnodrilus hoffmeisteri, Tubifex tubifex, T. barbatus, Limnodrilus udekemianus and L. profundicola, are very characteristic of environments that contain abundant organic matter (Sala et al., 1977; Marshall and Winterbourn, 1979; Lafont, 1984; Paoletti and Sambugar, 1984).

The success of tubificids in these environments is due to their ability to respire at very low oxygen tensions for a long time (Fisher and Beeton, 1975). For instance, Tubifex barbatus is able to live in oxygen-free water for one month (Berg and Jonasson, 1965). Investigations on the respiratory physiology of some tubificid species by Berg et al. (1962) showed that there is very little difference between tubificids in respect of their ability to take up oxygen at low oxygen concentrations.

As the water below a discharge of organic material becomes more oxygenated,

tubificid decrease in abundance and are replaced by the red larvae of Chironomus (Harrison, 1958b). As conditions improve further downstream and one passes to the region of higher oxygen content and reduced suspended solids, more and more species appear. The importance of chironomids declines, organisms such as Asellus in Europe, become abundant (Butcher, 1955). In this European, Asellus zone other dominant organisms include mollusks and leeches (Hynes, 1960).

As the self-purification process continues, other species of invertebrates appear in the community. In Europe and North America Gammarus, the fresh water shrimp is known to withstand a fair degree of siltation or organic pollution provided the dissolved oxygen level of the water is high (Chandler, 1970). Net-spinning caddis larvae are often increased in abundance by slight sewage pollution (Hynes, 1959a; Godfrey, 1977).

The species most sensitive to organic pollution are the stoneflies (Plecoptera) and to a lesser extent the mayflies (Ephemeroptera), which are often absent at mild levels of pollution (Mason, 1981). Wilhm (1975) also suggest that the presence or absence of mayflies in otherwise suitable habitats reflects the quality of the water which flows over them.

However, it is important to note that there are differing degrees of sensitivity among the Plecoptera and Ephemeroptera to organic pollution. For instance in Europe Amphinemura sulcicollis is more tolerant than other stoneflies and Caenis horaria and Baetis rhodani are more tolerant than other mayflies (Hynes, 1960). Harrison (1958b) also reports the persistence of Baetis harrisoni in organically polluted rivers in South Africa.

In general different communities of invertebrates show different resistance to organic pollution and each organism thrives best under a narrow range of environmental conditions. Therefore the invertebrates living in a stream show the integrated effect of water quality over the whole of their life history so that by taking biological samples it is possible to assess the condition of a stream over the previous times.

II. DESCRIPTION OF THE STUDY AREA

The Abo stream (Fig. 1) is a 4th order, tropical ($9^{\circ}.03'N$, $38^{\circ}.42'E$), high altitude (2600m), mountain stream, a tributary of the Kebena River which flows into the Akaki River. The latter is an important tributary of the Awash River.

The source of the stream is on the Entoto Mountain, North East of the city of Addis Ababa. After joining the Kebena River, this river flows southward through the city. The upper part of the drainage of the stream has a moderately steep gradient, whereas the lower part is less steep.

Although it has extended dry seasons the area is reasonably well watered, the average annual rainfall is 1160.9mm (Ethiopia, Statistical Abstract, 1984). The main rainy season extends from mid June to early September, and the dry season extends from October to early June. These correspond with summer and winter respectively. However, the little rains, which are short lived and less intense are experienced in March and April.

The upper part of the stream basin contains scattered villages along with agricultural land. The stream banks are covered with vegetation. Although tall trees are absent, there are clear indications that not long ago, the stream used to flow in heavily forested areas. This is evident from the remains of scattered trees and thick thornbushes present around its banks. The lower part of the stream catchment area contains a heavily settled urban district. It is devoid of any stream bed vegetation and its banks are bare.

Near its origin the stream is clean and clear but as it passes through the city the water becomes dark and acquires a strong offensive odour. Lower tributaries of the Kebena River come through the centre of the city of Addis Ababa and are loaded with organic wastes from houses, garages, offices, hospitals, laundries, and other municipal effluents.

The Abo-Kebena is fast flowing, rocky and gravel bottomed river which is normally shallow, but is subject to flash floods which produce very turbid

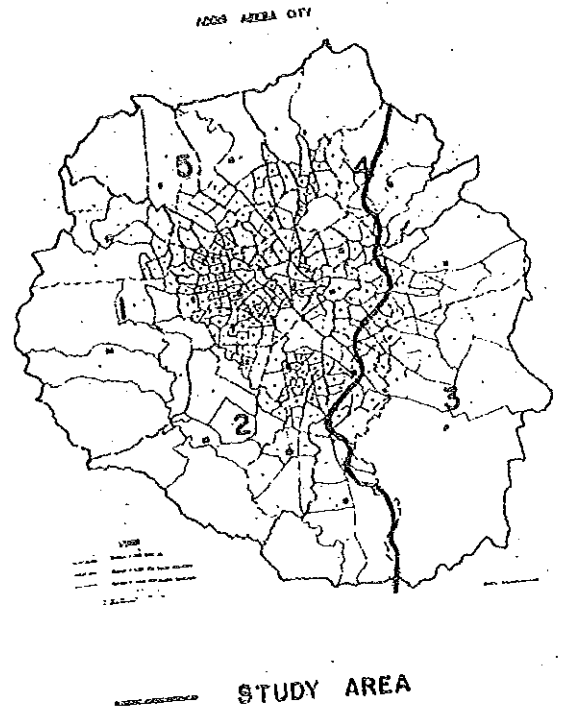
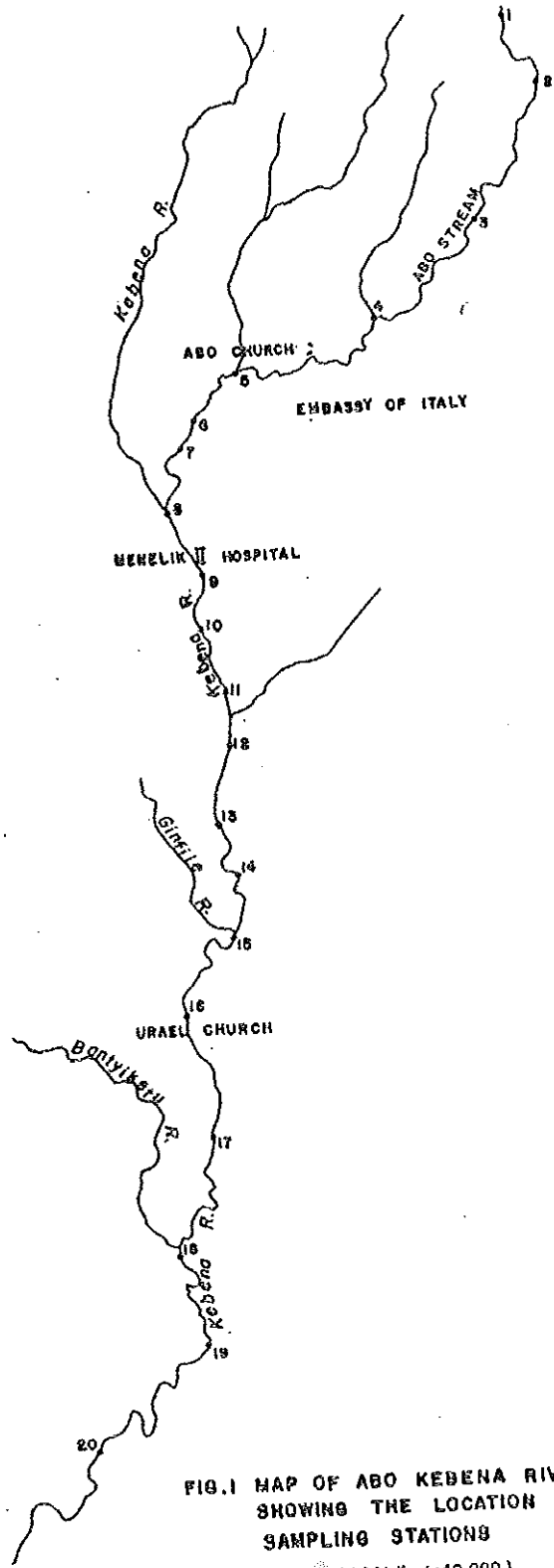


FIG.1 MAP OF ABO KEBENA RIVER
SHOWING THE LOCATION OF
SAMPLING STATIONS
(SCALE 1:40,000)

and torrential conditions during the wet season. Unquantified visual information indicates that flows in the wet season were four times higher than in the dry season, and the stream was more turbid or sediment laden in the wet season. Stream flow was very low during the dry season. Many small tributary streams ceased to flow during the dry season.

The 20 stations on the Abo-Kebena River cover a distance of 13.6km. The mean distance between stations is 680m. The positions of the stations were selected to enable comparisons of stream insect communities in polluted and unpolluted areas. Stations 1-4 are located upstreams of all known sources of urban and industrial pollution. All other stations are located in areas which are slightly to heavily polluted from domestic and municipal sources.

All the stations were visited for biological and chemical samples from July, 1984 to August 1985.

III. MATERIALS AND METHODS

1. Site Selection

Twenty stations were selected by inspection. Each was visited twice for physical, chemical and biological samples.

The criteria used in the selection of stations were stream depth, velocity and substrate. The stations selected had shallow water, (depths ranging from 20cm to 50cm) fast flowing current and a stream bed of rock and gravel which could be easily moved by a single operator. Accessibility and possible sites of organic inputs, such as bridges and confluences with other streams or rivers, were also considered.

2. Temperature

Field temperature measurements were taken with a mercury thermometer placed directly in the stream water from 10 - 11 a.m.

3. Water Quality Measurements

3.1. Sample collection

Water samples were collected in plastic bottles, from each station. These were brought to the laboratory for analysis of nitrate-nitrogen, orthophosphate and 5-day biochemical oxygen demand (BOD₅).

3.2. Methods of determination

In the laboratory nitrate-nitrogen concentration was measured colorimetrically by diazotization with sulphanilamide and by azo compound formation with N-(1-naphthyl - ethylene diamine di-HCl), and orthophosphate was measured colorimetrically using the stannous chloride method (Golterman et al., 1978).

Biochemical oxygen demand was measured using a Hach Manometric BOD meter which was kept at 20°C for 5 days in the dark (Hach Company, Amsterdam). The water samples were aerated before being transferred to the BOD bottles. To avoid errors introduced by carbon-dioxide evolution, a CO₂ absorbent (potassium hydroxide pellets) was used. Samples were diluted whenever necessary.

4. Faunal Sampling

4.1. Collection and Preservation

The fauna was sampled as described by Hellowell (1985). Macroinvertebrate samples were collected using a hand net (a mesh size of 0.2mm) with a triangular wire frame (approximately 25 cm) attached to a wooden handle, which was the size of a broom handle.

The net was held vertically facing upstream with the bottom

against the substratum. The substratum immediately upstream of the net was then vigorously disturbed with the feet and hands so that the dislodged invertebrates would be carried into the net by the current. Individual stones were also picked up and then scraped to dislodge attached animals. Sampling of animals was done for 30 minutes at each station. The net sample was transferred to plastic bags or jars and then 40% formaldehyde was added to preserve them for further examination in the laboratory.

4.2. Sorting

In the laboratory, samples were transferred into a conical net in a stand of the same mesh as used in collecting and the samples were washed by a spray of water. The fine silt was washed through the net.

The washed sample was then transferred to a white enamel dish half

filled with water. Large leaves, stones and obscuring detritus were then removed to make picking of animals easier. The macroinvertebrates were picked out with forceps and placed in a counting chamber for identification and enumeration.

4.3. Identification

The macroinvertebrates were identified under a dissecting microscope, to the generic, or wherever possible, the species

level. The Ephemeroptera and Chironomidae were identified by Prof. Harrison and Plecoptera were identified by Prof. Hynes, using African literature. Taxonomic works used in identification also include Ward and Whipple (1959), Freeman and De Meillon (1953), Pennak (1953), Freeman (1955,1956,1957,1958) and Wiederholm (1983).

Some of the larvae of insects were difficult to identify. Hence water samples containing live macroinvertebrates were brought back to the laboratory. The larvae were bred out in a trough containing stones and gravel similar to that of the natural habitat of the macroinvertebrates. Air was supplied with an air pump. Emerging adults were retained in a cage built of polyethene which was placed over the trough. A number of Chironomidae were bred out in the laboratory from samples taken in characteristic habitats.

5. Algal Samples

Stones were picked from the areas where faunal samples were taken. The stones were scraped and the scrapings were placed in vials containing water. Formaldehyde, 40%, was added to preserve the sample.

In the laboratory, each sample was mixed, mounted on a slide and identified under a compound microscope. Identification was done to the generic level. Taxonomic works used in the identification of algae were Needham and Needham (1958), Palmer et al. (1955) and Ward and Whipple

(1959).

6. Treatment of data

The macroinvertebrate data, for the dry and wet seasons, was analyzed using Students t-test (Elhance, 1976) to determine if there were significant seasonal differences in abundance of organisms. Graphs and tables were also used to summarize the results.

The diversity of faunal samples from along the river was assessed by use of the Chandler Biotic Score (CBS), (Chandler, 1970). The score for each indicator organism was determined by comparing its abundance to five levels of abundance given by the index. The total score of all species collected from one station was then computed to obtain the score for each station.

IV. RESULTS

1. Temperature

The stream temperature was fairly uniform throughout the year. The difference in average temperature between wet and dry season was very small, differing by about only 0.6°C. The highest temperature recorded was 17.5°C at station 20 (Fig. 3) and the lowest temperature was 13°C at station 3 (Fig. 2)

Water temperatures during the wet season were slightly higher than the dry season for each station. Temperature increased by about 3°C from head waters to 14km downstream in the dry season, and about 2.5°C in the same distance in the wet season. The dry season temperature increased irregularly from 13.5°C to 15°C in the first 6km of the stream (Fig. 2). The wet season temperature was uniform in the first 6km of the stream and a greater increase occurred in the lower 7.5km (Fig. 3).

2. Chemical

2.1. Nitrate-nitrogen

In the Abo-Kebena River, nitrate-nitrogen concentrations ranged from 0.3 to 14.8 mg l⁻¹. Lower values of nitrate were recorded during the wet season than during the dry season in most of the stations. However, in the upper part of the river wet season values were greater than dry season values (Figs. 4 and 5).

Nitrate concentrations were low in the upper part of the river for the first 4.5 km. After 4.5km there was a progressive increase downstream for a distance of 9.5 km (Fig. 4). Sharp increases of nitrate concentrations were recorded between some stations during the dry season whereas increases during the wet season were steady and uniform (Fig. 5).

Higher increases of nitrate-nitrogen occurred at stations 7,9,11,16

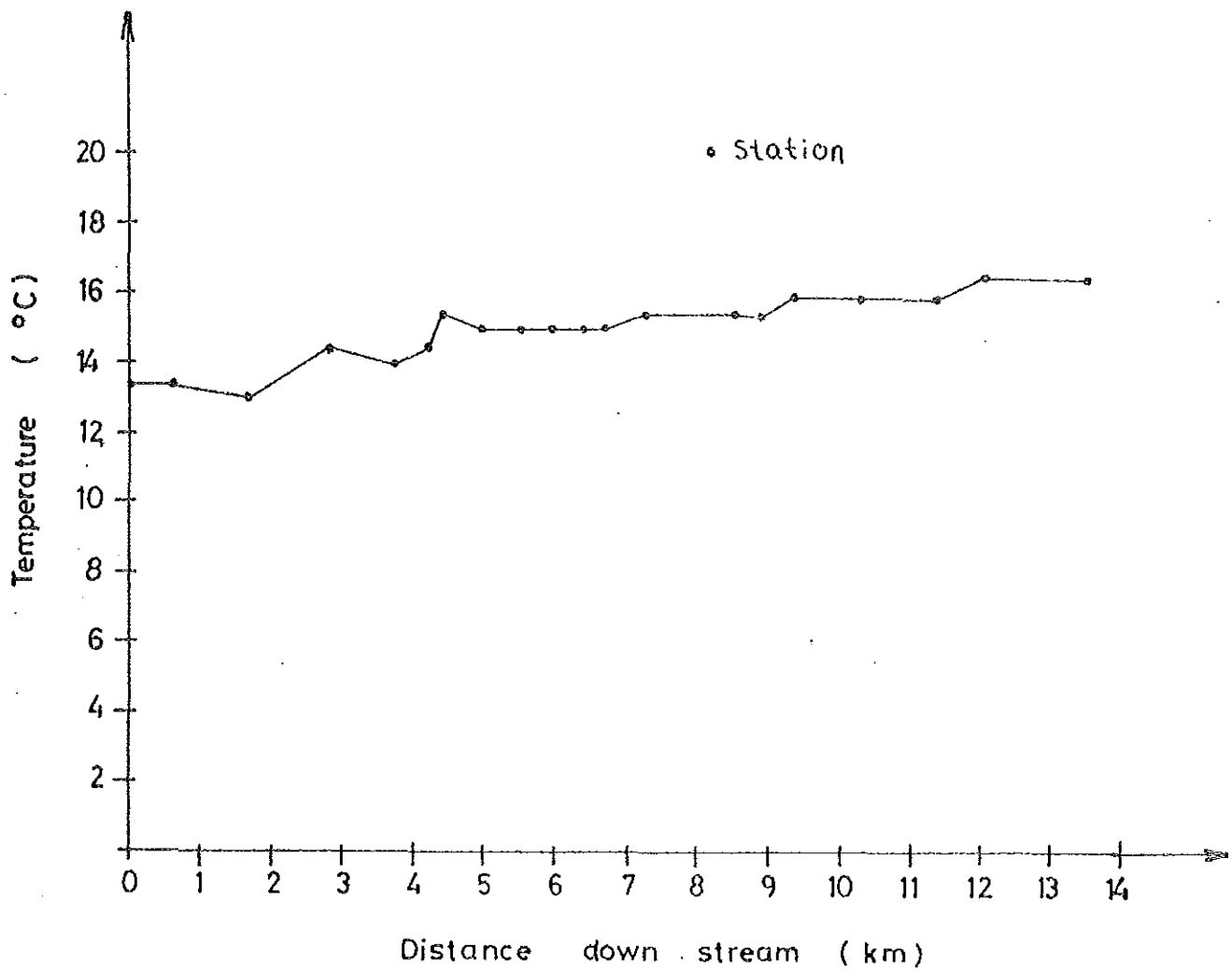


Fig. 2. Temperature of Abo-Kebena R.
(dry season)

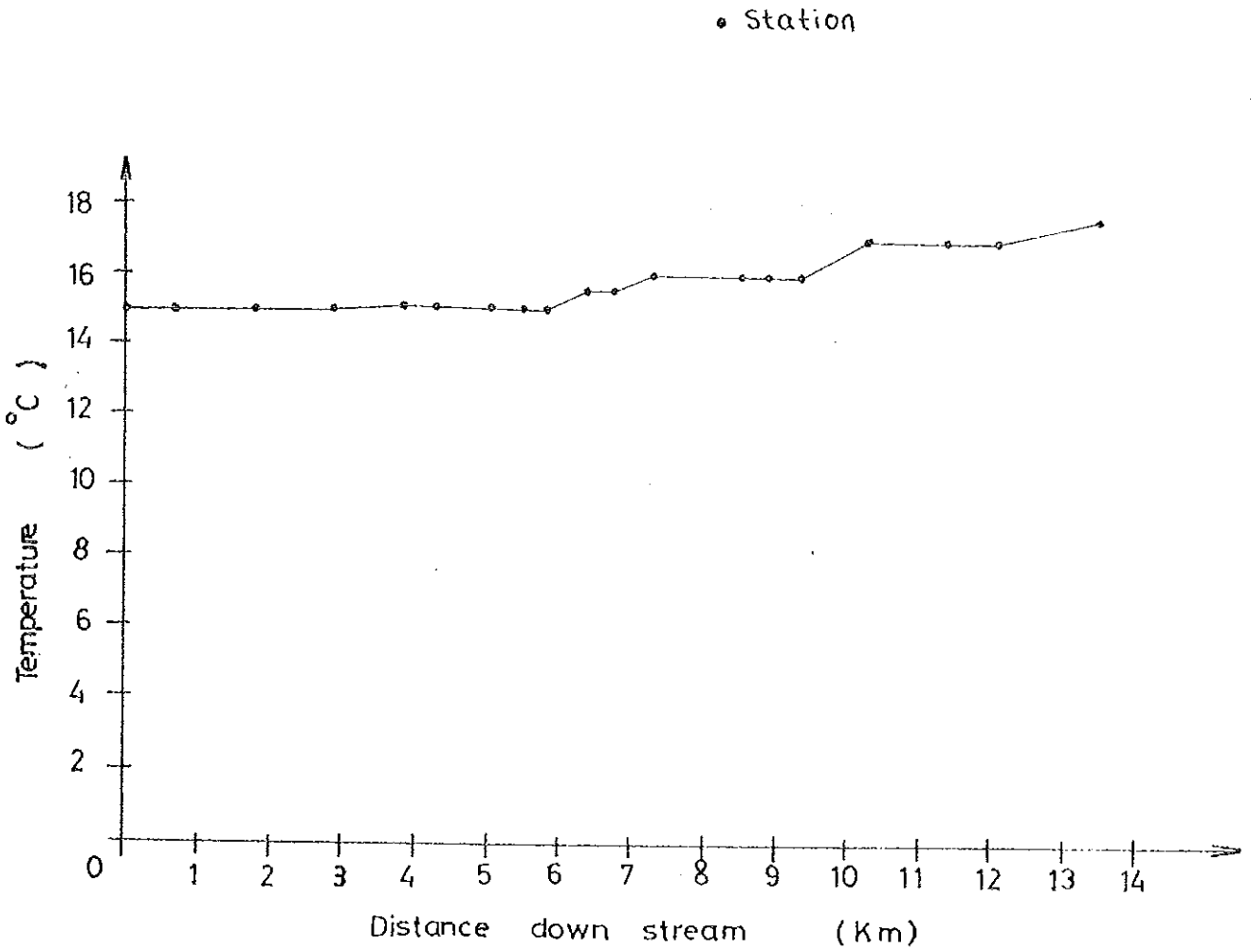


Fig 3 Temperature of Abo-Kebena R.
(wet season)

and 18. A decline in value was recorded at station 8, where Kebena River joins Abo stream, and also at station 14.

2.2. Orthophosphate

The phosphate levels in the Abo-Kebena River ranged from 0.01 mg l⁻¹ to 5.34 mg l⁻¹ (Table 1). Higher values of phosphate were recorded during the dry season than during the wet season except in the upper stations.

In the upper part of the river, phosphate concentrations were very low, below 0.1 mg l⁻¹. In the middle and lower stations, concentrations increased rapidly, reaching a maximum value of 5.34 mg l⁻¹ at the last station (Fig. 4). Sharp increases of phosphate levels were recorded at stations 7,9,11,16 and 18 and decline of values were recorded at 2 stations, namely, station 8 and station 14.

2.3. Biochemical oxygen demand (BOD₅)

The 5 day biochemical oxygen demand (BOD) of the Abo-Kebena River ranged from 0 to 64.5 mg l⁻¹ (Fig. 6). A clear seasonal variation was seen in the levels of BOD. Higher values were recorded during the dry season and lower values during the wet season except at the top 4 stations (Fig.6).

Low values were recorded at the upper part of the river from stations 1 to 5. Below station 5, there was steady and rapid increase in BOD and values reached a maximum of 64.5 mg l⁻¹ at station 20 during the dry season. Sharp increases in BOD occurred at stations 7,9,11,16 and 18. Small decreases of values were recorded at stations 8 and 14.

Most of the streams joining the Abo-Kebena River had no diluting effect, because they did not cause a reduction in the nutrient level below their point of entry to the river. The only exception

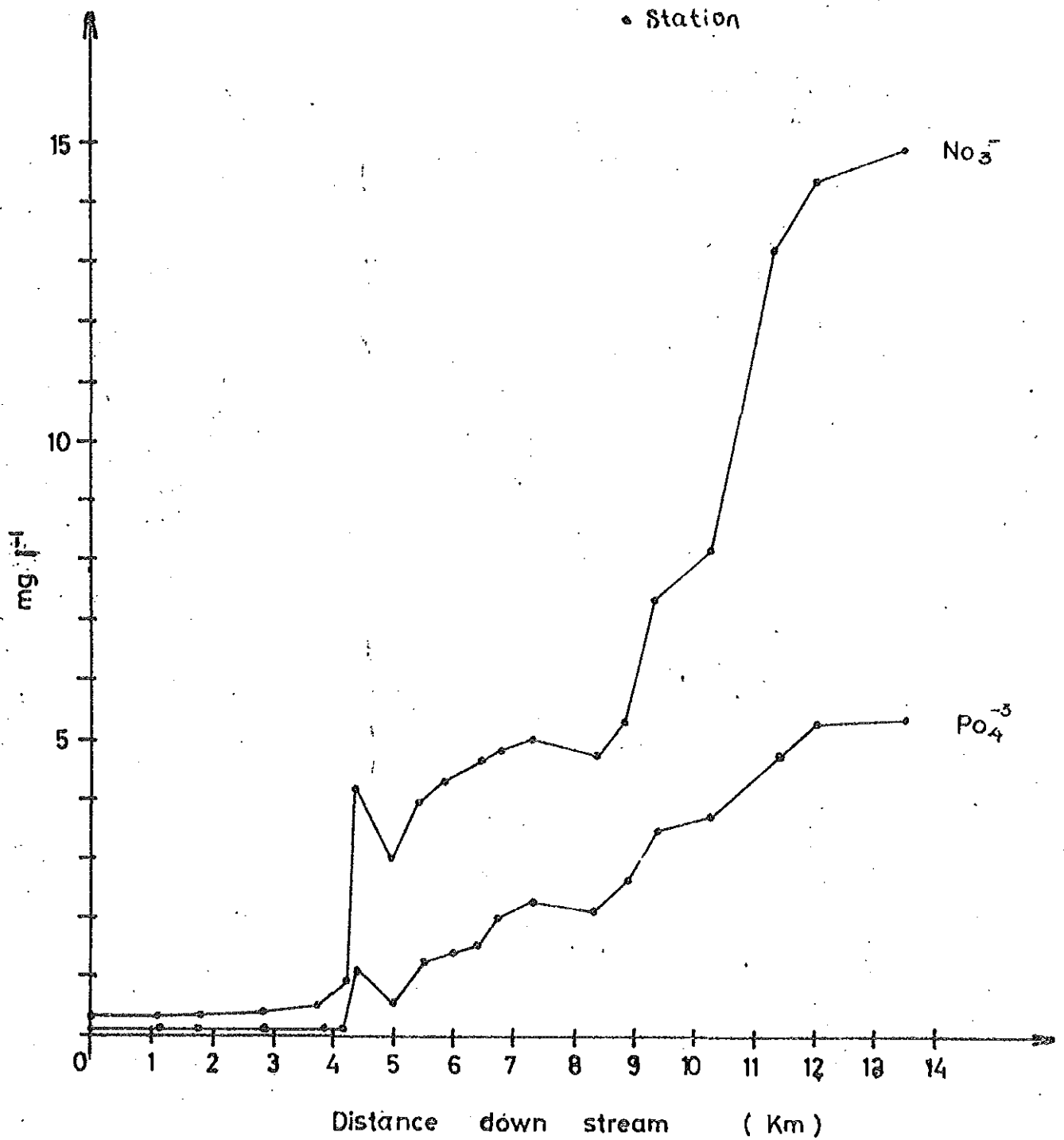


Fig 4 Nutrient level of Abo-Kebena R. as it flows through Addis Abeba (Dry season)

• Station

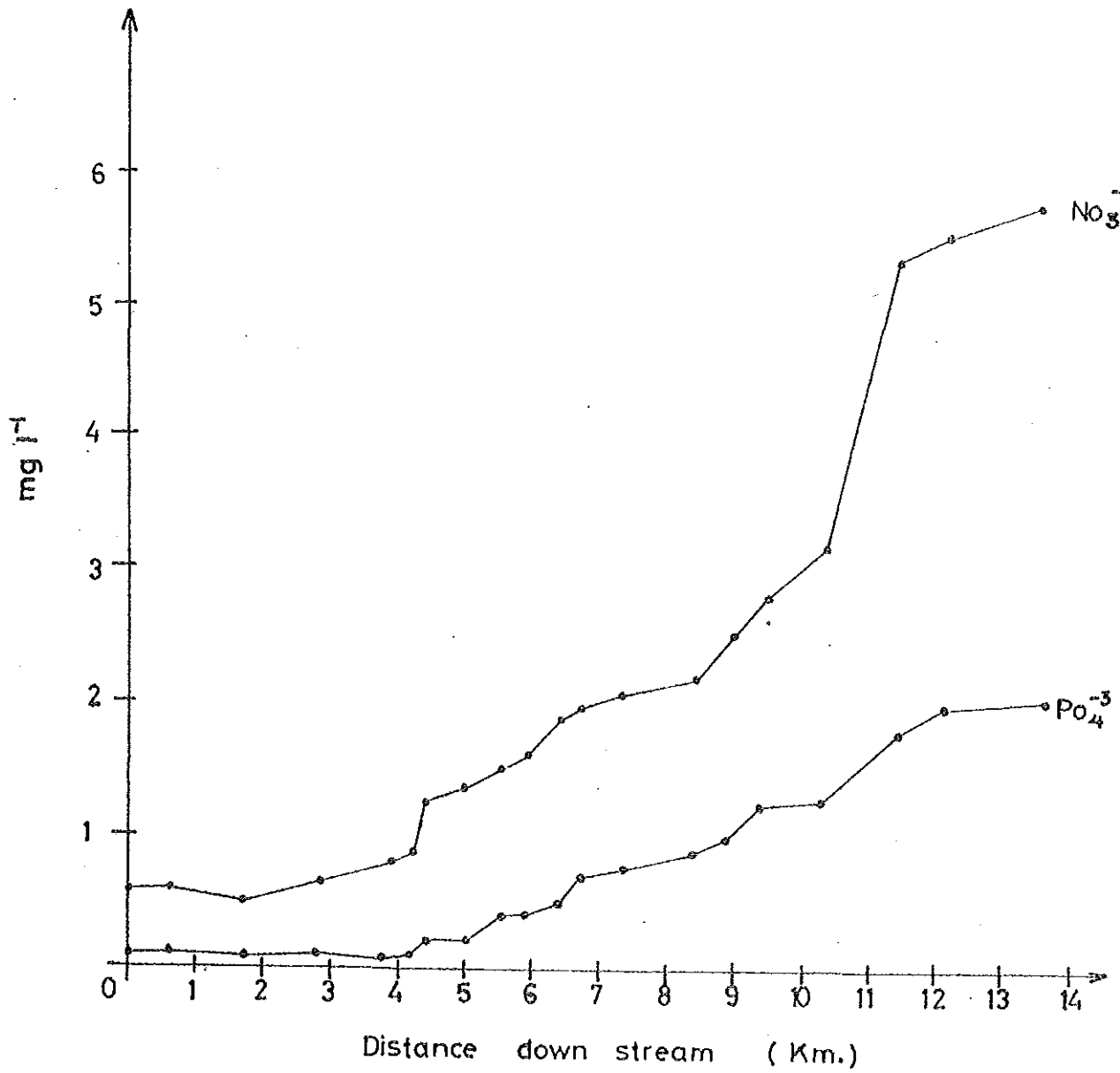


Fig. 5 Nutrient level of Abo-Kebena R. as it flows through Addis Abeba (Wet season).

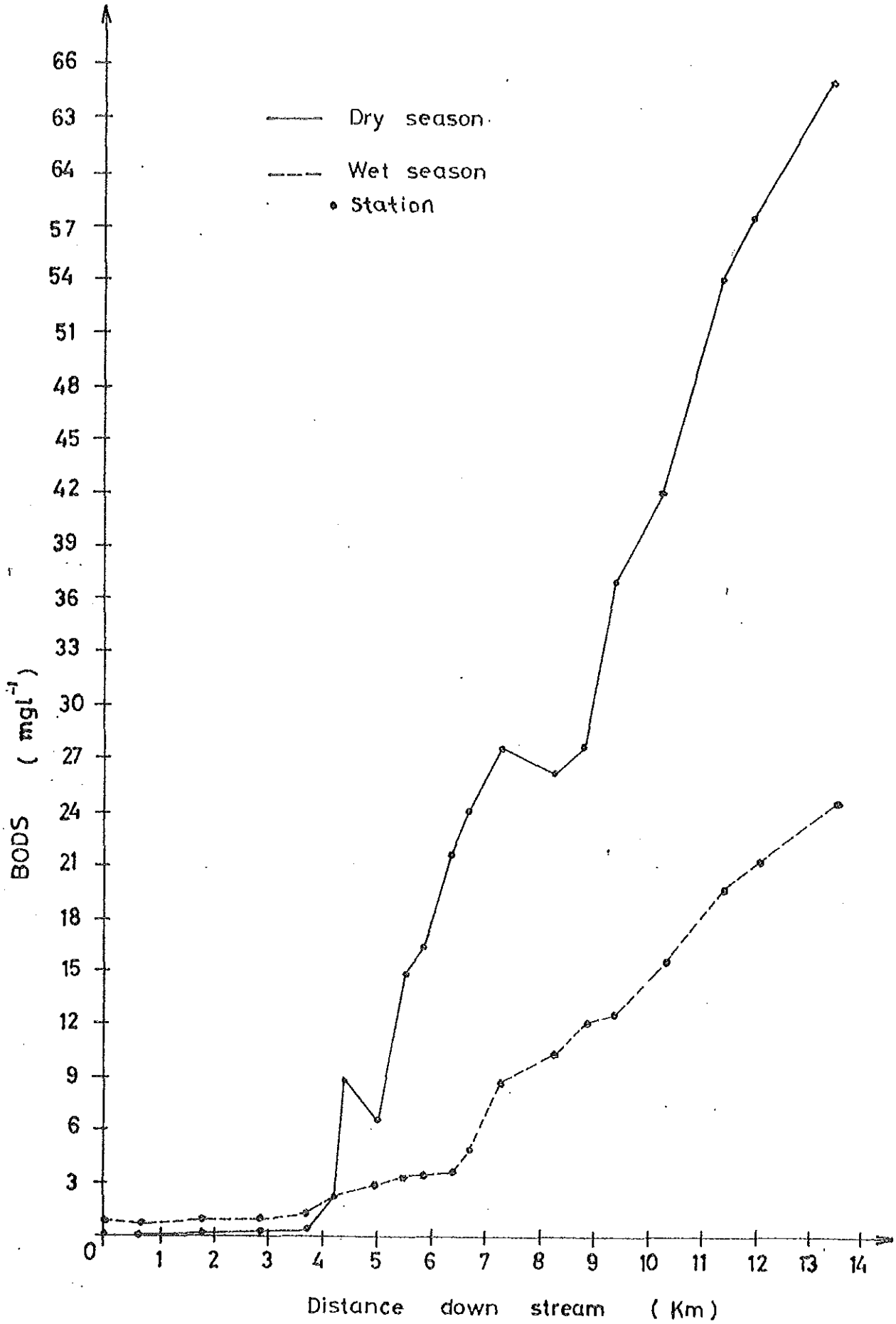


Fig. 6 BOD Profiles of Abo- Kebena R.

was the Kebena stream which did dilute the Abo-Kebena River (Figs. 4 and 6, station 8).

Domestic and municipal wastes from the centre of the city had a marked effect on the river. At station 16 and 18, gross pollution of the Abo-Kebena River, as measured by the nitrate, phosphate and BOD₅ occurred. Besides its contribution to the flow, Bantiyketu River supplied a large amount of organic matter. This is shown as a sharp increase of nutrient concentrations (Figs. 4, 5 and 6).

Another sharp increase in nutrient concentration was recorded at station 9. This is mainly due to a hospital outfall entering the river. Station 7 and 11 are the most accessible parts of the stream. At these stations, the people add sewage directly into the river or through overland drainage, wash their clothes, and even take baths. The effect of such activities on the river was evident from the measurements of the nutrients, where sharp increases are shown.

There is a small stream, not shown on Fig. 1, which drains densely populated residential area of the Bole and joins the Kebena River at Bole Bridge, station 19. Although the flow of this stream is very small, it is heavily polluted by organic wastes. This is evident from the massive growth of sewage - fungus, Sphaerotilus natans. Owing to its small size, it becomes diluted as it enters the main river.

At station 17, below Urael church, water from an agricultural area where vegetables are grown enters the Kebena River. The water for the irrigation comes from the polluted Abo-Kebena River. On its return to the river, the water seems less loaded with organic matter. However, it did not appear to dilute the receiving river. The absence of a diluting effect was probably of the small size of the 'agricultural' tributary.

3. Fauna of Abo-Kebena River:- abundance and diversity

Throughout the study period, 52 taxa and 18,934 individuals of benthic macroinvertebrates were collected. Taxonomic groups which constituted more than 1% of the total organisms included Trichoptera (1.1%), Tricladida (2.84%), Oligochaeta (6.54%), Diptera other than Chironomidae (11.1%), Chironomidae (54.86%) and Ephemeroptera (22.88%). Other groups which were represented in small numbers were Plecoptera, Coleoptera, Hirudinea and Mollusca (Table 1).

Major groups of organisms	dry season	wet season	total	% composition
Plecoptera	35	26	61	0.32
<u>Baetis harrisoni</u>	2399	1063	3462	18.28
Ephemeroptera (others)	538	332	870	4.60
Chironomidae	7501	2887	10388	54.86
Dipta (others)	1939	163	2102	11.10
Coleoptera	44	8	52	0.28
Trichoptera	135	75	210	1.11
Tricladida	515	22	537	2.84
Oligochaeta	1143	96	1239	6.54
Hirudinea	4	-	4	0.02
Mollusca	7	2	9	0.05
Total	14260	4674	18934	100

Table 1. Major groups of macroinvertebrates collected from Abo-Kebena River (total sample).

The mayflies were represented by several species. Among these Baetis harrisoni BARNARD and Caenis sp. were found abundantly and at most of the stations. Baetis harrisoni was the dominant mayfly comprising 18.2% of the total numbers collected and it was present in every station during the entire study. Other important mayflies included. Centroptilum varium CRASS, Centroptilum sudafricanum

LESTAGE, Afronurus harrisoni BARNARD, Afronurus peringueyi ESBEN-PETERSEN and Pseudocloeon maculosum CRASS. However, these were limited to the upper clean stations of the river.

The chironomids were the most abundant and important constituents of the organisms collected. They occurred at all stations during the entire study. At stations 6,7,8,9, 14 and 15 , Chironomids formed at least 60% of the entire fauna (Table 2) with Rheocricotopus capensis FREEMAN and Chironomus allaudi KIEFFER being the dominant organisms.

Other chironomids which were commonly present in the Abo-Kebena River were Cricotopus bizonatus and Cricotopus flavozonatus FREEMAN, Dicrotendipes pilosimanus, Ablabesmyia dusoleili, Cryptochironomus spp. and Parametriocnemus micans KIEFFER. During periods of high discharge the number of chironomids decreased; however, the proportion of chironomids remained high relative to other group of organisms.

Simulium spp. were second to the chironomids in abundance among the Diptera. They constituted 10.49% of the total catch. Dr. Harrison (personal communication) remarked that the Simulium are of four species. Although not as high as Simulium, Psychoda spp. were collected at the lower stations, namely at stations 17,18,19 and 20. Other dipterans, poorly represented, include Tipula spp., Culex spp., Bezzia spp., Forcipomyia spp. and Atrichopogon spp. The last three were collected only during the wet season.

Oligochaetes were present in most of the stations. However, they were most abundant at the lower stations, starting from station 12. Nais spp. was the dominant oligochaete, followed by Tubifex spp.

The coleopterans were represented by Elmidae and Psephenidae which were both limited to the upper reaches of Abo-Kebena River. Trichopterans were present in stations 1-8. The net-spinning Cheumatopsyche spp. and Hydropsyche spp. were fairly abundant

organisms but Hydroptila and Chimarra spp. were collected in low numbers.

The stoneflies (Plecoptera) were represented by one genus, Neoperla. They were restricted to the clean upper reaches of Abo-Kebena River.

4. Seasonal Variation in Invertebrate Communities

In the Abo-Kebena River, a clear seasonal variation is shown both in the density (Tables 2 and 3) and faunal richness (Fig. 7 & 8). In general, the number of individuals was low in the wet season and high in the dry season. The seasonal variation in abundance of organisms was analyzed statistically using Students t-test and it was found that the difference was significant at 0.05 level of significance. This trend was as true for most individual species as it is for total numbers, for only three taxa, Cricotopus spp., Paratrichoclaudeus micans and Pseudocloeon maculosum were more numerous in the wet season than in the dry season. Cricotopus spp. were so abundant during the wet season that they comprised 34% of the total fauna as compared with 3% during the dry season.

A very important feature about the stream was the extreme variability in flow in different seasons. The speed as well as the discharge increased 3 and 4 fold during summer floods as compared with the winter dry period. The load of silt increased from the dry season to the wet season.

As noted previously, the number of organisms collected during the dry season was much higher than those collected during the wet season. In the dry season, a total of 14,260 invertebrates was collected as compared with 4,674 during the wet season (Table 2). In the former, the mean collection was calculated to be 702 as compared to 234 in the latter. At station 13 1,476 individuals (Table 2) were collected during the dry season; in the wet season, this number was reduced to 161, which is almost 9 times lower (Table 3).

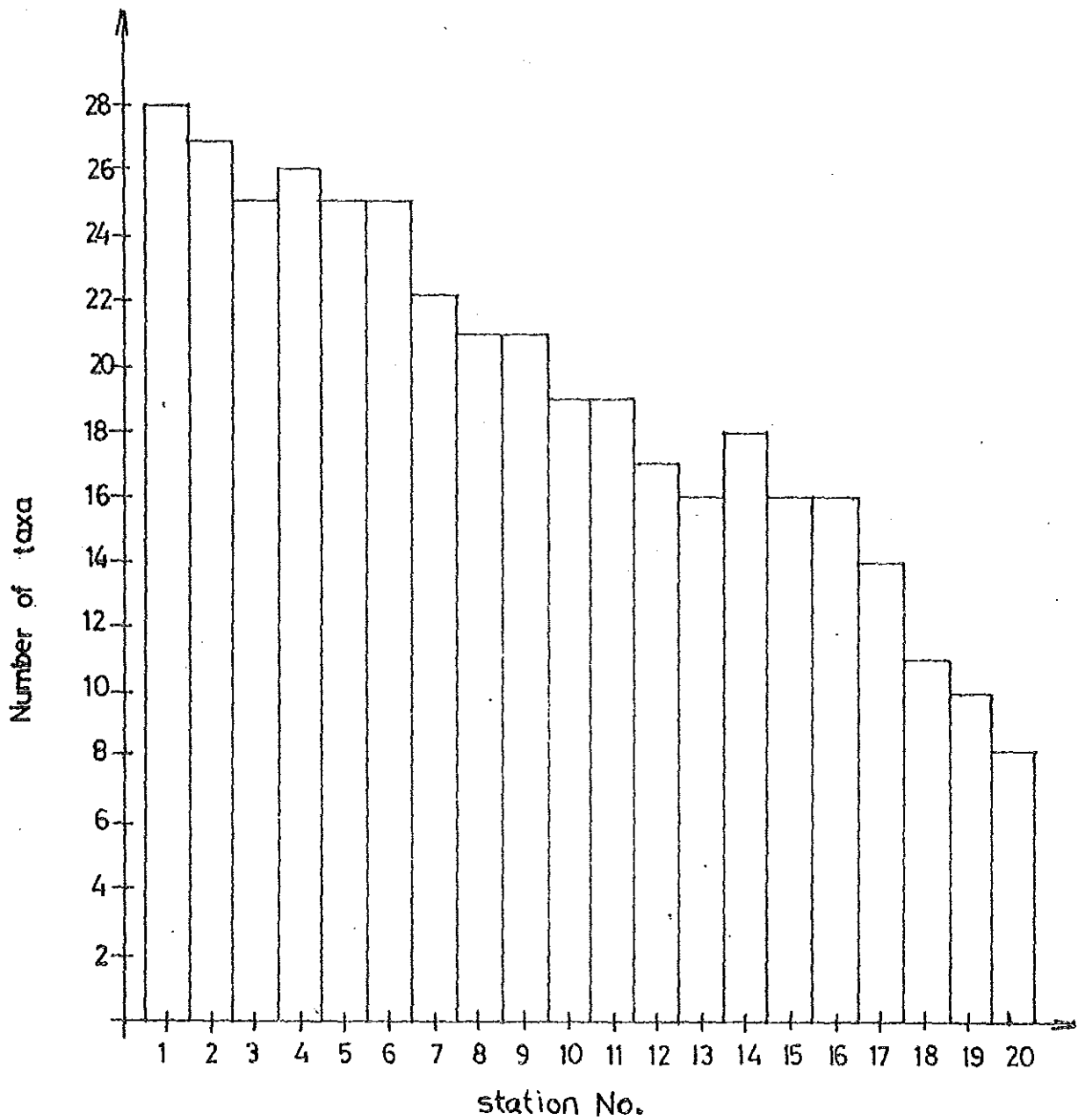


Fig.7 Number of taxa collected at each station
(Dry season)

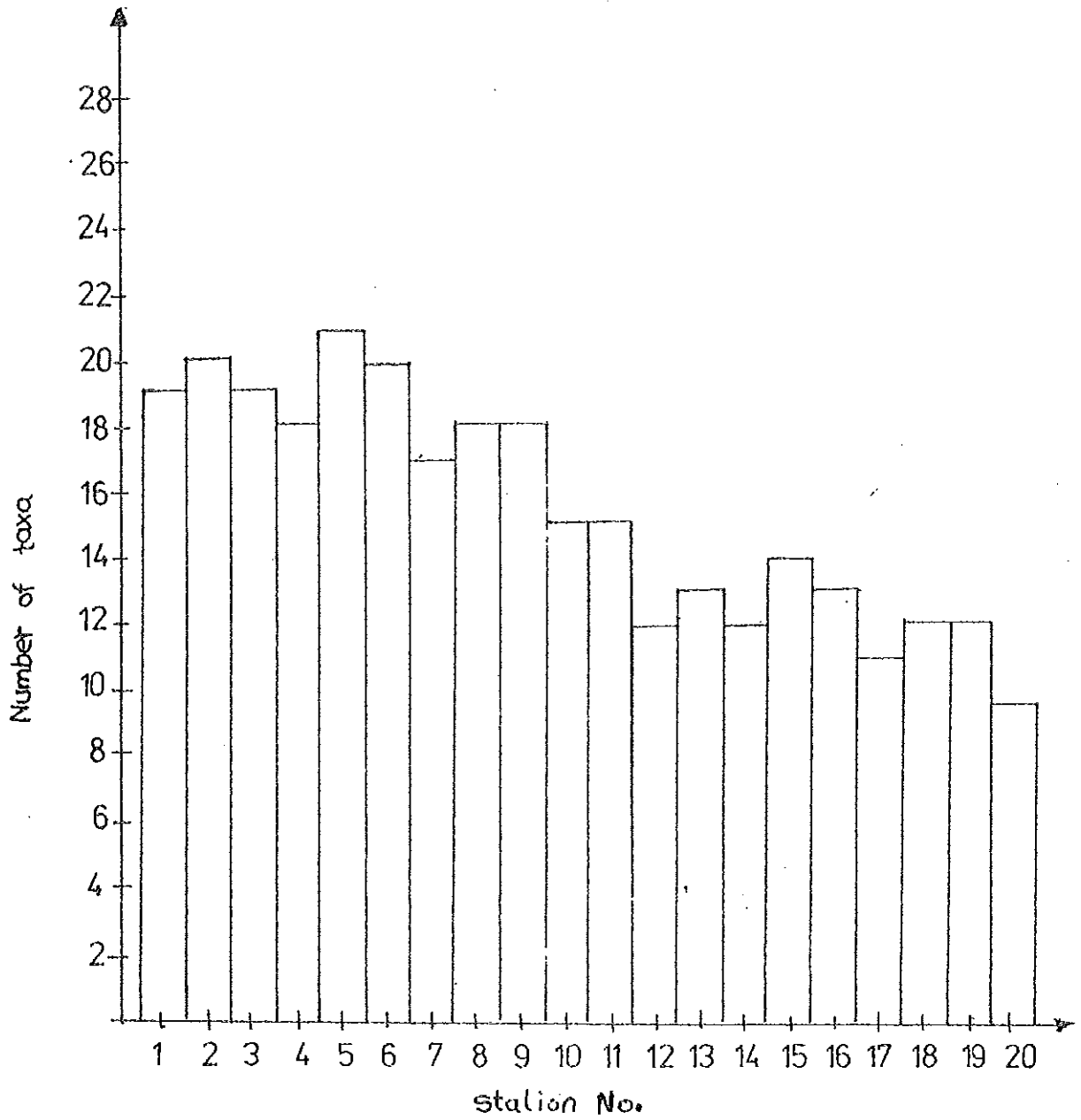


Fig.8 Number of taxa collected at each station
(Wet season)

Table 2. Number and percentage composition of fauna samples at each station (dry season)

Station	Pleco- ptera		Baet- ideae		Ephemer- optera (others)		Tricho- ptera		Dipt- era (others)		Chiron- omidae		Coleo- ptera		Oligoc- haeta		Tricladida		Mollusca		Total
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
1	15	5.59	120	44.78	41	15.3	13	4.85	26	9.7	35	13.06	15	5.6	1	0.37	2	0.75	-	-	268
2	10	2.81	150	42.13	33	9.27	25	7.02	65	18.26	51	14.33	11	3.09	2	0.56	9	2.53	-	-	356
3	7	1.49	136	28.0	32	6.82	31	6.61	130	27.72	106	22.6	9	1.92	-	-	16	3.41	-	-	469
4	3	0.67	113	25.11	14	3.11	21	4.67	46	10.22	201	44.67	5	1.11	-	-	46	10.22	1	0.21	450
5	-	-	204	32.28	43	6.80	9	1.42	41	6.49	309	48.89	2	0.32	2	0.32	21	3.32	1	0.16	632
6	-	-	86	10.93	65	8.26	19	2.40	45	5.72	509	64.68	1	0.13	1	0.13	60	7.62	-	-	787
7	-	-	72	9.05	31	3.9	14	1.76	85	10.68	550	69.11	1	0.13	1	0.13	42	5.34	-	-	796
8	-	-	58	7.99	17	2.34	3	0.41	114	15.7	489	67.36	-	-	13	1.79	29	4.00	3	0.41	726
9	-	-	65	7.58	10	1.17	-	-	198	23.1	516	60.21	-	-	26	3.03	41	4.79	1	0.12	857
10	-	-	89	10.30	31	3.59	-	-	207	23.69	445	51.50	-	-	26	3.01	64	7.41	2	0.23	864
11	-	-	123	10.66	68	5.89	-	-	278	24.09	534	46.27	-	-	69	5.98	82	7.11	-	-	1154
12	-	-	156	15.23	51	4.98	-	-	208	20.3	432	42.2	-	-	132	12.9	45	4.39	-	-	1024
13	-	-	352	23.85	28	1.9	-	-	138	9.35	753	51.01	-	-	172	11.65	33	2.24	-	-	1476
14	-	-	183	14.85	59	4.79	-	-	13	1.06	750	60.88	-	-	204	16.56	23	1.87	-	-	1232
15	-	-	148	12.82	12	1.04	-	-	41	3.56	840	72.79	-	-	111	9.62	2	0.17	-	-	1154
16	-	-	231	21.53	2	0.19	-	-	146	13.6	611	56.94	-	-	83	7.74	-	-	-	-	1073
17	-	-	95	16.76	1	0.17	-	-	109	18.92	237	41.15	-	-	125	21.70	-	-	-	-	567
18	-	-	8	4.4	-	-	-	-	33	18.13	74	40.66	-	-	67	36.81	-	-	-	-	182
19	-	-	9	7.5	-	-	-	-	6	5.0	35	29.17	-	-	70	58.33	-	-	-	-	120
20	-	-	1	1.37	-	-	-	-	10	13.7	24	32.88	-	-	38	52.05	-	-	-	-	73

Table 3. Number and percentage composition of fauna samples at each station (wet season)

Station	Plecoptera		Baetidae		Ephemeroptera (others)		Trichoptera		Diptera (others)		Chironomidae		Oligochaeta		Tricladida		Coleoptera		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
1	11	7.91	49	35.25	33	23.74	16	11.51	2	1.44	22	15.83	-	-	-	-	6	4.32	139
2	8	4.26	56	29.79	36	19.15	21	11.17	5	2.66	58	30.85	2	1.06	-	-	2	1.06	188
3	2	0.94	67	31.45	36	16.9	29	13.62	12	5.63	65	30.52	1	0.47	1	0.47	-	-	213
4	1	0.34	108	36.61	35	11.86	20	6.78	3	1.02	125	42.37	-	-	3	1.02	-	-	295
5	1	0.31	70	21.47	72	22.08	3	0.92	5	1.53	173	53.07	1	0.31	1	0.31	-	-	326
6	1	0.26	56	14.47	91	23.5	1	0.26	21	5.43	208	53.75	1	0.26	8	2.07	-	-	387
7	2	0.51	182	46.55	6	1.53	4	1.02	4	1.02	188	48.08	1	0.26	4	1.53	-	-	391
8*	-	-	193	42.32	4	0.88	1	0.22	18	3.94	230	50.44	4	0.88	5	1.1	-	-	456
9*	-	-	123	31.87	2	0.52	-	-	9	2.33	244	63.21	7	1.81	-	-	-	-	386
10	-	-	41	14.29	6	2.09	-	-	12	4.18	223	77.7	5	1.74	-	-	-	-	287
11	-	-	59	26.58	6	2.7	-	-	9	4.05	145	65.32	3	1.35	-	-	-	-	222
12	-	-	33	17.64	4	2.14	-	-	8	4.28	134	71.66	8	4.28	-	-	-	-	187
13	-	-	3	1.86	1	0.62	-	-	3	1.86	144	89.45	10	6.21	-	-	-	-	161
14	-	-	3	1.73	-	-	-	-	7	4.02	157	90.23	7	4.02	-	-	-	-	174
15	-	-	2	0.71	-	-	-	-	7	2.46	261	91.9	14	4.93	-	-	-	-	284
16	-	-	12	3.55	-	-	-	-	18	5.33	296	87.57	12	3.55	-	-	-	-	338
17	-	-	3	2.22	-	-	-	-	4	2.96	126	93.3	2	1.48	-	-	-	-	135
18	-	-	2	3.18	-	-	-	-	7	11.1	51	80.96	3	4.76	-	-	-	-	63
19	-	-	1	3.70	-	-	-	-	4	14.82	17	62.96	5	18.52	-	-	-	-	27
20	-	-	-	-	-	-	-	-	5	14.29	20	57.14	10	28.57	-	-	-	-	35

* Two Ancylyus were collected from these stations one from each.

During the wet season the fauna was less diverse at all stations than it was in the dry season. This was particularly evident in the upper stations (Fig. 7). For example, at station 1, 28 taxa were collected during the dry season as compared with 19 during the wet season (Table 6). However, more taxa were recorded during the wet season than during the dry season at two stations, namely, station 19 and 20. In addition, the difference in faunal richness between the clean station and most polluted station (station 20) was low during wet season in contrast with the dry season.

The dry season water quality of Abo-Kebena River as determined by Chandler's Biotic Score is shown in Fig. 9. The range of values calculated for all stations were between 213 and 1416. A progressive decline in the index value is also shown, indicating the deterioration of the water quality downstream.

Generally values were greater in the Abo-Kebena River, but lower values did occur at stations 14 to 20. Therefore based on the Chandler's biotic score stations 1,2,3,4,5,6,7 and 8 are very clean waters, station 9,10 and 11 are clean waters, and stations 12 to 20 are polluted waters.

5. Algae of the Abo-Kebena

The genera of algae noted abundantly in different parts of the Abo-Kebena River are shown in Table 4.

The most abundant genera throughout the study were Navicula, Nitzschia, Diatoma, Fragilaria, Synedra, Cyclotella, Tabellaria, Zygnema, Spirogyra, Cymbella, Cladophora, Closterium, and Stigeoclonium. Other algae which were commonly present were Achnanthes, Gomphonema, Nostoc, Oscillatoria, and Chroococcus.

During the rainy season, algae of all types became greatly reduced in their abundance. The filamentous algae Stigeoclonium and Cladophora were very sparse during the wet season.

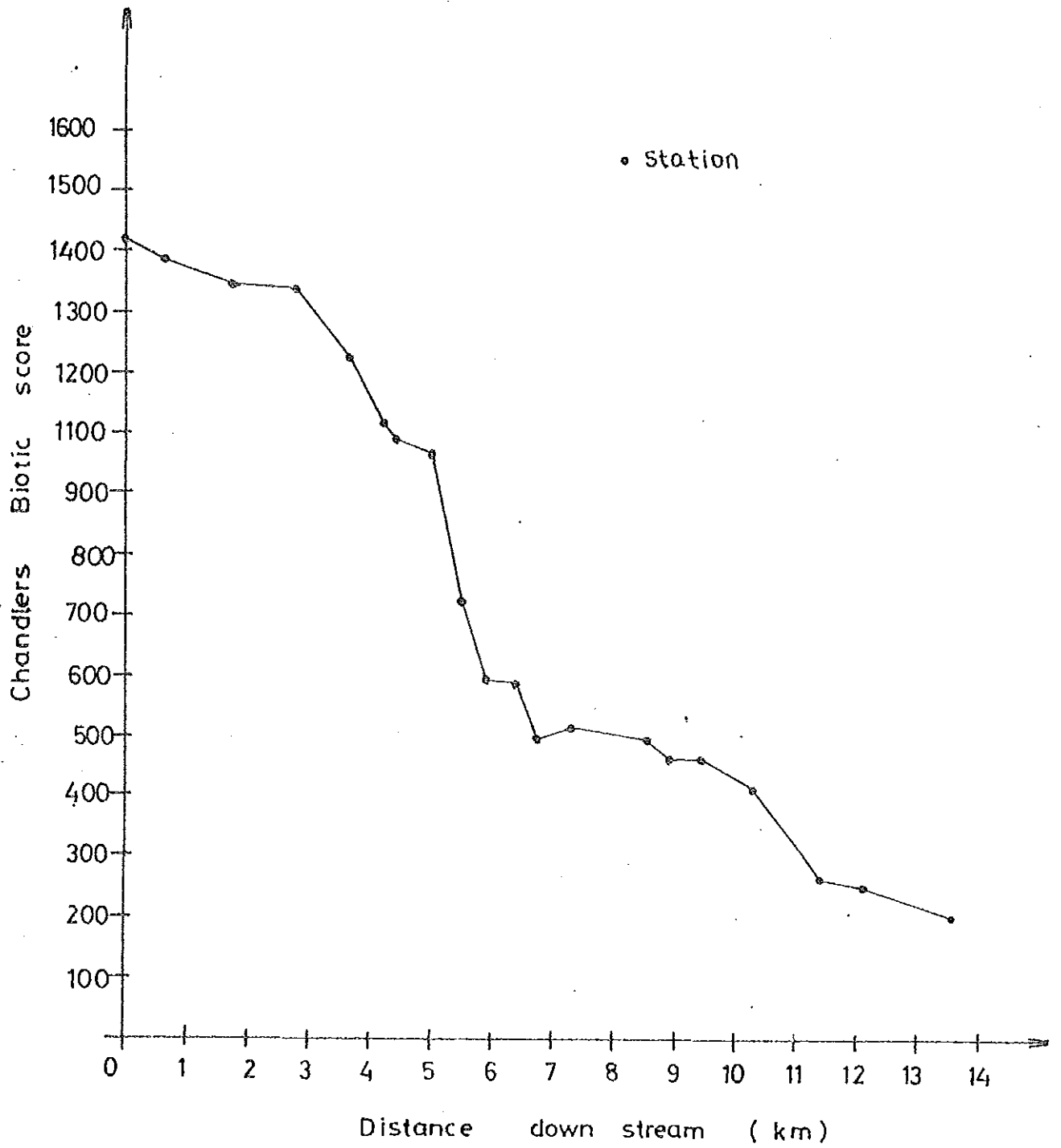


Fig. 9. Water quality of Abo-Kebena R. as determined by Chandlers Biotic score

In the Abo-Kebena River, it seems that the algae are distributed in different sections of the river. Algae which were found in the upper part of the river were Achnanthes, Pinnularia, Ankistrodesmus, Rhizoclonium, Cyclotella, and Meridion. In the middle part of the river the diatoms Navicula, Nitzschia, Diatoma, Chroococcus; the green algae Cladophora, Spirogyra, and Zygnema were the dominant algae. Blue greens such as Oscillatoria, Ulothrix, Rivularia, and Lyngbya were also commonly present, the former being noted in considerable numbers.

The lower part of the river had a diatom association mainly composed of Nitzschia, Diatoma and Navicula the former being noted in large numbers

Table 4. Genera of algae noted in different parts of Abo-kebena river

Clean water algae	algae of mild pollution	algae of heavy pollution
<u>Cyclotella</u> *	<u>Navicula</u> *	<u>Diatoma</u> *
<u>Pinnularia</u> *	<u>Chroococcus</u> *	<u>Navicula</u> *
<u>Tabellaria</u> *	<u>Tabellaria</u> *	<u>Nitzschia</u> *
<u>Gomphonema</u>	<u>Fragilaria</u>	<u>Cymbella</u>
<u>Fragilaria</u>	<u>Lyngbya</u>	<u>Fragilaria</u> *
<u>Surirella</u>	<u>Nitzschia</u> *	<u>Synedra</u>
<u>Meridion</u> *	<u>Cymbella</u>	<u>Stigeoclonium</u> *
<u>Achnanthes</u>	<u>Diatoma</u> *	<u>Closterium</u> *
<u>Cymbella</u> *	<u>Gomphonema</u>	<u>Oscillatoria</u> *
<u>Nitzschia</u>	<u>Zygnema</u> *	
<u>Rhizoclonium</u>	<u>Cladophora</u> *	
<u>Ankistrodesmus</u> *	<u>Spirogyra</u> *	
<u>Cladophora</u> *	<u>Synedra</u> *	
<u>Nostoc</u> *	<u>Oscillatoria</u>	
<u>Diatoma</u>	<u>Rivularia</u> *	
	<u>Ulothrix</u>	

* Algae which were noted abundantly.

as compared with the others. The desmid, Closterium was also found to be an important constituent of the algal community in this part of the river. However, none of the algae in the lower part of the Abo-Kebena River were as abundant as the green filamentous alga, Stigeoclonium. There was a heavy growth of this alga particularly at the last two stations (stations 19 and 20).

Some algae were found to have a wide distribution occurring in most of the stations of the river. These are the diatoms, Cymbella, Diatoma and fragilaria.

V. DISCUSSION

1. Temperature

The small temperature difference in the Abo-Kebena river over different seasons is not surprising because in the tropics the sun is overhead through the year and air temperature ranges are very small.

The uniformity of the temperature in tropical streams, such as the Abo-Kebena River, has important implications with regard to the timing and duration of the composition of organic matter. Warmer temperatures contribute to a more rapid decomposition. One would expect, therefore, the rate of oxidation of organic compounds to be similar throughout the year in the Abo-Kebena River unlike streams and rivers in temperate regions, which freeze over in winter. Nevertheless, because of the high altitude temperatures are much lower than most Afro-tropical streams which lie below the altitude of 2000m . This can be inferred from Yalden (1983).

The increase of temperature downstream is thought to be mainly due to warming by the sun and atmosphere and not only due to warm effluents entering the river. Similar observations have been made from the Tugela River (Oliff, 1960a) and the Jukskei River (Allanson, 1961) from South Africa.

Many workers, such as Tonapi and Rao (1977), Williams (1981) and Ross and Wallace (1982) have shown temperature as a primary determinant of distribution of macroinvertebrates in temperate waters. Further evidence that the ecology of invertebrates on East African mountains is intimately related to altitude is provided by van Someren's work (from Williams and Hynes, 1971) in a stream on Mount Kenya. The rise in temperature downstream in the Abo-Kebena is not great enough to cause major differences in longitudinal macroinvertebrate patterns of composition and abundance. This is because the section surveyed is relatively short with a small drop in altitude (300 m). Harrison and Hynes (1988) show that in Ethiopia a drop of at least 500m is needed to

produce obvious changes in the communities and, even then, the changes are not as great as those produced by the pollution in the Abo-Kebena River.

2. Nitrates and orthophosphates

Moraitou-Apostolopoulou and Ignatiades (1980) and Silsbee and Larson (1982) point out that, in clean, forested headwater streams the nitrate and phosphate levels are usually low, and nutrients are formed during the breakdown of natural allochthonous material, such as leaves. Lower down, little allochthonous material falls in so the nutrients are soon used up by the algae. The nitrate, phosphate and BOD₅ levels of the upper reaches of the Abo-Kebena River fall well within the range provided by Livingston (from Wilber, 1969) for undisturbed streams.

Many investigators, including Allanson (1961) and Venkateswarlu (1969) have reported that organic pollution may increase the nitrate and phosphate values downstream. This is because the organic pollutants are broken down (or "mineralized") by bacteria to release nitrates and

phosphates. In view of this, the present data are more or less consistent with their findings, because most of the lower stations, with their load of organic matter, were rich in nitrate and phosphate.

As noted earlier levels of nutrients were low at the upper clean stations. Values increased progressively with distance downstream. The enrichment of the stream as it passes through the city was so substantial that at station 20 nitrate levels were almost 40 times greater than they were at the upper unpolluted stations. The phosphate levels which were relatively low in the unpolluted part of the stream, rose to enormous amounts at the lower stations.

In addition to marked differences in the amounts of nitrate and phosphate within the river at any given station, clear seasonal variation was evident. Much larger amounts of nutrients were recorded in polluted portions of the river throughout the dry season than in the

wet season at any given station. This observation accords well with that of the Eersete River, South Africa (King 1981).

The seasonal variation in nutrient levels is mainly due to increased run-off and dilution of the river during the rainy season and a decrease in flow during the dry season. Many small streams which flow into the Abo-Kebena River dry up during the dry periods. However, higher values were recorded during the wet season than the dry season on the upper four stations. This could indicate increased organic pollution which arises from agricultural farm land around the river.

3. 5-day Biochemical Oxygen Demand (BOD₅)

Levels of BOD₅ were low in the upper part of the river which is expected in undisturbed waters. But values rose to enormous amounts at the lower part of the river.

High values of BOD₅ are usually associated with high organic matter. This is evident from the works of Oliff (1964), Allanson (1961), and Blum (1967), who surveyed many rivers and streams in South Africa. Therefore it can be stated that the lower part of Abo-Kebena River is highly polluted with organic matter as measured by the levels of BOD₅.

According to water quality standards for river and stream water (Sladeczek, 1965), stations 1,2,3,4, and 5 with BOD₅ values less than 1 mg l⁻¹ were very clean; stations 6,7 and 8, with BOD₅ values of 2-10 mg l⁻¹ were lightly polluted and the rest of the stations with values greater than 10 mg l⁻¹ were heavily polluted.

However, it may be that in hot climates the natural BOD₅ of a river or stream can be higher than in temperate climates and still support aquatic life. For example, the unpolluted River Turkwell in Northern Kenya is reported to have a BOD of 20-45 mg l⁻¹ (Mara, 1980). This suggests that water quality classifications of rivers and streams in tropical Africa are urgently needed taking local conditions into account. In spite of this the temperatures of the high altitude Abo-

Kebena River and the BOD situation would be expected to resemble that of southern Europe or South Africa.

4. Seasonal Structure of the Benthic fauna

The Abo-Kebena generally is similar to streams studied by Harrison (1958b), Chutter (1969) and in South Africa, King (1981) where there was a decrease in populations of organisms during the wet season. Consistent with these results, Mills (1976) noted a decrease in the number of organisms during wet season in the Mwenda River, Central Africa. As already mentioned in Section 5.4. , this is due to the stronger currents carrying many organisms away. Harrison and Hynes (1988) considered that, in Ethiopian rivers during the wet season, faunal reduction is the result of abrasion by sand and the molar effects of rolling stones and rocks. This was found to have catastrophic effects on the fauna of streams in mountain regions where soil erosion was very bad, far worse than anything seen in the upper, unpolluted stations of the Abo-Kebena River.

Another factor influencing the seasonal pattern in streams and rivers is that the area of the river bed under water is increased during the wet season, the same number of animals become dispersed over a greater area so that there are fewer organisms per sample. This can be important in relatively slow-flowing streams but in torrential streams more animals are simply washed away.

The rising water during flood periods affects the fauna both directly and indirectly. When the river is in spate, its eroding action is so high that the water becomes very turbid. This diminishes the amount of light and this obstructs the development of algae, which are at the base of the food chain in stream ecosystems. Hence, the density of the fauna becomes extremely poor, limited in part by the availability of food. A similar relationship, between algal density and abundance of macroinvertebrates, has been pointed out by Moore (1979).

It has been noted that, the stream was highly turbid after heavy rains.

The dense crop of diatoms and filamentous algae, particularly at the lower stations, was not evident during the wet season. Algae are important organisms at the base of the food chain where allochthonous input of materials is minimal in such rivers where its banks are devoid of natural vegetation.

The deposition of large amounts of silt was considered to have affected the feeding efficiency of some organisms. This was particularly true for Hydropsychidae (Harrison and Hynes, 1988). During the dry season, they were present up to the middle part of the river. In the wet season, their distribution was restricted to the upper part of the river. Although organic pollution was less in the wet season, there is no doubt that silt had a negative effect on the abundance and distribution of Hydropsyche spp. and Cheumatopsyche spp.. Many species of invertebrates therefore may have experienced seasonally alternating impacts of organic loading and sediment abrasion.

However, the contribution of Hydropsychidae to the total fauna is very low, below 1%. Therefore it can be said that the faunal reduction caused by affecting the feeding efficiency of macroinvertebrates during high discharge makes very little or no contribution in the reduction of the fauna in the Abò-Kebena River.

5. Effects of Organic Pollution on the Fauna

The patterns of invertebrate abundance and diversity were the result of complex interactions and seasonal variation of discharge, sediment and organic pollution. This study suggests a major impact of organic pollution on macroinvertebrate faunas.

The number of macroinvertebrates was low at the upper clean stations as compared with the polluted stations and the number of individuals was high at polluted stations. In addition the heavier the pollution, the lower was the diversity of the fauna. Such phenomena are well documented. Among those who have described changes in the abundance and diversity of benthic macroinvertebrates are Jolly and Chapman (1966),

Maciorowski et al. (1977) and Mohammed (1980).

At station 1, which is above any known sources of pollution, 268 individuals belonging to 28 different taxa were recorded, whereas at station 15, the 1154 individuals fell into only 16 different taxa. The faunal diversity varied with the amount of pollution. This observation agrees well with those of Sala et al. (1977), Bronmark et al. (1984), in relation to adverse effects of organic pollution on aquatic communities.

The effect of organic pollution on macroinvertebrates in the Abo-Kebena River was as described by several authors such as Hynes (1960), Mason (1981) and Hellawell (1985). Some organisms were restricted to the upper reaches of the river due to pollution. Those found in the clean part of the Abo-Kebena River were some Ephemeroptera, Plecoptera, Coleoptera, and Trichoptera, many of which are sensitive to low dissolved oxygen. On the other hand, organisms which predominated in the polluted part of the river were not found, or occurred in only small numbers in the fauna of unpolluted part of the river. These include the sludge worms, Naididae and Tubificidae, the red larvae of Chironomus sp. and the sewage fly Psychoda.

5.1. Clean water macroinvertebrates

Stations 1 to 6 had diverse macroinvertebrate populations when compared with the remaining stations (Figs. 7). Water quality measurements showed that in these stations nitrate, phosphate and BOD₅ were low, indicating the water to be clean (Figs 4, 5, and 6). Nitrates and phosphates (Blum, 1957) and BOD₅ (Hynes, 1960) are known to be low in unpolluted portions of streams.

In this part of the river, larvae of Trichoptera, Ephemeroptera, Plecoptera and Coleoptera were commonly present. Chironomids were also found, but in small numbers particularly at the top two stations. Among the ephemeropterans, Baetis harrisoni were abundant throughout the study, comprising 44.8% of the total catch. Similar reports were made by Hughes (1966) from undisturbed streams

of the Barberton area, South Africa, where this species was the most abundant mayfly.

In the upper part of a river, the faunal association is specialized for conditions where algae and other types of food material are sparse, the water is clear, surfaces are clean and the dissolved oxygen is constantly kept higher by the presence of low organic matter and the turbulent water (Harrison, 1960).

The clean water stations extended further downwards during the wet season than during the dry season. This was evident from the presence of stoneflies and mayflies, which are sensitive to even mild organic pollution, below station 6. The nutrient levels were also low. Short and Ward (1980) comment that Plecoptera nymphs are conspicuous components of the macroinvertebrate fauna in unpolluted mountain streams.

5.2. Effect of light organic pollution

The disturbances on the Abo-Kebena River started at station 7. They were reflected both in the chemical and biological characteristics of the river.

Nutrient levels increased rapidly. Sensitive species such as Neoperla spp., Centroptilum varium, C. sudafricanum, Afronurus harrisoni, and A. peringueyi disappeared. Another effect of light organic pollution was the increase in numbers of Baetis harrisoni, Simulium spp., Chironomidae and Dugesia spp.. The results of the present study are in agreement with those of Harrison (1958a) who noted the disappearance of some sensitive species and the increase in numbers of Baetidae, Simulium spp. and Chironomidae in the Great Berg and Dwars Rivers, South Africa due to organic pollution. Such changes in the abundance and distribution of the fauna provide clues to the nature and source of polluting material.

The growth and multiplication of chironomids was favoured by

introduction of organic matter into the river. This was evident from the composition of the fauna, where in most collections they formed over 50% of the total macroinvertebrates (Table 4). Allanson (1961) also noted the abundance of chironomids in an organically polluted river in South Africa. The most important chironomid species in the Abo-Kebena River were Rheocricotopus capensis, Cricotopus bizonatus, Chironomus allaudi, Polypedilum spp., Dicrotendipes pilosimanus and Rheotanytarsus spp., of which the first two were the most common, and the next two subdominant, and the last two were low in abundance.

The Triclad, Dugesia and the caddisworms Hydropsyche and Cheumatopsyche were present although they totally disappeared as the extent of pollution increased in the course of the river. Oligochaetes were also present here, but unlike the others they showed a progressive increase in their numbers downstream.

5.3. Effects of heavy organic pollution

The observation reveals that the nutrient level at the lower section of the Abo-Kebena River was so high that it had affected the normal fauna replacing it with those which are adapted to such adverse conditions as high organic matter and low dissolved oxygen. Higher organic load is usually associated with low dissolved oxygen (Hynes, 1959b; 1960; Lester, 1975).

As the river passes through the densely populated parts of the city, there is more input of domestic and municipal waste. Tributaries loaded with large amounts of organic matter also join the Abo-Kebena River, thereby affecting the macroinvertebrate community.

Examination of the species composition of the fauna indicates that the communities at polluted stations are peculiar and are limited more and more to certain few species of Oligochaeta, Psychodidae and Chironomidae which are indicators of organic enrichment.

Psychoda are very good indicators of highly enriched waters and may occur in the septic zone of organically polluted rivers (Hynes, 1960). Although present in small numbers, Limnophora larvae were also found to resist heavy organic pollution.

During the dry season, the fauna of the lower stations was largely dominated by the oligochaetes, with Nais, Tubifex and Limnodrilus, making up more than 50% of the total organisms collected at the last two stations. Most oligochaetes can survive gross organically polluted environments because of their ability to survive low oxygen concentrations (Fisher and Beeton, 1975; Chapman and Brinkhurst, 1984). In a recent report Slepukhina (1984) states that in water bodies of all types, the mass development of oligochaetes and the reduction of the species richness are indicators of large quantities of organic matter. In view of this the present condition of the Abo-Kebena River confirms the above facts and suggestions.

Among the Chironomidae, which thrived and multiplied to a large extent in the polluted lower Abo-Kebena River were Chironomus allaudi and Rheocricotopus capensis. Other chironomids which were found to tolerate organic pollution were Cricotopus bizonatus and Polypedilum spp. However, even the number of chironomids was greatly reduced at stations 18, 19 and 20 by severe organic pollution (Table 2).

Simulium were also found to be resistant to organic pollution, although they too declined progressively as pollution became severe, until they were eliminated at station 19. The only mayflies which survived the heavy organic pollution were Baetis harrisoni and Caenis spp.. The latter were less tolerant and were eliminated earlier. Baetis harrisoni was so tolerant that it comprised 21.5% of the total catch at one of the heavily polluted stations (station 16). B. harrisoni is reported to resist a considerable amount of organic pollution in the Krom River, South Africa (Harrison, 1960b).

It is interesting to note that organic matter supplied by one of the tributaries, Bantuyketu River, which drains the heavily populated area of the city has greatly reduced the richness of the benthic fauna below station 18 with a consequent reduction in the number of macroinvertebrates.

Biotic indexes have been widely used as the best method for assessing the impact of effluents on macroinvertebrate communities (Kovalak, 1981). Based on the macroinvertebrate data, the Chandler's biotic score (CBS) (Chandler, 1970) was used to assess the water quality of the Abo-Kebena River. Critical comparisons of biotic indices indicate that CBS and its modifications the best and most reliable generalized index for the assessment of water quality (Cook, 1976; Mason, 1981).

Index values of the upper clean part of the Abo-Kebena River were high as expected. Values decreased downstream indicating the deterioration of water quality. According to Hellawell (1978), index values less than 500 are considered typical of perturbed benthic communities and values as high as 2000 have been obtained.

Although low values were obtained in the lower part of the Abo-Kebena River where there is organic enrichment, the severity of pollution was not reflected in the index values. The ecology of a stream in a temperate zone could be different from the ecology of a stream in tropics. Indiscriminate uses of pollution indices may therefore lead to erroneous conclusions (Hellawell, 1985). Thus, the use in tropical Africa of biotic indices developed for temperate regions need further investigation, and development of a suitable biotic index which best measures the community structure in tropical streams and rivers is urgently needed.

There is no sign of recovery at the downstream stations. Two reasons could account for this. First, at practically every site of the river there is additional introduction of more sewerage and

unsewered domestic waste from the city. Secondly, in its lower course, the river has a lower gradient and fewer rapids than in the upper part of the river. Hence it would seem that the process of self-purification and the reduction of nutrient levels are probably too slow and generally incomplete. Harrison and Hynes (1988) noted after the river has passed through the town of Akaki, the fauna was almost normal with many of the usual Ephemeroptera, Trichoptera and other stony run organisms.

In general the biology of the Abo-Kebena River shows a considerable disturbance throughout most of its length, with a fauna lacking the characteristic clean water organisms such as stoneflies, mayflies, and caddisworms. The nutrient levels remained high, the CBS was also very low. The data discussed above thus clearly indicates the effects of organic pollution on the fauna, and also the utility of macroinvertebrate density and distribution for assessing the degree of organic pollution in water sewage system. However, other factors such as current speed, type of substratum, dissolved substances, zoogeography, temperature play important role in regulating the occurrence and distribution of stream dwelling invertebrates (Hynes, 1970). Hence, detailed autoecological studies are required before a final relationship is established.

6. Effects of organic pollution on algae

Several authors (e.g. Butcher, 1947; Fjerdingsstad, 1964; Hancock, 1973) have suggested the use of algae as environmental indicators. Whitton (1975) comments that algae have a sufficiently well defined habitats that from the mere knowledge of occurrence of species, it is possible to infer quite a lot about its environment. Therefore, the presence of a few dominant species can be used to provide some guide to environmental conditions.

The algae of Abo-Kebena seemed to behave similarly as is reported in the temperate zone. There is clear indication that organic pollution, as measured by nitrate, phosphate and 5-day biochemical oxygen demand in

the river caused a longitudinal variation in the abundance and distribution of the algae. The importance of nitrates and phosphates in the ecology and distribution of algae have been pointed out by Venkateswarlu (1969).

In the Abo-Kebena River, algae were found to be associated with different levels of organic matter. The diatoms Achnanthes, Meridion, Pinnularia, Cyclotella and the green alga Ankistrodesmus were the dominant organisms in the clean upper reaches of the river where nitrates and phosphates were low. Achnanthes species are known to show inverse relationship with nitrates (Venkateswarlu, 1970). Similarly Harrison et al. (1960) suggested that the reproduction of Achnanthes largely depends on the oxygen content of the water. A heavy growth of the green alga Cladophora was also noted in the lower part of the clean section of the river where the current is very slow.

Algae which were found to be favoured by mild organic pollution were species of Navicula, Zygnema, Chroococcus, Nitzschia, Oscillatoria and Diatoma. The dominant alga in this section of the river was the diatom, Nitzschia. A similar relationship, between diatom density and nitrate-nitrogen, has been reported by Dakshini and Soni (1980). The presence of abundant Nitzschia species indicate moderately strong pollution of the water as most of the species of Nitzschia require dissolved organic matter for their metabolism (Cholonkoy, from Olive and Price, 1978). In this zone of the river Cladophora were also abundant forming dense mats over the substratum. The presence of the filamentous green alga, Cladophora abundantly in a particular site is linked to an increase in nutrients (Pitcairn and Hawkes, cited in Mason, 1981).

In the lower section of the river where it is rich in organic matter, the diatoms diatoma, Navicula, Nitzschia fragilaria and the green algae, Stigeoclonium and Closterium became abundant. However, none of them grew as luxuriously as the filamentous green alga Stigeoclonium in the heavily polluted part of the Abo-Kebena River. Similar observation was made by Jolly and Chapman (1966) where they noted heavy growth of Stigeoclonium in an organically enriched stream in USA.

Among the diatoms, Tabellaria, Fragilaria and Diatoma had a wide distribution throughout the study.

Algae are commonly used organisms in the detection of water qualities in many parts of the world. The present data of algae of Abo-Kebena River is insufficient to make a valuable conclusion about the indicator organisms of the river. It demands a good taxonomic knowledge and the algae need to be identified to species level. Stevenson (1984) noted that Navicula viridula is intolerant whereas Navicula seminulum is tolerant to organic pollution. Thus, two closely related forms of the same genus could be indicators of contrasting stream conditions.

Although detailed study of the algae was not done, further investigation of these organisms may indicate their usefulness as indicators of pollution in tropical Africa, as is already well established in the sub-tropical and the temperate zone.

VI. COMPARISON WITH OTHER DEGRADED STREAMS AND RIVERS IN AFRICA

1. Chemical

High nitrate and orthophosphate levels have been commonly noted in African rivers as well as those in other parts of the world. These plant nutrients come from break down of organic materials but concentrations in the water can vary greatly depending on nature of pollutant and the distance of the sampling station from the outfall. These plant nutrients are used up by algae and higher plants in the stream bed but they usually persist for a considerable distance in a fast-flowing stream.

Nitrate levels higher than those in the Abo-Kebena have been noted in the River DO and River Kan, Ivory Coast (Rai, 1974), Jukskei-Crocodile River, South Africa (Allanson, 1961), but lower levels were found in the Ghelede Stream, Nigeria (Hassan, 1981) and the Eersete River, Cape, S. Africa (King, 1981), the Buffalo River, S. Africa (Oliff, 1963). Levels similar to those of the Abo-Kebena were found in the Klip River (Hancock, 1973) and the Apies River (Lenhard, 1965), both in the Transvaal, S. Africa.

Orthophosphate concentrations in the polluted section of the Abo-Kebena were comparable with those of the Eersete River but lower than the Ghelede Stream. High BOD₅ have also been recorded from other African rivers such as the Krom, Cape, S. Africa (Harrison, 1958b) which is comparable with that of Abo-Kebena River. The BOD₅ reported from Jukskei River, S. Africa (Allanson, 1961) is lower whereas values recorded from the River Nairobi, Kenya (Mara, 1980) are much more higher than the Abo-Kebena River.

As pointed out before, the composition of the benthic fauna, especially that of stony runs, is a better indicator of the presence and severity of organic pollution than chemical tests taken at some instant in time. Other authors have reported community changes in the stony run fauna

very similar to those found in the Abo-Kebena.

2. Fauna

Light pollution: Harrison, Great Berg River (1958a), Oliff, Bushmans River (1960), Allanson, Jukskei River (1961) and Chutter, Vaal River (1971) all report the same type of decrease in sensitive species and similar increases in green chironomid larvae (mainly Orthocladinae) as found in the Abo-Kebena. As the Great Berg River and the Jukskei River have similar temperature regimes as the Abo-Kebena, it is not surprising to find the same species of baetid mayfly larvae, Baetis harrisoni. In all three rivers, this species appears to benefit from the mild pollution and is found in great numbers. Unfortunately the earlier authors were not able to identify their chironomid larvae but according to Dr. A.D. Harrison (Pers. Commun.) the same or similar species of adults have been obtained from all three rivers.

Heavy pollution: Not many heavily polluted rivers or streams have been studied in Africa, but Harrison (1958b), Krom River reports the same type of degradation as found in the Abo-Kebena with the normal fauna replaced by Oligochaeta, such as Limnodrilus and Tubifex, the red larvae of Chironomus sp. and Psychodidae. Similarly Hassan, (1981) noted a fauna composed of only tubificids and Dipteran larvae, in the Ghelede stream, Nigeria.

Harrison (1958b) and Allanson (1961) in their study of rivers in South Africa also report Baetis harrisoni to be remarkably resistant to heavy pollution, although its numbers are reduced, which is similar to the condition observed in the Abo-Kebena. In all three cases the streams are torrential and the agitation of the water must result in some dissolved oxygen being present as these nymphs cannot live under anoxic conditions.

It was pointed out earlier, Limnophora larvae were among those organisms who were found in the organically enriched section of the Abo-Kebena River. To date, no author has reported the persistence of these

organisms in heavily polluted streams or rivers in Africa. This could probably be due to their absence or presence in few numbers in those regions studied. According to Dr. H.B.N. Hynes (personal communication.) Limnophora are found rarely in the temperate zone whereas in the tropics they are present in large numbers. Therefore in areas where they are scarce they could be missed from samples.

VII. SUMMARY OF RESULTS AND INTERPRETATION OF IMPACTS

This is a review of results and conditions observed in the River Abo-Kebena. Table 8 summarizes principal results for the convenience of the reader after dealing with the discussion of the results. The table lists features qualitatively along the river. Quantified data are given in text and figures.

In the upper part of the river, the water was clean and clear. Nutrient levels were very low which is expected in undisturbed streams or rivers. Macroinvertebrates were more diverse and less dense. Chandler's biotic scores for the invertebrates were very high and were within the ranges given for clean waters.

As the river enters the city, it becomes a dump for domestic and municipal wastes. The clarity of the water decreased. Nitrate, phosphate and BOD₅ levels increased depending on the amount of organic matter. Organisms which are favoured by slight organic pollution became abundant and sensitive species disappeared. In addition dense growth of filamentous algae appeared.

With increased input of organic matter from the densely populated areas of the city, the colour of water became dark with an offensive odour. Levels of nitrate, phosphate and BOD₅ became very high, the diversity of invertebrates was low and the fauna was dominated by few pollution tolerant organisms.

Chandler's biotic score was also very low which is characteristic of polluted waters. Dense mats of filamentous algae were present on the lower course of the river indicating organic enrichment. Samples taken at the last station showed no sign of recovery of the river from its organic load.

The results of the present investigation clearly showed the effects of organic pollution as measured by nitrate, phosphate and BOD₅ on the river fauna. The effects were two fold; both the abundance and the composition

of macroinvertebrates were altered. The algae were also affected by organic pollution.

Table 5. Integrated Summary of Results

water condition	upstream	mid-stream	lower part of the stream
water clarity	clear	brown	dark and with odour
Temperature	stable seasonally	stable seasonally and close to that	similar to upstream
Slope	high	medium	low
BOD ₅	very low	high	very high
orthophosphate	very low	high	very high
Nitrate	low	high	very high
Algae	bare on rocks	increased growth of algae	dense growth of algae
Chandler's biotic score(CBS)	very high	high	low
Invertebrates	-high diversity -low density	-less diverse -high density	-low diversity -density increased but decreased as pollution becomes severe
	- fauna composed of clean water invertebrates	-appearance of indicators of pollution -sensitive species disappeared.	-fauna dominated by pollution tolerant organisms

VIII. CONCLUSION AND RECOMMENDATION

The study reveals that:

1. The River Abo-Kebena, on its upper reaches, before it enters the city of Addis Ababa is low in nitrates, phosphates, and BOD₅ and rich in macroinvertebrate species, which show the cleanness of the water.
2. It becomes polluted as it passes through the city. The degree of pollution varies in relation to the amount of organic matter introduced. The integrity of the river macroinvertebrate community was seriously disrupted.
3. The pollution is severe enough to inhibit the development of species of animals associated with clean waters. The increased number of chironomids and oligochaetes, and the presence of the sewage fly Psycoda spp. at the lower stations, is a good evidence of enrichment of the river.
4. The characteristic biological integrity found at reference stations was not reestablished at the lower part of the river. Nutrient levels remained high throughout the study. In view of this, recovery is not shown as encountered by the chemical and biological parameters in the Abo-Kebena. This is mainly attributed to continuous accessions of untreated sewage from domestic and municipal sources and a decrease in flow gradients.

5. It is therefore concluded from both biological and chemical analysis that the River Abo-Kebena is heavily polluted and the water is unfit for personal, domestic and recreational purposes.

Based on the present observations, the following recommendations are made.

- a. In spite of being contaminated, some people depend on the stream water for washing clothes, and bathing, therefore the public should be warned of the potential dangers of using the water.
- b. It has been noted that the polluted water of the river is used for irrigation to grow vegetables for commercial purposes in the city. The quality of those food items produced through use of polluted water must be investigated to prevent the health hazards associated with the consumption of contaminated vegetables.
- c. The problem of water pollution could become more serious in the future as the population of the city continues to grow rapidly. A complete urban sewage collecting system may be economically unfeasible. A system to divert the Abo-Kebena and other polluted rivers in the city and treat such water leaving the city may be feasible and would result in the flow of cleaner water to downstream users.
- d. However, there must be a long term plan to separate the sewage collection and transport system from rivers and streams in the

city. This ensures the flow of cleaner water both in the city and out of the city.

- e. Practically no research has been carried out in this country and it is time to expand much further, the information foundation upon which important water use planning may be based in order to preserve the ecology of rivers and streams in the cities and to ensure better health conditions.

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Appendix - A Nitrate, orthophosphate, BOD₅ and temperature at each station (dry season).

Station No.	nitrate mg l ⁻¹	orthophosphate mg l ⁻¹	BOD ₅ mg l ⁻¹	temperature (°C)
1	0.30	.01	---	13.5
2	0.32	.01	.05	13.5
3	0.30	.02	0.1	13.0
4	0.38	.02	0.3	14.5
5	0.50	.025	0.5	14.0
6	0.82	.055	2.5	14.5
7	4.2	1.1	9.0	15.5
8	3.00	0.50	6.5	15.0
9	4.04	1.30	15.0	15
10	4.30	1.35	16.5	15
11	4.6	1.5	22.0	15
12	4.8	1.95	24	15
13	5.0	2.3	27.5	15.5
14	4.75	2.1	26.0	15.5
15	5.3	2.57	29.0	15.5
16	7.4	3.5	37.0	16
17	8.1	3.7	42	16
18	13.2	4.75	54	16
19	14.3	5.25	58	16.5
20	14.8	5.34	64.5	16.5

Appendix - B Nitrate, orthophosphate, BOD₅ and temperature at each station (wet season).

Station No.	nitrate mg l ⁻¹	orthophosphate mg l ⁻¹	BOD ₅ mg l ⁻¹	temperature (°C)
1	0.62	.08	0.9	15
2	0.60	.08	0.7	15
3	0.5	.07	1.0	15
4	0.64	.08	1.25	15
5	0.76	.06	1.5	15.1
6	0.88	.09	2.5	15.1
7	1.30	.20	3.00	15
8	1.38	.21	3.5	15
9	1.51	.39	3.7	15
10	1.63	.40	4.0	15.5
11	1.92	.504	5.5	15.5
12	2.00	.70	8.8	16.0
13	2.1	.83	10.5	16.0
14	2.2	.88	12.25	16.0
15	2.5	1.01	12.6	16
16	2.8	1.25	14.0	16
17	3.2	1.3	15.5	17
18	5.4	1.83	20.0	17
19	5.55	1.95	22.5	17
20	5.75	2.01	24.5	17.5

Appendix - C Total number of organisms, number of taxa and CBS for each station.

Station No.	No. of Organisms collected	Number of taxa	Chandler's Biotic Score
1	268	28	1416
2	356	27	1391
3	469	25	1352
4	456	26	1345
5	632	25	1233
6	796	25	1187
7	796	22	993
8	726	21	971
9	857	21	734
10	864	19	603
11	1154	19	597
12	1024	17	498
13	1476	16	518
14	1232	18	501
15	1154	16	472
16	1073	16	473
17	567	14	420
18	182	11	267
19	120	10	255
20	73	9	213

APPENDICES: D to X - Type and number of Invertebrates Collected at Each Station.

APPENDIX D

Station 1

Invertebrates	dry season	wet season
<u>Neoperla</u>	15	11
<u>Baetis harrisoni</u> BARNARD	120	49
<u>Centroptilum varium</u> CRASS	4	4
<u>Centroptilum sudafricanum</u> LESTAGE	3	3
<u>Pseudocloeon maculosum</u> CRASS	21	8
<u>Afronurus peringueyi</u> ESBEN-PETERSON	7	1
<u>Afronurus harrisoni</u> BARNARD	5	13
<u>Caenis</u> spp	1	4
<u>Hydropsyche</u>	5	3
<u>Cheumatopsyche</u>	6	6
<u>Hydroptila</u>	1	2
<u>Chimarra</u>	1	5
<u>Sinilium</u>	24	2
<u>Limnophora</u>	1	--
<u>Tipula</u>	1	--
<u>Corynoneura dewulfi</u> : GEOTGHEBUER	1	--
<u>Cricotopus flavozonatus</u>	2	14
<u>Rheocricotopus capensis</u> (FREEMAN)	3	1
<u>Parametricnemus scotti</u> (FREEMAN)	21	3
<u>Rheotanytarsus</u>	3	1
<u>Polypedilum</u>	1	--
<u>Chonchapelopia trifascica</u> (FREEMAN)	1	1
<u>Ablabesmyia dusoleilu</u>	2	--
<u>Paramerina</u>	1	--
Elmidae	13	6
Psephenidae	2	--
<u>Dugesia</u>	2	--
<u>Tubifex</u>	1	--

APPENDIX E

Station 2.

Invertebrates	Dry weight	Wet season
<u>Neoperla</u>	10	8
<u>Baetis harrisoni</u>	150	56
<u>Centroptilum varium</u>	4	1
<u>Centroptilum sudafricanum</u>	8	1
<u>Pseudocloeon maculosum</u>	13	12
<u>Afronurus peringueyi</u>	3	4
<u>Afronurus harrisoni</u>	5	15
<u>Caenis spp.</u>		3
<u>Hydropsyche</u>	9	7
<u>Cheumatopsyche</u>	7	9
<u>Hydroptila</u>	4	3
<u>Chimarra</u>	5	2
<u>Simulium</u>	63	5
<u>Limnophora</u>	2	--
<u>Corynoneura dewulfi</u>	1	--
<u>Cricotopus flavozonatus</u>	5	52
<u>Rheocricotopus capensis</u>	4	1
<u>Parametriocnemus scotti</u>	17	--
<u>Cardiocladius oliff FREEMAN</u>	4	--
<u>Rheotanytarsus</u>	14	2
<u>Polypedilum</u>	2	--
<u>Ablabesmyia dusoleili</u>	2	--
<u>Chonchapelopia trifascia</u>	1	1
<u>Paramerina</u>	1	2
Elmidae	10	--
Psephenidae	1	2
<u>Dugesia</u>	9	--
<u>Tubifex</u>	2	2

APPENDIX F

Station 3

Invertebrates	dry season	wet season
<u>Neoperla</u>	7	2
<u>Baetis harrisoni</u>	136	67
<u>Centroptilum varium</u>	2	1
<u>Centroptilum sudafricanum</u>	5	1
<u>Pseudocloeon maculosum</u>	15	6
<u>Afronurus harrisoni</u>	4	13
<u>Afronurus peringueyi</u>	2	4
<u>Caenis spp.</u>	4	11
<u>Hydropsyche</u>	12	14
<u>Cheumatopsyche</u>	6	13
<u>Hydroptila</u>	9	1
<u>Chimarra</u>	4	1
<u>Simulium</u>	127	9
<u>Limnophora</u>	3	3
<u>Cardiocladius Oliffi</u> FREEMAN	9	-
<u>Cricotopus flavozonatus</u>	3	63
<u>Rheocricotopus capensis</u>	71	--
<u>Parametriocnemus scotti</u>	7	1
<u>Pseudosmitta spp.</u>	--	1
<u>Rhentanytarsus spp.</u>	14	--
<u>Polypedilum spp.</u>	1	--
<u>Chironomus allaudi</u> KIFFER	1	--
Elmidae	7	--
Psephenidae	2	--
Leech	2	--
<u>Tubifex</u>	--	1
<u>Dugesia</u>	16	1

APPENDIX G

Station 4

Invertebrates	dry season	wet season
<u>Neoperla</u>	3	1
<u>Baetis harrisoni</u>	113	108
<u>Centroptilum varium</u>	1	0
<u>Centroptilum sudafricanum</u>	1	2
<u>Pseudocloeon maculosum</u>	7	14
<u>Afronurus harrisoni</u>	3	--
<u>Afronurus peringueyi</u>	--	4
<u>Caenis spp.</u>	2	15
<u>Hydropsyche</u>	7	6
<u>Cheumatopsyche</u>	3	4
<u>Hydroptila</u>	6	--
<u>Chimarra</u>	5	10
<u>Simulium</u>	45	3
<u>Limnophora</u>	1	--
<u>Cricotopus flavozonatus</u>	9	115
<u>Rheocricotopus capensis</u>	151	2
<u>Polypedilum</u>	--	1
<u>Ivetenia calvescens (EDWARDS)</u>	3	--
<u>Parametriocnemus scotti</u>	2	2
<u>Cardiocladius oliffi</u>	--	1
<u>Thienemanniella</u>	3	--
<u>Chironomus allaudi</u>	23	2
<u>Ablabesmyia dusoleili</u>	4	--
<u>Chonchopelopia trifascia</u>	3	--
<u>Paramerina</u>	23	2
<u>Rheotanytarsus</u>	2	3
Elmidae	4	--
Psephenidae	1	--
<u>Dugesia spp.</u>	46	3
<u>Ancylus</u>	1	--

APPENDIX H

Station 5

Invertebrates	dry season	wet season
<u>Neoperla</u>	--	1
<u>Baetis harrisoni</u>	204	70
<u>Centroptilum varium</u>	2	1
<u>Centroptilum sudafricanum</u>	1	--
<u>Pseudocloeon maculosum</u>	5	8
<u>Afronurus harrisoni</u>	6	--
<u>Afronurus peringueyi</u>	1	8
<u>Caenis spp.</u>	28	56
<u>Hydropsyche</u>	2	--
<u>Cheumatopsyche</u>	1	--
<u>Hydroptila</u>	5	2
<u>Chimarra</u>	1	1
<u>Simulium spp.</u>	41	5
<u>Cricotopus flavozonatus</u>	16	146
<u>Rheocricotopus capensis</u>	249	3
<u>Parametrioctenus scotti</u>	--	2
<u>Cardiocladius oliffi</u>	--	2
<u>Polypedilum spp.</u>	1	4
<u>Chironomus allaudi</u>	3	2
<u>Criptochironomus spp.</u>	3	4
<u>Ablabesmyia dusoleili</u>	20	8
<u>Chonchapelopia trifascica</u>	7	1
<u>Rheotanytarsus spp.</u>	10	1
<u>Elmidae</u>	2	--
<u>Tubifex</u>	1	1
<u>Limnodrilus</u>	1	--
<u>Ancylus</u>	1	--
<u>Dugesia</u>	21	1

APPENDIX I

Station 6

Invertebrates	dry season	wet season
<u>Neoperla</u>	--	1
<u>Baetis harrisoni</u>	86	56
<u>Centroptilum sudafricanum</u>	1	--
<u>Pseudocloeon maculosum</u>	4	2
<u>Afronurus harrisoni</u>	1	3
<u>Afronurus peringueyi</u>	5	--
<u>Caenis spp</u>	54	86
<u>Hydropsyche</u>	5	--
<u>Cheumatopsyche</u>	12	--
<u>Chimarra</u>	2	1
<u>Simulium spp.</u>	37	20
<u>Limnophora spp.</u>	8	1
<u>Cricotopus flavozonatus</u>	56	152
<u>Rheocricotopus capensis</u>	325	2
<u>Parametrioctenus scotti</u>	1	1
<u>Rheotanytarsus spp.</u>	21	8
<u>Ivetenia calvescens</u>	--	1
<u>Corynoneura dewulfi</u>	--	1
<u>Polypedilum spp.</u>	6	3
<u>Chironomus allaudi</u>	16	2
<u>Criptochironomus spp.</u>	14	5
<u>Ablabesmyia dusoleili</u>	66	13
<u>Chonchopelopia trifascica</u>	3	--
<u>Paramerina spp.</u>	1	--
Elmidae	1	--
<u>Dugesia spp.</u>	60	8
<u>Limnodrilus spp.</u>	--	1
<u>Nais spp.</u>	1	--
Leech	1	--

APPENDIX J

Station 7

Invertebrates	dry season	wet season
<u>Neoperla</u>	--	2
<u>Baetis harrisoni</u>	72	182
<u>Pseudocloeon maculosum</u>	3	1
<u>Afronurus peringueyi</u>	3	3
<u>Caenis spp.</u>	25	2
<u>Hydropsyche</u>	3	--
<u>Cheumatopsyche</u>	9	--
<u>Hydroptila</u>	2	3
<u>Chimarra</u>	1	1
<u>Simulum spp.</u>	84	3
<u>Limnophora spp.</u>	--	--
<u>Tipula spp.</u>	1	1
<u>Corynoneura dewulfi</u>	1	--
<u>Cricotopus bizonatus</u>	32	134
<u>Rheocricotopus capensis</u>	270	1
<u>Paratrichocladius micans</u>	--	2
<u>Polypedilum spp.</u>	135	31
<u>Criptochironomus spp.</u>	5	--
<u>Chironomus allaudi</u>	84	12
<u>Ablabesmyia dusoleili</u>	7	6
<u>Chonchopelopia trifascica</u>	1	--
<u>Rheotanutarsus spp.</u>	15	2
<u>Elmidae</u>	1	--
<u>Dugesia</u>	42	4
<u>Nais</u>	1	--

APPENDIX K

Station 8

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	58	193
<u>Pseudocloeon maculosum</u>	2	--
<u>Afronurus peringueyi</u>	1	1
<u>Caenis spp.</u>	14	3
<u>Hydropsyche</u>	1	--
<u>Cheumatopsyche</u>	2	--
<u>Hydroptila</u>	2	1
<u>Simulium spp.</u>	113	17
<u>Bezzia spp.</u>	--	1
<u>Limnophora spp.</u>	1	--
<u>Paratrichocladus micans</u>	--	5
<u>Cricotopus bizonatus</u>	26	75
<u>Cardiocladus oliffi</u>	245	47
<u>Rheocricotopus capensis</u>	--	2
<u>Parametricnemus scotti</u>	--	3
<u>Chironomus allaudi</u>	104	36
<u>Polypedilum spp.</u>	105	61
<u>Ablabesmyia dusoleili</u>	5	1
<u>Chonchopelopia trifascica</u>	1	--
<u>Rhectanytarsus</u>	1	--
<u>Dugesia</u>	29	5
<u>Tubifex</u>	1	3
<u>Limnodrilus</u>		
<u>Nais</u>	12	1
<u>Ancyclus</u>	3	1

APPENDIX L

Station 9

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	65	123
<u>Pseudocloeon maculosum</u>	4	--
<u>Caenis spp.</u>	6	2
<u>Simulium</u>	194	7
<u>Limnophora</u>	3	--
<u>Tipula</u>	1	--
<u>Forcipomyia</u>	--	1
<u>Atrichopogon</u>	--	1
<u>Cricotopus bizonatus</u>	53	75
<u>Paratrichocladius micans</u>	--	2
<u>Rheocricotopus capensis</u>	197	96
<u>Orthocladius spp.</u>	--	2
<u>Ivetenia calvescens</u>	--	1
<u>Polypedilum spp.</u>	58	7
<u>Dicrotendipes pilosimanus</u>	1	--
<u>Chironomus allaudi</u>	195	53
<u>Limnophyes natalensis KIEFFER</u>	1	--
<u>Criptochironomus spp.</u>	2	--
<u>Parametriocnemus scotti</u>	3	7
<u>Ablabesmyia dusoleili</u>	3	1
<u>Rheotanytarsus spp.</u>	3	--
<u>Dugesia</u>	41	--
<u>Ancylus</u>	1	1
<u>Tubifex</u>	3	2
<u>Limnodrilus</u>	3	4
<u>Nais</u>	21	1

APPENDIX M

Station 10

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	89	41
<u>Caenis spp.</u>	31	6
<u>Simulium spp.</u>	205	12
<u>Limnophora spp.</u>	2	--
<u>Cricotopus bizonatus</u>	78	16
<u>Rheocricotopus capensis</u>	168	71
<u>Pseudosmitta spp.</u>	1	--
<u>Parametriocnemus scotti</u>	-	1
<u>Paratrichocladius micans</u>	1	1
<u>Tvetenia calvescens</u>	--	1
<u>Criptochironomus spp.</u>	1	--
<u>Chironomus allaudi</u>	157	123
<u>Polypedilum spp.</u>	22	7
<u>Dicrotendipes pilosimanus</u>	4	2
<u>Ablabesmyia dusoleili</u>	9	1
<u>Rheotanytarsus spp.</u>	4	--
<u>Dugesia</u>	64	--
<u>Ancylus</u>	2	--
<u>Tubifex</u>	7	2
<u>Limnodrilus</u>	4	1
<u>Nais</u>	15	2

APPENDIX N

Station 11

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	123	59
<u>Pseudocloeon maculosum</u>	--	3
<u>Caenis spp.</u>	68	3
<u>Simulum spp.</u>	253	8
<u>Limnophora spp.</u>	24	--
<u>Tipula spp.</u>	1	--
<u>Forcipomyia spp.</u>	--	1
<u>Cricotopus bizonatus</u>	43	58
<u>Rheocricotopus capensis</u>	130	36
<u>Orthocladus spp.</u>	--	2
<u>Paratrichocladus micans</u>	2	8
<u>Parametricnemus scotti</u>	--	2
<u>Polypedilum spp.</u>	41	1
<u>Dicrotendipes pilosimanus</u>	2	--
<u>Chironomus allaudi</u>	297	35
<u>Rheotanytarsus spp.</u>	2	1
<u>Ablabesmyia dusoleili</u>	15	2
<u>Chonchapelopia trifascica</u>	1	--
<u>Paramerina spp.</u>	1	--
<u>Dugesia</u>	82	--
<u>Tubifex</u>	80	--
<u>Limnodrilus</u>	11	--
<u>Nais</u>	38	3

APPENDIX O

Station 12

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	156	33
<u>Caenis spp.</u>	51	4
<u>Simulium</u>	189	6
<u>Limnophora</u>	19	1
<u>Culex</u>	--	1
<u>Cricotopus bizonatus</u>	25	69
<u>Rheocricotopus capensis</u>	124	14
<u>Paratrichocladius micans</u>	1	3
<u>Polypedilum spp.</u>	15	--
<u>Dicrotendipes pilosimanus</u>	1	--
<u>Chironomus allaudi</u>	249	48
<u>Ablabesmyia dusoleili</u>	11	--
<u>Rheotanytarsus spp.</u>	5	--
<u>Pseudosmitta spp.</u>	1	--
<u>Dugesia</u>	45	--
<u>Tubifex</u>	39	2
<u>Limnodrilus</u>	28	1
<u>Nais</u>	65	5

APPENDIX P

Station 13

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	352	3
<u>Caenis spp.</u>	28	1
<u>Simulium</u>	136	3
<u>Limnophora</u>	2	--
<u>Cricotopus bizonatus</u>	5	103
<u>Tvetenia calvescens</u>	--	1
<u>Rheocricotopus capensis</u>	519	17
<u>Pseudosmitta spp.</u>	--	3
<u>Paratrichocladius micans</u>	--	6
<u>Chironomus allaudi</u>	201	12
<u>Polypedilum spp.</u>	10	--
<u>Dicrotendipes pilosimanus</u>	4	--
<u>Paramerina spp.</u>	--	2
<u>Ablabesmyia dusoleili</u>	6	--
<u>Chonchapelopia trifascica</u>	2	--
<u>Rheotanytarsus spp</u>	6	--
<u>Dugesia</u>	33	--
<u>Tubifex</u>	57	4
<u>Limnodrilus</u>	12	3
<u>Nais</u>	103	7

APPENDIX Q

Station 14

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	183	3
<u>Caenis spp.</u>	59	--
<u>Simulium</u>	11	5
<u>Culex</u>	2	--
<u>Limnophora</u>	--	2
<u>Cricotopus bizonatus</u>	24	95
<u>Rheocricotopus capensis</u>	182	18
<u>Paratrichocladius micans</u>	1	18
<u>Chironomus allaudi</u>	490	35
<u>Polypedilum spp.</u>	14	3
<u>Dicrotendipes pilosimanus</u>	23	-
<u>Ablabesmyia dusoleili</u>	8	1
<u>Paramerina</u>	2	5
<u>Rheotanytarsus</u>	4	--
<u>Tanytarsus</u>	2	--
<u>Dugesia</u>	23	--
<u>Tubifex</u>	69	4
<u>Limnodrilus</u>	52	1
<u>Nais</u>	83	2

APPENDIX R

Station 15

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	148	2
<u>Caenis</u> spp.	12	--
<u>Simulium</u>	33	5
<u>Culex</u>	8	2
<u>Paratrichocladius micans</u>	--	14
<u>Cricotopus bizonatus</u>	50	134
<u>Parametriocnemus scotti</u>	--	2
<u>Rheocricotopus capensis</u>	177	25
<u>Limnophyes natalensis</u>	1	--
<u>Pseudosmitta</u> spp.	--	1
<u>Chironomus allaudi</u>	548	68
<u>Polypelidum</u> spp.	18	1
<u>Dicrotendipes pilosimanus</u>	34	16
<u>Ablabesmyia dusoleili</u>	4	--
<u>Paramerina</u> spp.	3	--
<u>Tanytarsus</u> spp.	5	--
<u>Dugesia</u>	2	--
<u>Tubifex</u>	38	5
<u>Limnodrilus</u>	22	7
<u>Nais</u>	51	2

APPENDIX S

Station 16

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	231	12
<u>Caenis spp.</u>	2	--
<u>Simulium</u>	145	17
<u>Culex</u>	1	-
<u>Ptychochaetodes sp.</u>	-	1
<u>Cricotopus bizonatus</u>	12	160
<u>Rheocricotopus capensis</u>	121	32
<u>Cardiocladius oliffi</u>	3	--
<u>Paratrichocladius micans</u>	1	6
<u>Chironomus allaudi</u>	440	73
<u>Polypedilum spp.</u>	13	6
<u>Dicrotendipes pilosimanus</u>	11	17
<u>Ablabesmyia dusoleili</u>	6	2
<u>Paramerina</u>	2	--
<u>Tanytarsus spp.</u>	1	--
<u>Tubifex</u>	14	7
<u>Limnodrilus</u>	9	4
<u>Nais</u>	60	1

APPENDIX T

Station 17

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	95	3
<u>Caenis</u> spp.	1	--
<u>Simulium</u>	108	3
<u>Psychoda</u> sp.	1	1
<u>Cricotopus bizonatus</u>	2	82
<u>Rheocricotopus capensis</u>	35	10
<u>Cardiocladius oliffi</u>	2	1
<u>Chironomus allaudi</u>	160	24
<u>Polypedilum</u> spp.	17	3
<u>Dicrtendipes pilosimanus</u>	15	5
<u>Ablabesmyia dusoleili</u>	6	1
<u>Tubifex</u>	20	2
<u>Limnodrilus</u>	17	--
<u>Nais</u>	88	--

APPENDIX U

Station 18

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	8	2
<u>Simulium</u>	7	5
<u>Psychoda sp.</u>	5	2
<u>Rheocricotopus capensis</u>	16	1
<u>Cardiocladius oliffi</u>	1	--
<u>Cricotopus bizonatus</u>	--	34
<u>Limnophyes natalensis</u>	--	1
<u>Chironomus allaudi</u>	52	4
<u>Polypedilum spp.</u>	4	2
<u>Dicrotendipes pilosimanus</u>	1	8
<u>Limnophyes natalensis</u>	--	1
<u>Tubifex</u>	48	2
<u>Limnodrilus</u>	39	--
<u>Nais</u>	23	1

APPENDIX V

Station 19

Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	9	1
<u>Simulium</u>	--	2
<u>Limnophora</u>	3	1
<u>Psychoda sp.</u>	3	1
<u>Limnophyes natalensis</u>	-	1
<u>Rheocricotopus capensis</u>	10	1
<u>Cricotopus bizonatus</u>	--	7
<u>Chironomus allaudi</u>	22	5
<u>Polypedilum spp.</u>	2	2
<u>Dicrotendipes pilosimanus</u>	1	1
<u>Tubifex</u>	35	3
<u>Limnodrilus</u>	24	2
<u>Nais</u>	11	--

APPENDIX W

Station 20

Type of Invertebrates	dry season	wet season
<u>Baetis harrisoni</u>	1	--
<u>Simulium</u>		2
<u>Limnophora</u>	4	--
<u>Phychoda sp.</u>	6	3
<u>Rheocricotopus capensis</u>	6	2
<u>Cricotopus bizonatus</u>	--	6
<u>Limnophyes natalensis</u>	--	1
<u>Chironomus allaudi</u>	15	7
<u>Polypedilum</u>	2	--
<u>Dicrotendipes pilosimanus</u>	--	2
<u>Tubifex</u>	18	5
<u>Limnodrilus</u>	13	3
<u>Nais</u>	7	2