IMPACT OF WATER QUALITY CHANGES ON RIVERINE MACROZOOBENTHIC DIVERSITY: A CASE STUDY OF RIVER GATHARAINI, KIAMBU DISTRICT, KENYA.

BY

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DECLARATION

This thesis is my original work. Except where acknowledgment is given, the paper is not substantially similar to work that has previously been or is being submitted for fulfilment of an academic requirement in any other university.

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DEDICATION

This thesis is dedicated to my dear parents Zacharia Ndaruga and Deborah Wanjiku in recognition of their great commitments and sacrifice in providing for my education from childhood to this day. It is also dedicated to all those who care for our environment.

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LIST OF ABBREVIATIONS

AAAS - American Association for the Advancement of Science

ANOVA - Analysis of Variance

C.E.Q - Council on Environmental Quality (in America)

E.C - Electrical Conductivity

F.T.U. - Formazin Turbidity Unit

GOK - Government of Kenya

IUCN - International Union for Conservation of Nature and Natural Resources

KARI - Kenya Agricultural Research Institute

KIFCON - Kenya Indigenous Forests Conservation

KNES - Kenya National Environment Secretariat

KWS - Kenya Wildlife Service

L.S.D. - Least Significant Difference

Ms - Microsiemens

NAS - National Academy of Sciences (in America).

NBU - National Biodiversity Unit

NMK - National Museums of Kenya

N.R.C. - National Research Council (in America)

OTA - Office of Technology Assessment (in America).

T.D.S. - Total Dissolved Solids

U.N - United Nations

UNEP - United Nations Environment Programme

UNICEF- United Nations Children's and Education Fund

U.S - United States

W.H.O. - World Health Organisation

WRI - World Resources Institute

WWF -World wide Fund for Nature

ABSTRACT

This study investigated the impact of water quality changes on the ecological structure of macro invertebrates in a tropical river. The macro-fauna was expected to change with changes in water characteristics. River Gatharaini was selected as the study area and several sampling stations were selected along its gradient. Selection of the sampling stations was based on the prominent land use immediately upstream which could discharge pollutants into the river either directly or indirectly through erosion. Major land use systems considered are arable/mixed farming, coffee plantations, industry (Kamiti Tannery factory) and housing estates.

The water parameters studied include TDS, EC, pH, DO, temperature and turbidity. A core sampler was used in sampling of macro invertebrates. This study was carried out for 7 months at a sampling interval of 28 days.

The results indicated significant seasonal and station variations in all the water quality parameters except temperature. Macrozoobenthic diversity trends also showed significant spatial trends along the river gradient although monthly trends were not significant. The greatest spatial temporal variation in water quality and species diversity was noted below the tannery factory whose water quality characteristics shows extreme pollution making it void of fauna life. With decreased pollution levels, the river showed signs of recovery several kilometers downstream where pollution tolerant species predominate This suggests that a self purification process was in place.

1.1 INTRODUCTION

Chemical assessments of water quality have always been an essential element in the protection of rivers particularly when water is required for human consumption. However, chemical monitoring alone does not tell us much on the effects of pollution on the living organisms.

The natural quality of terrestrial water bodies is determined by quality of surface run off and ground water discharge (Fish, 1992). Thus the quality of water coming from underground aquifers depends on the chemical composition of the bedrock with which it is in contact. As the water flows along the river, organic matter is added into it from autochthonous (produced within the ecosystem) or allochthonous (transported into the system from elsewhere) sources. This organic load increases downstream such that large rivers have a greater organic load than the smaller streams. Events in the riparian ecosystem largely determine the quantity, quality, timing and retention of allochthonous organic material received by streams (Cummins et al, 1980). Apart from organic matter, inorganic inputs of nitrogen, phosphorus and other elements in lentic and lotic ecosystems come from groundwater seepage, overland flow, leaching and breakdown of allochthonous organic matter that has been transported into the stream. Inputs of inorganic nutrients to lakes and rivers are highly influenced by land use within the watershed.

Interest for this study was raised by the fact that environmental monitoring, assessment and conservation are required for such rivers. This can only be done through repeated and standardised evaluation of water quality and biota to detect any significant changes. Surveillance provides information of changes in

population and distribution of species of special concern and is a good tool in sustainable management of biological systems. Studies of water quality changes and biological diversity of river Gatharaini was considered critical in undestanding how they function and how human alteration of catchments and watersheds affect riverine biodiversity and productivity. It is expected that data from this study could form the baseline for future monitoring of water quality and aquatic biodiversity of river Gatharaini and other rivers sharing the Aberdare catchment.

1.2 STATEMENT OF THE PROBLEM

River Gatharaini passes through the following land use types on its way downstream; arable farms, coffee plantations, housing estates and industries like Kamiti Tannery Factory. These land use types discharge different types of wastes into the river which in turn affects the river's water quality and it's associated biological diversity. Thus this study seeks to answer the following question:- ***"What impact do changes in water quality along river Gatharaini have on the riverine macrozoobenthic diversity?"***

In most parts of the world, population increase, urbanisation and agricultural intensification has occurred at high rates since 1960's. River Gatharaini catchment is no exception. Excessive nutrient loading due to recent agricultural intensification and increased domestic and industrial wastes are expected to have significant ecological effects on receiving waters of river Gatharaini. Consequences of such impacts on the water quality are reflected in the nature, variety and abundance of aquatic biota ranging from

minor modifications in species composition to complete degradation of natural assemblages.

1.3 THE OBJECTIVES OF THE STUDY

The goal of this study was to establish the impact of riverine water quality changes on macrozoobenthic diversity. In order to accomplish this, the following objectives were proposed to guide the study.

1. To determine physical - chemical characteristics of water along river Gatharaini so as to detect if there are any significant changes as it passes through various land use types.
2. Identify the various macrozoobenthic organisms present in the river.
3. Establish the density and diversity trends of the various macrozoobenthic organisms in the river and relate them to the physical chemical changes taking place in the river.
4. Identify some indicator species which can be used by wetland managers to detect changes in water quality.

1.4. RESEARCH QUESTIONS

In order to focus the study to the set objectives, the following questions were set:

1. Does the water quality change along the horizontal (altitudinal) gradient of river Gatharaini?
2. Which macrozoobenthic organisms occur along the river?
3. Is the distribution, diversity and abundance of macrozoobenthic organisms affected by changes in water quality?

1.5. MAJOR ASSUMPTIONS

This study assumed that:

1. The macrozoobenthic organisms were evenly distributed in the river channel.
2. Any water quality changes likely to be observed are principally due to influence of discharges along the river channel.
3. Any changes in the distribution, diversity and abundance of macrozoobenthos is attributable to the changes in water quality observed.

1.6. HYPOTHESIS OF THE STUDY

This study was conceived around two null hypotheses;

1. The water quality of the river is not affected by the changes in land use system adopted upstream.
2. Changes in water quality does not affect the distribution, abundance and diversity of macrozoobenthic organisms in the river.

1.7. AREA OF STUDY

This study was carried out in a small all weather stream called Gatharaini. This river originates from Kabete and Karura forests in Kiambu district and flows into Nairobi Province before joining river Nairobi. River Gatharaini catchment originates from Limuru division and passes across Kiambaa division before entering Nairobi Province where it joins with river Nairobi (Fig. i)

River Gatharaini occurs between latitude 1°10'S and 1°14'S and longitude 36°45'E and 36°57'E (Fig i). The whole river extent is about 40km long and descends from altitude 1840 to 1500m above sea level. Thus the average gradient of the river is 1:8.5km. The

average annual rainfall in this region varies from 1000-1500mm (Fig. iv) bimodally distributed with peaks in March-April and Sept-Oct (Waters and Odero, 1986). The width of the river varies from 45cm at the source to 2m below the tannery. Depth varies from 10cm at the source to 95cm below the tannery. The depth and width of the river were greatest during the rainy month of March and April when it overflows the banks.

The whole study area catchment lies in one of the most productive regions of Kenya. Agriculture, Industrial production and housing estates are the main land use systems (Fig. ii).

A combination of good soils, suitable climate, well developed infrastructure and close proximity to Nairobi makes river Gatharaini catchment area the most economic region for farming in the country. Small scale farming dominates with about 70% of families having less than 1.2 ha. of farmland (Kimani and Kimei, 1989). Subsistence crops grown include maize, beans, potatoes, bananas, sorghum and sweet potatoes. Horticultural crops grown here include vegetables such as kale, carrots, cabbages, tomatoes, spinach and onions. Fruits grown include avocados, pawpaws and bananas.

Coffee is the main cash crop grown along the catchment. The small scale farmers in Kiambu district own 8,300 ha of coffee while plantations own 16,000 ha. The large scale farms are highly mechanized especially with respect to preparation of the land, weeding and spraying. Most estates irrigate their crops and use artificial fertilizers and pesticides. These large scale farms have higher yields than small scale farms. Small farms use human labour in cultivation, weeding, spraying and harvesting. Animal manure as well as fertilizers are used. In small scale farms,

subsistence crops are consumed by the family while the surplus is sold at the local market. Yields from annual crops are comparatively low despite widespread use of fertilizers and other farm inputs indicating that soil fertility in intensively cropped lands is very low (Kimani and Kimei, 1989). The river therefore experiences extensive pollution by fertilizers and pesticides (section 4.1) from the small scale and large scale farms.

Several industries are found along river Gatharaini catchment. These includes several coffee processing factories situated within the coffee estates. Kamiti Tannery factory is also situated along the river course. These factories are responsible for introducing varying amounts of toxic wastes into the river (section 4.1).

River Gatharaini passes through varying types of rocks on its way downstream (fig. iii). The upper parts of the river are dominated by Limuru Trachytes and quartz trachytes. The river then flows over the Nairobi trachytes and then through Lower Kirichwa valley tuffs. Some sections downstream are dominated by Middle and Upper Kirichwa valley tuffs. The underlying rocks are volcanic larva, tuffs and basement complex. The tertially trachytic larva which covers most of the area is derived from the ancient fissures on the Eastern flanks of the rift valley. These rocks were formed during the Cenozoic and Quarternary era (Buckle, 1978).

These varying rock types have greatly influenced the soil types occuring along the catchment (fig v). The R1 soils are developed on the Limuru trachytes. They are well drained, very deep, dark reddish Nitisols. Soils of R2 are mainly developed on the Nairobi trachytes and Kerichwa valley tuffs. They are well drained, extremely deep dusky red Nitisols (Sombroek et al, 1982). Due to the depth and high porosity, Nitisols are able to store large amounts

of plant nutrients and soil moisture. This makes them very useful for agriculture.

Soils in the Phonolitic larva plateaus (L) are mainly developed on the Phonolites which in some cases may be overlain by the Kerichwa valley tuffs. They are poorly drained, deep, dark greyish, cracking clay Vertisols. Vertisols are usually characterised by high chemical fertility but have poor physical properties. They are normally very hard when dry then sticky and plastic when wet (FAO-UNESCO, 1990)

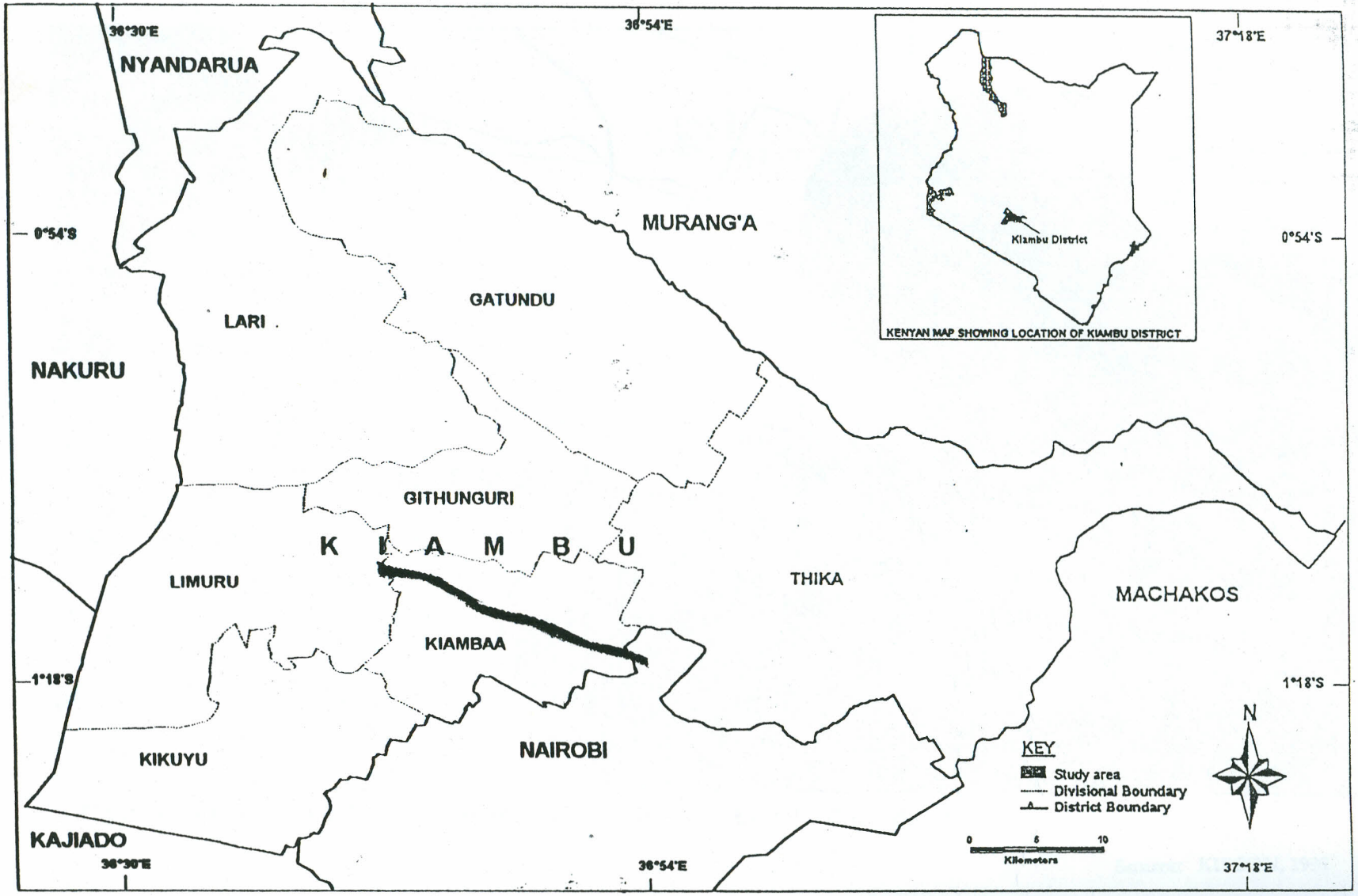


Fig. I: Map of Kiambu District showing administrative boundaries

Source: KIFCON, 1992

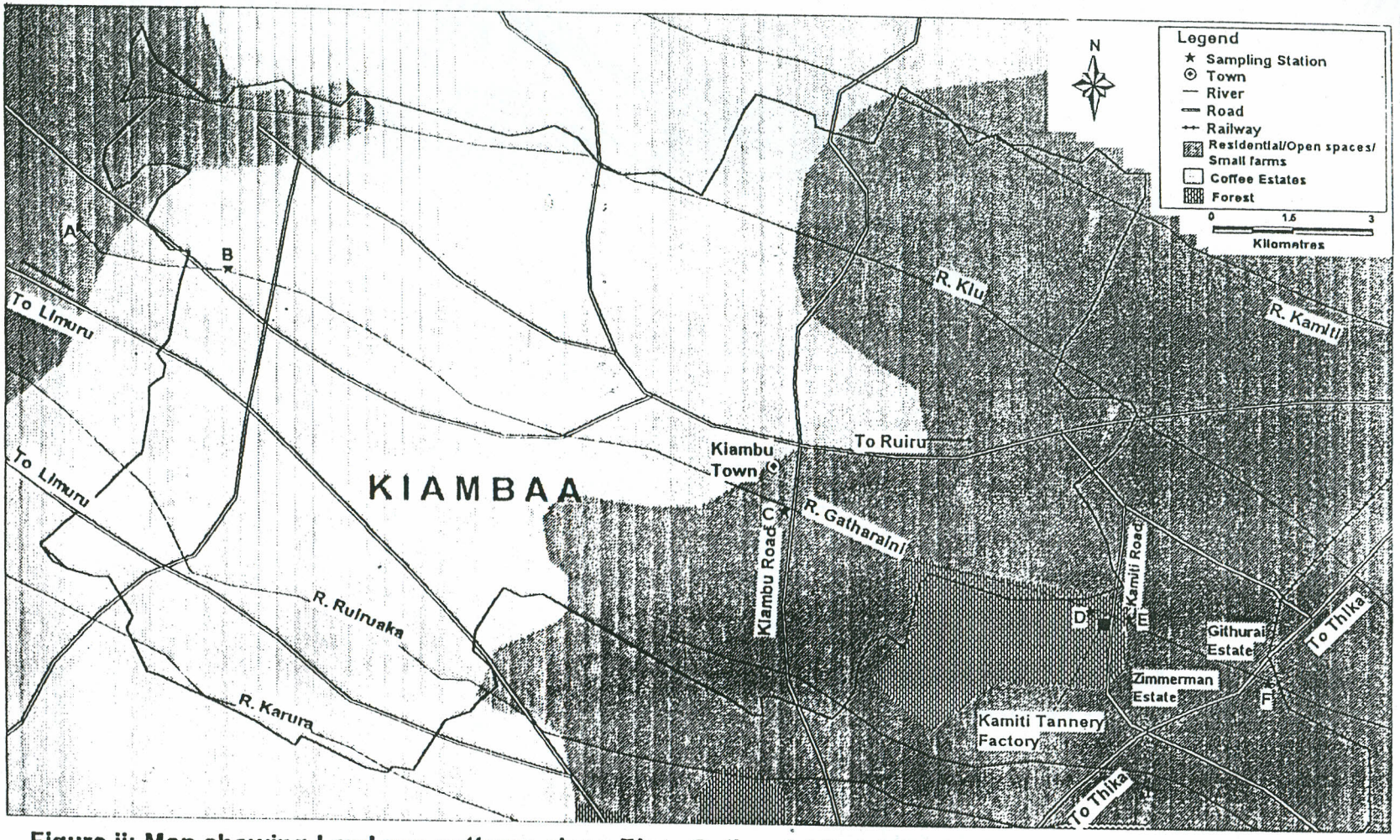


Figure ii: Map showing Land use patterns along River Gatharaini Catchment

Source: KIFCON, 1992

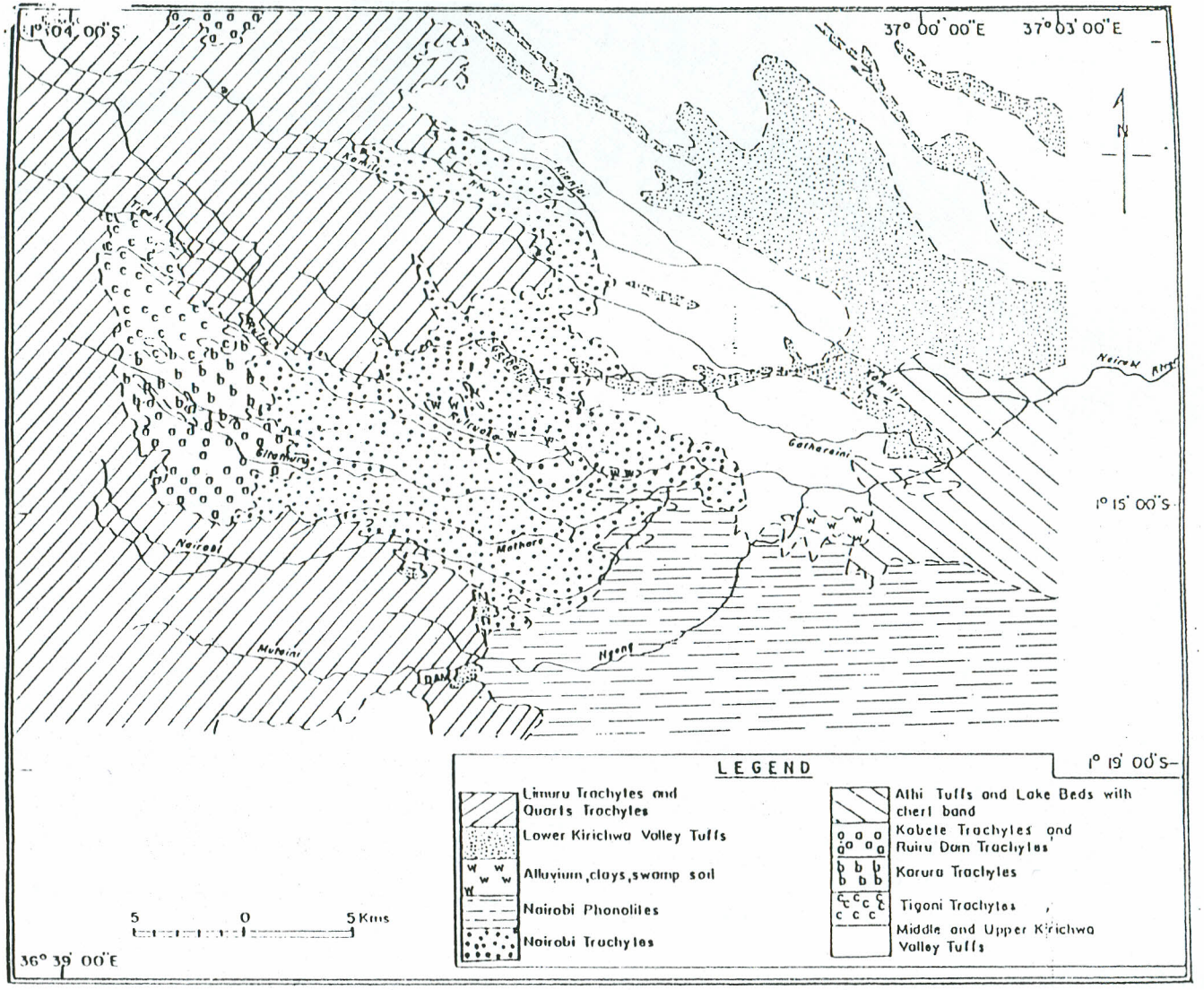


Fig. iii: Geology patterns along river Gatharaini

Source: Survey of Kenya, 1967

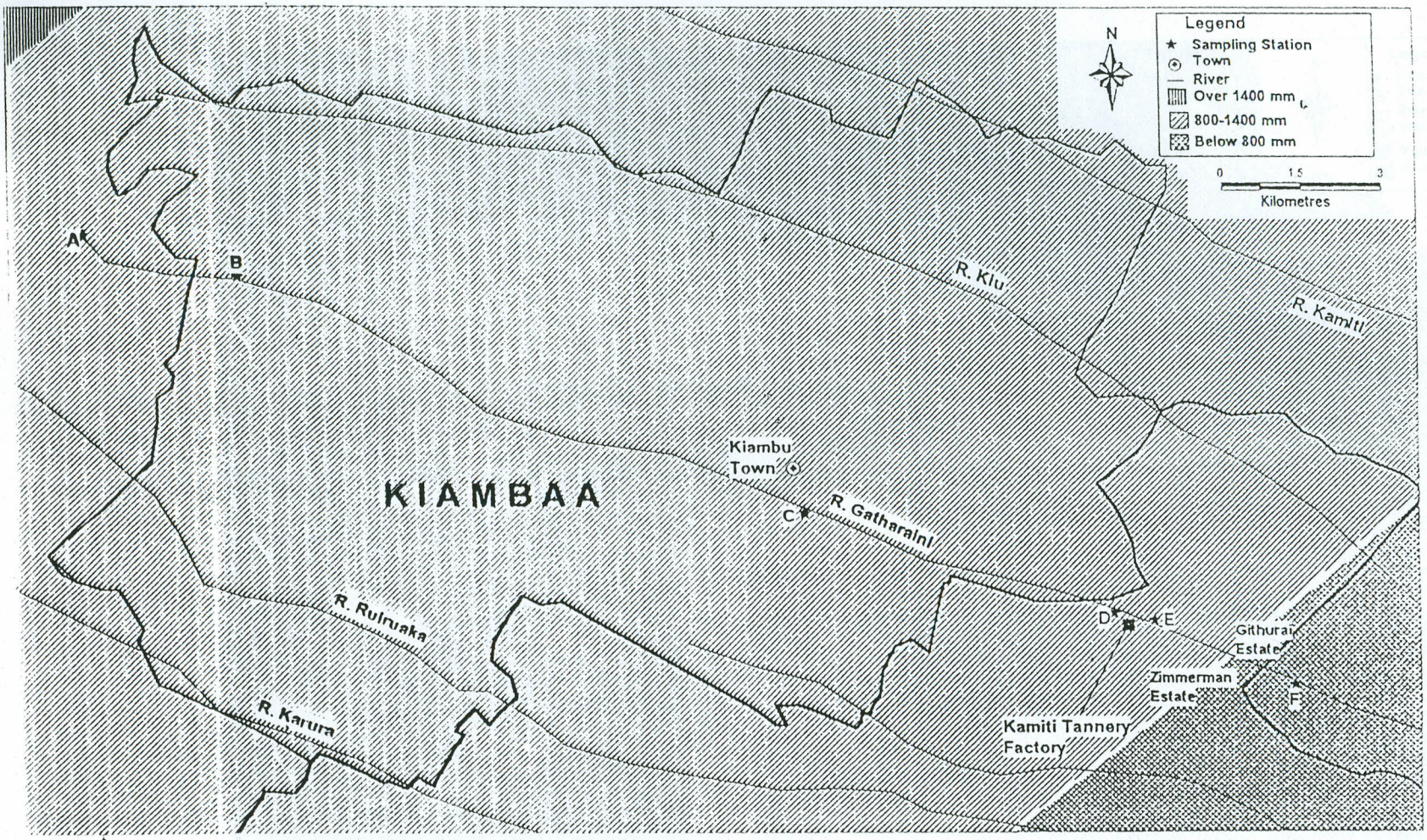


Figure iv: Map showing Average Annual Rainfall patterns along River Gatharaini Catchment

Source: KIFCON, 1992

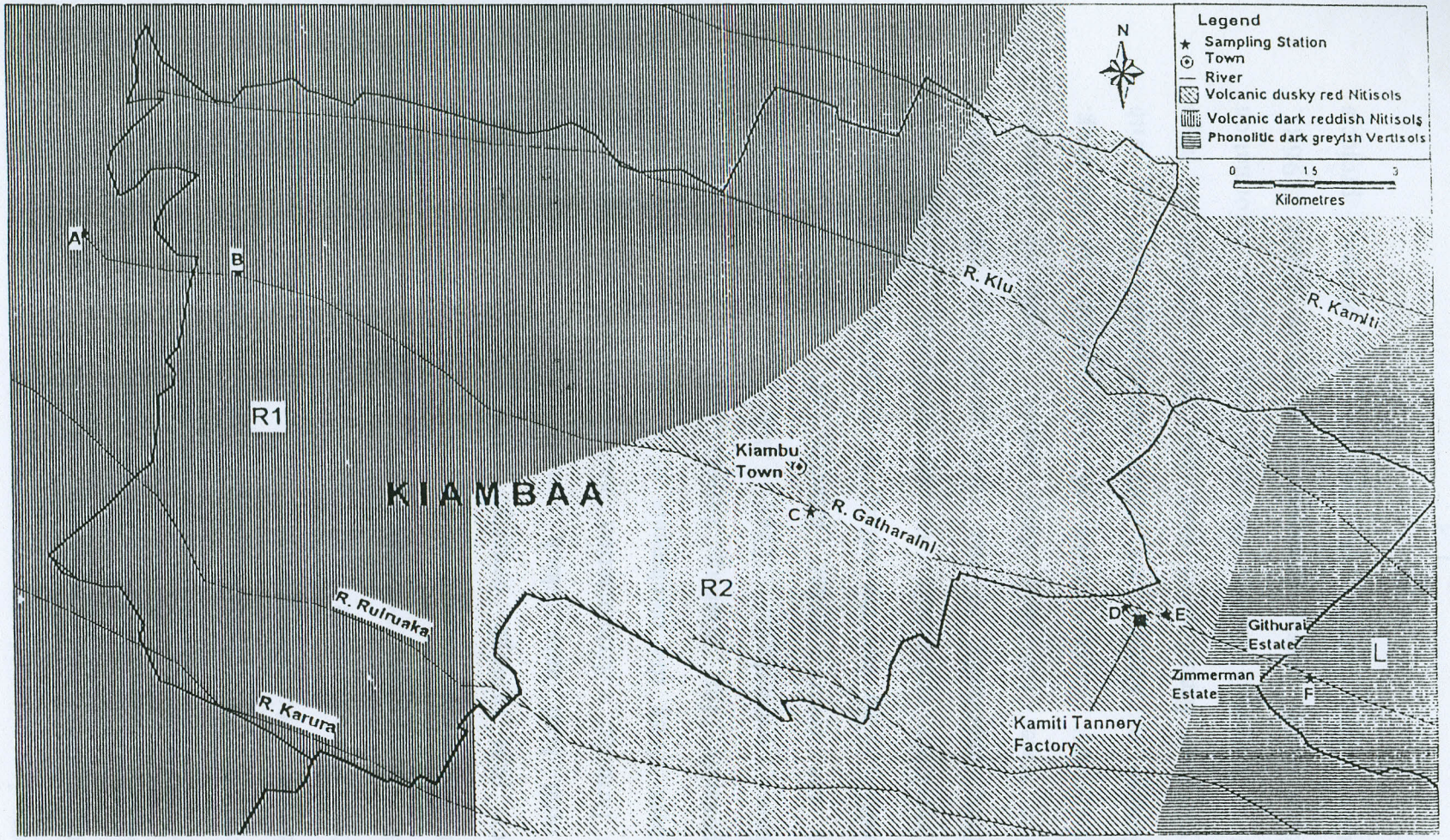


Figure v: Map showing Soil patterns along River Gatharaini Catchment

Source: KIFCON, 1992

1.8. SIGNIFICANCE OF THE STUDY

The natural environment is under continued threat due to different land use types proposed and undertaken. In most cases the entire habitats and species assemblages are altered or totally replaced for example by construction of industries, highways, airports, dams and residential estates. Further effluents from the resultant land use types may get into natural ecosystems causing changes in the carrying capacity of the ecosystem or even the wiping out of some species. In Kenya population growth, urbanization, industrialization and agricultural intensification are now significant matters of concern because of resultant pollution (NBU 1992).

Most rivers in Kenya originate from the highlands. As they flow down-slope they pass through densely populated areas. They also pass through rural land uses which consist mainly of subsistence and cash crop farming. Urbanisation and industralisation are also common land uses along the catchments of most rivers. These land uses are responsible for altering former natural habitats that existed in these watersheds. They also introduce pollutant discharges into the rivers either directly or indirectly through erosion and runoff. This has the effect of reducing the volume of clean water available especially in the lowlands. This has deleterious effects especially to the rural population who entirely depend on river water for their daily needs. Data on chemical composition of many large rivers of the world is lacking. Limnological Studies of streams are fewer than those dealing with lakes. In Kenya, most limnological work has been confined to large lakes especially in the Rift Valley, but only very little information is available about small lakes, reservoirs and rivers (Lind, 1968). Thus this research was timely as one of the pioneer projects

designed to give information on the water quality status of rivers which serve regions with different land uses. Pollution has also been identified as a major disturbance in rivers causing changes in species assemblage in aquatic ecosystems (Kinyua and Pacini, 1991).

This study was also aimed at assessing the impact of changes in physical and chemical conditions of river water on the resident aquatic biota. So, other than providing a general picture of the chemical and biological conditions of river Gatharaini, this study can provide a good reference point of effects of urbanization, industrialization and agricultural intensification on tropical water bodies. Hence this study has provided useful information necessary in planning appropriate land use systems in Kenya and other tropical African Countries.

1.9. LIMITATIONS OF THE STUDY

1. Due to hardships involved in identification, classification and counting of macrozoobenthic organisms, sampling was carried out in 6 stations.
2. Because of shortage of time and lack of adequate finances, only the most essential water quality parameters were measured.

2.0. DEFINITION OF TERMS

1. Biological diversity (biodiversity) may be defined as the sum total of genotypes of living organisms. Wilson (1992) defined biodiversity as the variety of organisms considered at all levels, from genetic variants belonging to the same species to arrays of taxonomic units (family, genera and species). It also comprise the variety of ecosystems in terms of both the communities of

organisms within particular habitats and the physical conditions in which they live. Another widely used definition of biodiversity is "the variety and variability among living organisms and the ecological complexes in which they occur."(OTA, 1987).

2. Biological resources include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value to humanity (United Nations Convention on Biodiversity, 1992)

3. Community refers to all the biological populations of different species that live within a common geographical area (Stansfield, 1977)

4. Conservation is defined as the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining it's potential to meet needs and aspirations of future generations. Thus conservation embraces preservation, maintenance, sustainable utilisation, restoration and enhancement of the natural environment (IUCN, UNEP, WWF, 1980)

5. Disturbance refers to any relatively discrete event in time that removes organisms and opens up space which can be colonised by individuals of the same or different species (Townsend, 1989).

6. Ecosystem refers to the biotic community and its non-living environment as an interacting system (Southwick, 1976)

7. Evolution is a Scientific theory proposing that higher forms of life have descended from lower forms by a gradual process of modification through natural mechanisms (Stansfield, 1977)

8. Macrozoobenthos - Animals visible to the naked eye living in the bottom layer of any body of water.

9. Species - can be considered as an assemblage of freely interbreeding organisms exhibiting characteristics which are distinctive from other assemblages (Stansfield, 1977)

10. Sustainable development is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs (UNEP, 1992)

11. Wetlands - refers to areas of marsh, fen, peatland or water whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water the depth of which at low tide does not exceed six metres (Dugan, 1990).

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

As discussed in Chapter 1 river Gatharaini catchment area is a region with diverse land use systems. Most of these land use systems have only come up recently mainly due to population pressure and economic considerations. Today the land use systems are undergoing dynamic changes as new economic land use practices are adopted.

Thus it can clearly be seen that, today, economic forces control human exploitation of both living and non living natural resources. Most of the economic processes are much faster than most ecological processes (Stenseth, 1992). It is important to understand the interaction between economics and ecology in the exploitation of natural resources. This is because complicated and unexpected dynamic behaviour may emerge from such interactions (Stenseth and Maynard, 1984). Differences between economic and ecological considerations lies on the fact that economists aim at finding equilibrium conditions while ecologists focus more on the study of dynamic changes resulting from perturbations around an equilibrium (Maynard, 1985).

Along river Gatharaini, many land use types are represented (Fig. ii). These include arable farming, coffee estates, industrial land use (Kamiti tannery factory) and residential land use. From arable and coffee estates there are massive inputs of fertilizers and pesticides to boost production. It has been discovered that these gain access to the riverine system and the most probable means is through runoff as a result of soil erosion from the farmlands. Indeed increased levels of nutrients and pesticides have been recorded in

rivers passing through Kiambu district (Kiithia and Musingi, 1995). From industrial and residential land use systems inorganic discharges such as heavy metals, and other ionic discharges may be released directly into the river. Organic discharges such as sewage and detergents may also get into the river from residential land use. These discharges cause deterioration in water quality, for example reduced dissolved oxygen levels, increase in turbidity causing reduction in light penetration or even increase in pH. All these decrease the aesthetic value of the river water and in most cases make the water unfit for human consumption. This leads to a reduced volume of clean quality water available especially in the lowlands. Several studies have implicated industrial wastes and sewage disposal as the main causes of water pollution which often lead to loss of aquatic life (Njuguna, 1978; Kinyua and Pacini, 1991). Thus introduction of pollutants into the aquatic ecosystems is a big problem which even leads to loss of the biological diversity in these regions or replacement of natural biota by tolerant species thus changing the community structure of the aquatic habitats. Indeed change in land use result in destruction of habitats and loss of biological diversity.

2.2. BIOLOGICAL DIVERSITY

The world's biological diversity is a vast and often undervalued resource. Consisting of every form of life from the minutest microbes to the largest organisms, biodiversity refers to the variety and variability of all plants, animals and micro-organisms and the ecological complexes in which they occur (OTA, 1987). The diversity of life on earth has always been dynamic. The earth's biodiversity, that is its ecosystems, species and genes are a product

of over 3000 million years of evolution (Zedan, 1995). Within this time small changes have accumulated in populations resulting into a multitude of living forms closely adapted to the physical conditions they face and to each other. Global biodiversity has therefore fluctuated through geological time as evolution has added new species and extinction has taken others away (Ehrlich *et al*, 1963). Evolution and extinction thus are natural processes which are the responses of populations of organisms to changes in their physical and biological environment. (Jablonski, 1991).

Cultures from ancient times to the present day have exploited biodiversity. The fundamental ethical, cultural and economic values of biodiversity has been recognised in religion, art, and literature from the earliest days of recorded history (McNeely *et al*, 1990). Some of our most important crops and livestock were developed from their wild relatives by neolithic farmers from various parts of the world about ten thousand years ago. These farmers soon realised that some species were more suitable than others in terms of having beneficial characteristics and being suited to their specific requirements. Thus they selected, bred and used these individuals in preference to others, practices that continue to this day. Through selection and breeding, human societies have developed thousands of local races of crops and livestock each fitting a particular need in a specific physical environment and evolving in harmony with the diverse systems of land and natural resources management of which they are integral parts.

The maintenance of this diversity has until recently been assured by traditional systems of agriculture and land use. However with advent of scientific breeding, new plant varieties, animal breeds and strains of micro-organisms began to be developed through

selective breeding in response to needs of quite different intensive production systems (OTA, 1987). The development of modern varieties, breeds, strains and production systems while increasing productivity and helping to satisfy needs of a rapidly growing population has also created problems. Performance of these new varieties hinges on substantial external inputs, for example fertilisers and pesticides which are sometimes deleterious to the environment (Zaden, 1995). Without such inputs their potential will not be realised. It has also led to production of large genetically uniform fields and herds which are vulnerable to rapid spread of pests and pathogens. These breeders depend upon the availability of a pool of diverse genetic material represented by local races and wild relatives in an effort to keep ahead of tomorrow's unexpected calamities since in themselves modern varieties provide a very restricted gene pool for further breeding. Thus diverse biological systems are necessary reservoirs if further improvement is to be realised (NRC, 1982).

Various other important values of biodiversity have been recognised although much yet remains to be discovered (CEQ, 1980) especially in the humid tropics whose potential of genetic resources is considered greatest (AAAS, 1981). According to Van der Zon (1995), biodiversity plays four main functions which are regulation, support, *information and production functions.* Forests and other plant cover are essential for regulation of the hydrological cycle upon which we depend for water. Thus the plants through transpiration help in providing moisture to the atmosphere which then falls as rain which serves both surface and underground reservoirs. Plants play a great support role in that they are the sole producers in all ecosystems. They provide energy and

nutrients to all other organisms in the food chains. So, a diverse ecosystem is supported by diverse numerous producers. Biodiversity plays a great role in providing information on the nature, variety and functions of various organisms and this helps in keeping options open for the future (Abramovitz, 1991).

Biodiversity has many production functions. Wild species have long been the foundation for agriculture and will continue to play a vital role in providing new genetic material and even new species for crop use. Wild species have also provided many medicines among them analgesics, antimalarial drugs, contraceptive agents, cancer treatment and many others (Moreno and Schvartzman, 1975; Myers, 1979; WR1, 1993). Examples include the 3000 plant species known to posses anticancer properties 70% of which are from humid tropical forest (Wilkes, 1981). In the US 25% of all prescriptions contain active ingredients that are still extracted from plants (Fansworth, 1988). Thus wild plants, game, fish, timber, medicinal plants, fiber and fuelwood provide products upon which people depend on for health well being and local trade (Abramovitz, 1991).

2.3. THREATS TO BOLOGICAL DIVERSITY

Great changes have been observed in global biodiversity status. I n the past geological times, environmental changes occurred over relatively long periods of time often taking millions of years and hence organisms had enough time to evolve. However the environmental changes affecting biodiversity today have a different origin, order and magnitude than those recorded in geological annals. Today the rates and scale of environmental changes brought about by human activities have increased to the

point where a great many species may not have sufficient time in which to migrate and adapt (Ruskin, 1992). Estimates of the total number of species inhabiting the earth vary between 4 and 30 million. To date however only 1.4 million have been identified and far fewer have been seriously studied (Wilson, 1989). Most of the unidentified fauna and flora are thought to reside in tropical rain forests which cover only 7 percent of the earth's land surface (UNEP, 1989).

Environmental changes are a big threat to ecosystems, habitats, communities, species and genetic material. So when changes occur in the environment the organisms have to change or to adapt in accordance with the external dictation. Since some of the environmental changes are abrupt and tremendous most of the organisms go into extinction (Abramovitz, 1991). Naturally without human intervention one to ten species per year would be lost (Reid and Miller, 1989). But as a result of human actions, an even increasing number are lost even before being discovered. It is estimated that between 10,000 and one million animal species become extinct each year (Van der Zon 1995). By destroying them, we deny both our children and all future generations the opportunity to use natures bounty to create new technologies and produce new crops and medicines (UNEP and UNICEF, 1990).

Globally habitats and ecosystems are disappearing beneath agriculture, cities, industrial developments and dams. They are also becoming irreversibly damaged by pollution, over use and erosion. Many species are also threatened by over exploitation. The burgeoning needs of a rapidly growing population, poverty, inequitable land distribution, economic and political constraints and global climatic change also affect biodiversity (McNeely *et al*, 1990).

Illegal trade and competition with introduced alien species also affect biodiversity (Zaden, 1995).

Loss of genetic diversity is occurring much faster than species extinctions. Mutations brought about by chemical toxins in the environment are permanent and are transmitted to succeeding generations endowing the organisms with a superior or inferior traits. These toxins may eliminate some genetically distinct parts of a species yet not cause extinction. Breeders throughout the world are engaged in developing better and high yielding cultivars of crop plants and animal breeds to be used on an increasing larger scale. Traditional food crops and animal breeds are being abandoned and even lost for ever in favour of the newly developed ones. Worldwide food crop yields are increasing but the yield comes from ever fewer varieties (Zaden, 1995). Thus uniformity is replacing diversity. The main problem is that most countries do not have a complete inventory of their plants and most of the knowledge on their use is held by traditional societies whose very existence is now threatened (Guarino,1995). Loss of genetic variability makes the species more vulnerable to other factors such as susceptibility to inbreeding and also reduced adaptability to environmental changes (Soule, 1991).

Globally half of all marshes and wetlands have been lost. In North America the tall grass prairies have been reduced by 99 percent in area (WRI, 1990). The tropics, home for more than half of all species are being deforested at an alarming pace especially in the last 20 years. During this period tropical rain forests, one of the most species rich habitats in the world have been reduced by 42%. In early 1980's it was estimated that annual deforestation in the tropics was 11.4 million hectares (WRI, 1990). Estimates are that

Latin America loses 1.3 percent of its remaining forests each year while Asia loses 0.9 percent and Africa loses 0.6% (WRI, 1990). The consequence for many of the species that inhabit these dwindling areas is likely to be extinction. Other affected areas include the croplands and rangelands which are quickly being transformed into deserts. In tropical Africa, Asia and in Temperate regions, grasslands have been reduced by more than half their original extent. This has led to loss of many habitats and the communities and species inhabiting these areas have been adversely affected. These problems are by no means restricted to developing countries. Massive loss of forest, rangelands and coastal resources has already occured in the industrialised nations and continues at a rapid pace (Abramovitz, 1991).

All the causes of loss of biodiversity above tend to hinge around several social-economic and political changes experienced in most parts of the world. According to McNeely et al (1990), these changes include:-

- inequalities in the distribution of power, information and resources.
- the effects of global market forces and market failures that do not value natural resources.
- separation of environment conservation and economic development often involving the decline of indigenous systems of resource management
- Unsustainable levels of resource demand at a global level and lack of an ethical commitment to sustainability.

2.4. CONSEQUENCIES OF DECLINE OF BIODIVERSITY

This continued land degradation and loss of biodiversity can have adverse consequences to human kind. It can lead to increased poverty, increased incidence of environmental refugees and serious health problems. When fuelwood becomes scarce, poor families cook less, eat less nutritious meals and face serious malnutrition (Snyder, 1990). When land becomes infertile, many men leave the villages and seek wage employment in urban centres leaving an increasing number of female headed households marred by great poverty (Dankelman and Davidson, 1988; Sadek, 1989; U.N. 1989). Human and industrial pollution caused by a growing population moving to rivers, lakes and coastal regions affect water quality and this adversely affects aquatic resources worldwide. Clean water, abundant fisheries and other flora and fauna are needed to attract tourism revenue which has become a major portion of many economies (WRI, 1990). With degradation of biological diversity, this revenue will no longer be available leading to increased poverty.

Degradation of biological resources may also lead to catastrophies. Deforested and other disturbed areas experience temporary and or permanent disruptions of water supplies leading to increased flooding, reduction of water quality and productive decline of fisheries. Decreased biodiversity will also lower the opportunity of using wild relatives as potential breeding material and this would lead to lowered productivity which cannot sustain the ever increasing world population (Zaden, 1995).

Thus the maintenance of healthy and diverse natural resources is fundamental for survival of the human race. The intense pressure

on biodiversity will continue to increase unless appropriate conservation oriented measures are taken.

2.5 HUMAN FACTORS AFFECTING BIODIVERSITY IN KENYA.

The distribution of biodiversity in Kenya is shown on the table below

Table 3: Kenya's flora and fauna diversity

Organisms	**Total No of species**	**Remarks**
Animals	25,375	-For birds and mammals the total reported probably reflect true biodiversity - In other taxa conclusive information is not presently available.
Plants	6817	- algae excluded -majority (86%) are flowering plants - Angiospermatophyta
Micro-organisms	1841	-Includes viruses, monerans microfungi and protoctistans. -Micro algae are not included

Source: NBU 1992.

However rapid changes have occurred in Kenya leading to decline of biodiversity. Several human factors have been identified as attributing to this decline. These include population increase, conflict in land use activities, utilisation of energy resources, urbanisation, industrialisation and mining.

2.5.1 Population increase

In Kenya population growth has been rising. In 1962 population stood at 8.5 million people while in 1989 population had increased to 24 million. By the year 2000 the country expects to have a population of between 32-35 million people (Ominde, 1981). This brings about increased demand for land, food, facilities and industrial goods. In order to meet these needs, natural resources of land, soil, water and biodiversity will be extensively and intensively exploited. This if not managed properly with conservation insight would lead to great environmental degradation and biodiversity extinction.

2.5.2. Urbanisation and Industrialization

In 1948 Kenya had 17 towns with a total population of 276,000 people. In 1969 this rose to 48 towns with a total population of 1,079,908 people with Nairobi and Mombasa accounting for 70% of the total urban population. By 1979 there were 90 urban centres with a total population of 2 - 3 million people. (Ondiege, 1988).

Rapid urbanisation greatly affects biodiversity because it leads to clearing of vegetation for construction of highways, industries and residential areas. For example Mombasa district's natural vegetation is now seriously threatened especially the Mangrove forests which are cut down for construction and building materials (KNES, 1984). Karura forest in outskirts of Nairobi has been deforested to pave way for residential, agricultural and industrial land. This can be emphasised by the fact that the government has suggested that Kiambu municipality should be allocated 100 acres of land from Karura forest for residential and industrial development (Kimani and Kimei, 1989).

Kenya has one of the relatively more developed industrial sectors in subsaharan Africa with major manufacturing activities that include for example food processing, beverages, tobacco, footwear, textiles, cement, paper and pulping, chemical and metal products and agroprocessing. These will develop further since the government plans to offer incentives for establishment of core industries for manufacture of iron and steel, machine tools, dyes, fertilizers, pesticides and phamaceutical products (Republic of Kenya, 1989).

Pollution is a major environmental problem in Kenya with growing urbanisation and industrialisation. For example high pollution levels in lake Victoria waters are attributed to Nzoia and Nyando rivers which are polluted by textile, sugar and paper and pulp mills (MOWD, 1976). Pollution also comes from increased number of industries and urban population which spills industrial and domestic wastes direct into the lake (Tumbo-Oeri, 1982).

2.6. WATER QUALITY DETERIORATION IN KENYA.

Tropical rivers, lakes and wetlands are among the richest, most important yet least studied habitats in the developing world. The critical scientific and economic importance of these systems has been noted and it has been recommended that they be studied much more intensively and monitored for long term changes (NAS, 1980)

Watershed development projects of all kinds inevitably alter river systems and other ecosystems and their biota usually before scientific investigations of unmodified watersheds and basins take place. Thus current research must focus on river systems and other ecosystems prior to development if any accurate characterisation is

to be made of their biological diversity, ecosystem functions and hydrological dynamics. NAS (1980) noted that tropical wetlands are highly vulnerable to destruction by drainage, conversion to intensive agriculture and the alteration of associated river systems. The problem of water quality degradation in Kenya has been known for long but has not been seriously addressed. The problem was first exposed after 3 case studies of 3 rivers; Nzoia, Nyando and Kerio, all in Western Kenya (MOWD, 1976). These studies reported the chemical characteristics of the water shortly before and after establishment of factories along their courses. Nzoia river drains into lake Victoria and carries effluents discharged from Pan African Paper Mills in Webuye upstream and from Mumias sugar factory downstream. Nyando river also drains into lake Victoria and carries effluents from sugar factories of Muhoroni and Chemilil (MOWD, 1976). In early 1970's over 30 Kms of Nyando river course was polluted by mollasses. Kerio river drains the Kerio valley with intermittent flow into lake Turkana. It is periodically polluted by effluents from fluospar factory established 2 decades ago.

High levels of pollution has been reported in other Kenyan rivers. Studies on river Nairobi have revealed that it's principally characterised by anaerobic conditions, that is, dirty black water bubbling methane and hydrogen sulphide, with blackened beds and banks. The water is a health hazard and normal river biota is absent. The major causes of pollution in this river are industrial effluents, domestic sewage and urban runoff (Njuguna, 1978). A study by Kinyua and Pacini (1991) on the Nairobi-Athi river system showed increase in heavy metal levels resulting from industrial effluents. The metals identified include lead, mercury,

chromium, zinc, copper, iron and manganese. MOWD/ NCC/ UNDP/ WHO 1976 joint report indicated increasing concentration of pollutants in sites within and in the vicinity of Nairobi city. A study by Kiithia and Musingi (1995) revealed that water in most Nairobi river sub-catchments was highly polluted. Major pollutants identified include heavy metals, pesticides, organic materials and suspended solids. Occurrence of the pollutants was attributed to the land use activities occuring upstream, mainly agricultural, industrial, commercial activities and urban runoff.

Lake Nakuru is fed by the Enjoro, Enderit and Makaria rivers and seasonal springs (Maskal, 1987). The lake is a spectacular avifauna lake for flamingoes, pelicans and waders. There are also large mammals like waterbucks, lions, impalas and buffaloes. Substantial revenue is generated through gate collections and camping fees by the government. Maintenance of ecological processes in the lake are threatened by pollution from Nakuru town. Industrial effluents, sewage and agricultural wastes from surrounding farmlands find their way into the lake. An integrated land use policy for the lake catchment is needed to protect the lake (Crafter *et al*, 1992).

2.7 EFFECTS OF WATER QUALITY DEGRADATION ON BENTHIC ORGANISMS

Various ecological studies conducted in various parts of the world have established the effects of different types of discharges, which generally affect water quality on benthic organisms. A summary of major effects of these discharges based on the results of these field surveys and classified according to the ecological factor most affected is given in subsequent sections of this chapter.

2.7.1. PHYSICAL CHANGES

2.7.1.1. Turbidity, colour and suspended solids.

Increase in turbidity, colour and suspended solids comes about as a result of discharge of organic and inorganic enrichment of water and also from discharge of suspended materials such as silt from agricultural land or from working mines (Ryan, 1991). This causes a reduction in light penetration thereby suppressing primary production by algae and macrophytes (Quinn *et al*, 1992). This in turn affects benthic invertebrates which depend directly or indirectly on plants for food. These invertebrate populations are therefore suppressed or even eliminated in severe conditions.

Under less severe conditions, suspended solids may have a direct selective effect on filter feeding invertebrates such as *Hydropsyche* and *Simulium*. These organisms strain food particles including micro-organisms from the water and are seriously affected by having their feeding mechanism choked. This may result into a marked change in species composition and abundance.

Turbidity may also affect the outcome of a predator prey relationship by reducing the ability of the predator which sought its prey by sight (Ryan, 1991). The most serious effect of suspended solids on benthic communities occurs when these solids settle to blanket the stream bed. When this occurs in a riffle, the lithophilous fauna such as mayflies, stoneflies and caddis are seriously affected and may be replaced by a silt community including Oligochaetae, pulmonate snails and chironomid larvae .

2.7.1.2. Temperature

Ecological effects of increased temperatures on benthic invertebrate communities are complex. Cold water stenothermal species such as

Crenobia alpina and stoneflies naturally inhabit small upland streams which rarely receive thermal discharges. However temperature in upland streams may be affected by man's activities such as deforestation. Lowland areas are naturally hotter and upland streams bring a cooling effect while they themselves experience increased temperatures. Lowland benthic invertebrates are eurythermal and are less affected by thermal discharges especially when the temperature does not exceed 30°C (Mann, 1965)

An increase in temperature alters the physical environment in terms of both reduction in density of water and its oxygen concentration and this may affect the aquatic organisms (Mason, 1991).

Scientific evidence shows that elevated temperatures accelerates the life cycle of some aquatic insects making them emerge earlier. In an experimental stream maintained 10°C above a control stream at natural temperatures, peak macroinvertebrate density occured 3 - 4 weeks earlier, while some species began reproduction 2-3 months earlier (Arthur *et al*, 1982). The development of eggs, was more rapid, while life cycles were shortened in some invertebrates living in a river below a heated discharge (Howells and Gammon, 1984).

Temperature changes may increase the vulnerability of a species to predation and parasitism. Countant et al (1976) observed that rapid temperature decrease of about 6°C which may occur when the quality of thermal effluent is reduced, increased the susceptibility of juvenile channel Catfish (*Ictalurus punctatus*) to predation by large-mouth bass (*Micropterus salmoides*). Young bluegill also become significantly more vulnerable to predation by

large mouth bass when exposed to a 9°C cold shock (Wolters and Coutant, 1976)

With reference to parasites Aho *et al* (1976) found that in the mosquito fish (*Gambusia affinis*), the metacercariae of the body cavity digenean fluke *Diplostomum scheuringi* were most numerous in fish from waters not receiving thermal pollution.

Cherry et al (1974) found that highest diversity of bacterial types were present in the temperature range of 16-19°C. Temperatures above this decrease diversity but increase the total population while at lower temperatures, both diversity and population size were reduced. Oden (1979) observed that the population density of the littoral meiofauna in a reservoir was reduced at sites receiving thermal effluents, and detailed analysis of the rotifer community showed a decreased species richness compared with a site not receiving thermal effluents.

Thus temperature changes are a feature of natural ecosystems so that organisms have the ability to adapt to the altered conditions provided by thermal effluents. Except for unusually severe thermally polluted conditions, macro invertebrate communities of rivers are relatively little affected by thermal discharge because homeostatic mechanisms at work within the community minimise the damage.

Above 30°C there is a general suppression of benthic fauna and only the tolerant species such as chironomids occur. Elevated summer temperatures may lead to suppression of less tolerant species which may finally be replaced in winter through rapid recolonisation from drift fauna (Trembley, 1960; Langford and Aston, 1972). Fish have the ability to vacate water which is temporarily inimical to them (Langford, 1983)

2.7.2. CHEMICAL CHANGES

2.7.2.1. Toxins

According to Mason (1992) major types of toxic pollutants in freshwater ecosystems include

- Heavy metals such as Lead, Nickel, Cadmium, Zinc, Copper and Mercury arising from many industrial processes and some agricultural uses.
- Organic compounds such as Organochlorine pesticides and herbicides, Poly Chlorinated Biphenyls (PCB's), Chlorinated aliphatic hydrocarbons, solvents, straight chain Surfactants, Petroleum hydrocarbons, Polynuclear aromatics, Chlorinated dibenzodioxins, Organometallic compounds, Phenols and Formaldehyde. These arise from a wide variety of industrial, agricultural and some domestic sources.
- Gases, such as chlorine and ammonia
- Anions such as cyanides, fluorides, sulphides and sulphites.
- Acids and alkalis

Toxic discharges bring about a reduction in numbers of species present and also on the total number of individuals present, that is a reduction in variety and abundance. Different species vary in their vulnerability to specific pollutants. Sensitivity of individuals of a particular species to a pollutant may be influenced by internal factors such as sex, age or size. For instance, the females of crayfishes *Procambarus clarkii* and *Faxonella clypeata* were much more tolerant to mercury than their male counterparts (Heit and Fingerman, 1977).

Studies have shown that pollutants effects are usually more prominent at certain critical stages in the organism life cycle and

this greatly affects the success of the population in presence of the pollutant. The developmental or larval stages of an animal are generally more vulnerable to toxic pollutants than adults (Mance, 1987; Kelly, 1988).

Selective elimination of less tolerant species results in reduction in competition and predation and may result in some cases in an increase in the population of the more tolerant species. As the toxin becomes diluted or otherwise reduced downstream, there is a successive reappearance of species according to their degrees of tolerance to the toxin. Different invertebrate taxa exhibit different degrees of tolerance to different toxins. Several leeches showed an unusually high tolerance to DDT and it was found that in some species this was due to a metabolic activity of the leech to detoxify the insecticide by dehydrochlorinating the DDT to the non toxic DDE. This is because lipophilic contaminants partition into the lipid fraction of organisms and thus tend to bioaccumulate (Cornell, 1990)

2.7.2.2. Salinity

In natural waters, salts of Sodium, Calcium, Potassium and Magnessium have individual toxicities that are mutually concentrated or antagonised to produce a physiologically balanced solution. However any discharge which increases the concentration of one ion upsets this natural balance and may create toxic conditions. Freshwater organisms adapted to low osmotic pressure conditions may be affected by increases in osmotic pressure caused by increased salinity.

Freshwater invertebrates differ greatly in their tolerance to salinity. In insects, the Odonata and Diptera have the most species

tolerant of chloride concentration greater than 1000g/l (Roback, 1974). Amongst the diptera, the most tolerant species are the Chironomidae.

Discharges which result in a fairly stable saline condition without changing other conditions result in replacement of the natural biota by one tolerant of the increased salinity. Certain species such as the brine shrimp (*Artemia salina*), the salt fly (*Ephydra riviparia*), certain rotifers and diatoms are characteristic of such replacement communities. Intermittent highly saline discharges create conditions in which neither the normal fresh water community nor the replacing community can exist (Clement and Jones, 1954).

2.7.2.3. pH

Many industrial effluents are either alkaline or acidic. However, the presence of other constituents makes it difficult to assess the direct effect of pH on stream communities. pH is an essential factor affecting toxicity of pollutants. Within range of 5.0 to 9.0 pH has little direct effect on benthic invertebrates. Within this range different taxa adapt differently. Most British leeches are found over the whole range (Mann, 1965) whereas Gastropoda are mostly found in waters above pH 7.0 (Harman, 1974) and bivalves between pH range 5.6 to 8.3 (Fuller, 1974). Of the insects (Roback, 1974), coleoptera occur within the widest pH range. Helminthidae occur above pH 8.5 while Chironomidae occur over a wide range below pH 4.5 and above pH 8.5.

Increase in acidity causes a reduction in numbers of several phytoplanktonic algae especially the green algae that is Chlorophyceae (Mulholland *et al,* 1986). Acidification also leads to

a marked decrease in the number of invertebrates species present in water bodies (Fryer, 1980).

Reduction in richness of the stream fauna and flora could be due to a combination of physiological stress, a change in food supply and a reduction in predators. Aquatic invertebrates need to actively take up Sodium, Potassium, Calcium ions and Chloride for survival and their uptake is dependent on external concentrations. In acid waters, ion concentrations may be too low while hydrogen and aluminium ions may become dominant in the water. Being small and mobile they may be transported inwards instead of Sodium, Potassium and Calcium and thus upset the normal internal equilibrium possibly leading to fatal loss of vital ions from blood and tissue (Sutcliffe and Hildrew, 1989). This leads to elimination of sensitive species.

2.7.2.4. Deoxygenation

Depletion of dissolved oxygen may result either from organic or inorganic enrichment and also from discharge of industrial effluents containing reducing agents such as sulphites and ferrous salts. Such effluents are also associated with other pollutants which make it difficult to assess the effects of deoxygenation (Hawkes, 1967).

Organic pollutants originate from domestic sewage (raw or treated), urban run off, industrial effluents and farm wastes. Amongst the industries which produce effluents containing substantial amounts of organic wastes are the food processing, brewing industries, dairies, abbattoirs, tanneries, textile and paper making factories. Discharge of biodegradable organic matter such as sewage or wastes from processing of biological materials result in increase of

decomposer community of the stream ecosystem that is bacteria, fungi and protozoans (Daufel, 1972) whose population decrease as nutrients get used up or diluted. This decomposer community break down the complex organic molecules into simple inorganic molecules. This process of self purification requires sufficient amount of oxygen. .The respiratory demand of the decomposer population (mainly microbial) bringing about oxidation of wastes result in depletion of the dissolved oxygen in the water. This deoxygenation leads to elimination of sensitive species leading to increase of those populations able to tolerate the resultant anoxic conditions.

Thus organic pollution affects the organisms living in a stream by lowering the available oxygen in the water. Degree of deoxygenation depends on a number of factors such as the dilution that occurs when the effluent mixes with more water within the stream, biological oxygen demand (BOD) of the discharge and of the receiving water, the nature of the organic material, the total organic load in the river, temperature, the extent to which re-aeration occurs from the atmosphere, the dissolved oxygen in the stream and the numbers and types of bacteria in the effluent (Klein, 1962). In organic enriched streams, clean water fauna is eliminated at the point of discharge of pollutants. Sludge worms (Tubifiscidae) may be the only macroinvertebrates present immediately below the discharge and in some cases of very severe pollution, even these may be absent. As conditions improve, blood worms, larvae of the midge *Chironomus* become abundant and as the stream gradually re-oxygenates, the clean water fauna increases in numbers and diversifies (Mason, 1991)

Inorganic enrichment (autrophication) comes about as a result of discharge of inorganic nutrient salts such as nitrates and phosphates into the river. Majority of polluting nutrients enter watercourses from sewage treatment works, in untreated sewage or from farming activities. Sources might be discrete such as a specific sewage outfall, or diffuse such as from farm lands within the catchment.

Inorganic enrichment causes an ecological imbalance encouraging the luxuriant growth of filamentous algae such as *Cladophora.* This affects the diurnal oxygen pattern and the nature of the river bed oxygen pattern causing changes in the invertebrate community assemblage just as in organic pollution. A detailed study of the benthos of an unpolluted broad and a culturally enriched broad (Mason, 1977) showed that the unpolluted site had 40 benthic taxa, 17 of them occurring commonly. The enriched site had 22 taxa only 7 of them occurring commonly. This reflects a great decline in biodiversity due to pollution.

CHAPTER THREE

3.0 RESEARCH DESIGN AND METHODOLOGY

3.1 Selection of sampling sites

This study was conducted in 6 stations set along the length of river Gatharaini (Fig.ii). The stations were selected on the basis of the prominent land use system occurring along the river which could discharge toxic pollutants into it either directly or indirectly by runoff. The first station was situated at the source of one of the tributaries (river Kaski). Water at this point is derived from underground aquifers. There is minimal water pollution from land use activities around (Plate 1). This point served as a control point against which the other 5 stations down stream were compared. The second station was situated at the heart of many small scale, intensively cultivated farms. The main crops grown here were maize, beans, vegetables, sweet potatoes, tomatoes, bananas and arrow roots (Plate 2). The third station was situated within the coffee estates just before the river crosses the Nairobi-Kiambu road. Above this station are large coffee estates and coffee processing factories such as Ibonia, Northmoor, Miserara, and Barua estates (Plate 3) together with coffee processing factories. This point is ideal in assessing the impact of various contaminants discharged from intensive plantation agriculture. The fourth station was situated just above the Kamiti tannery factory. This station was ideal in assessing the impact of tannery discharges found 200 metres downstream (Plate 4). The fifth station was situated just below Kamiti tannery factory (Plate 5a and b). These two stations were ideal in this study as they clearly quantify the effect of industrial land use on water quality and on benthic diversity. The sixth station was situated below Zimmerman and Githurai housing

estates. (Fig.ii). The little volume of water in the stream made it ideal for this study as there was minimal dilution effects of the contaminants by the flowing water. Hence the impact of the contaminants could easily be determined.

3.2 Sampling strategies and duration

Each sampling station consisted of a river section of 25 metres long on a horizontal profile. The sampling station was subdivided into five transects each five metres long. From every transect, one sample of each of the seven parameters was collected or recorded randomly per sampling time. This makes a set of 5 samples per station per sampling time. Collection of the samples was done for a period of 7 months. The time interval between the samplings was 28 days. Water chemistry was tested at the same time as the macrozoobenthic sampling (Bradt 1974, Bradt and Wieland 1978).

3.3 Macrozoobenthic sampling

The vertical core sampler used was one metre long and 14 centimetres in diameter (Plate 1b). Sampling of mud in all the sampling stations was done to a depth of 10 cm. The sediment mud scooped out was put separately in well labelled polythene bags and preserved using 4% formalin to counteract the possibility of predatory animals consuming other sampled animals. In the laboratory the sediment mud was washed and filtered using 1.0 mm and 0.125 mm sieves (Mathooko, 1995) and any entangled animal removed using a pair of forceps. The filtered sediment material was washed clean, kept in sorting pans and flooded in sugar solution (300 grams per litre) and stirred (Lind, 1974). The organisms floated and were scooped out using a pair of forceps. The

heavy bodied organisms were picked from the bottom of the sorting pans using forceps. The organisms were then washed off the sugar solution and preserved in 70% alcohol solution. The macrozoobenthic organisms were identified, counted and reported as numbers per square metre. Identification and classification of the organisms was done at the National Museums of Kenya.

3.4 WATER PARAMETERS

3.4.1 Dissolved oxygen. (D.O.)

The Azide modification of the Winkler method was used (Sawyer and McCarty, 1978). This method is superior as it eliminates interferences by nitrite ion which occurs principally in sewage effluents. Water was collected using sampling bottles washed with dilute nitric acid. In the field, 2 Ml of manganous sulphate was added into the collected water to arrest any dissolved oxygen in the water.The water was then taken to the laboratory and 2 Ml of Winkler reagent and 2 Ml of conc. Sulphuric acid added. The mixture was then titrated using N/40 thiosulphate solution. The Manganous sulphate, Winkler reagent and the Thiosulphate solution used in this experiment were prepared using standard methods (Apha, 1975).

3.4.2 pH

pH was measured in the field using a portable pH meter (model 6301 Rabenau-Londorf). The pH meter probes were dipped into the flowing water and pH read (Plate 6).

3.4.3 Total dissolved solids (T.D.S.) and electrical conductivity (E.C.)

These were determined in the field using a portable TDS meter (model 4075 Jenways). T.D.S. probes were dipped in the flowing water and E.C. and T.D.S. read (Plate 6).

3.4.4 Turbidity

A turbidimeter was used (model - Hach 2100A). About 200 millilitres of water was collected from the field using clean bottles. 100 Ml of this water was put into a special turbidity bottle in the laboratory, and shaken thoroughly to counteract sediments settling effect. The bottle was then inserted into the turbidimeter and turbidity of the water determined (Laperriere, 1994).

3.4.5 Water and air temperature

This was measured in the field using a temperature probe attached to a TDS meter (model 4075 Jenways).

3.5 Data treatment

After collecting the relevant data on each parameter, statistical analysis were carried out to test whether there were any significant differences between the stations during the sampling period. For water quality analysis, the mean values were determined for each station per month and the test for significance was done using Analysis of Variance (ANOVA) and Simple Linear Regression ANOVA. This was done using Microsoft Excel version 3.0 computer software.

For macrozoobenthic organisms, various tests were done to determine Species Diversity, Species Evenness and Coefficient of

Similarity. Test for significance was done using ANOVA and Simple Linear Regression ANOVA.

Details of these calculations are discussed in subsequent sections of chapter four and five.

Plate 1a: Station A situated at the source of river Kaski, a tributary of river Gatharaini. (Note the start of farming activity just after the source. The source of the river is at the far background).

Plate 1b: Core sampler for sampling macroinvertebrates

Plate 2: Station B situated at the heart of arable/ mixed farming. (Note the green vegetables (Kale), maize, sugarcane and bananas

Plate 3: Station C situated below the coffee estates. (The extensive Barua coffee estate is visible at the background behind the tall trees).

Plate 4: Station D situated above the Kamiti Tannery Factory. (Note the vast swamp partly cultivated with arrowroots but dominated by reeds (*Cyperrus imensus*). This wetland could have had a purifying effect on the water).

Plate 5a: Station E situated below Kamiti Tannery Factory. (The water was dark in colour. The vegetation along the river was black and destroyed partly by pollution and partly by human activity. Note the intensive arrowroot farming).

Plate 5b: Kamiti Tannery Factory and Zimmerman housing estate. (The factory is situated at the right extreme end. Station E was situated behind and between these two houses in the foreground. Station D was situated just 100 metres upstream from the tannery.)

Plate 6: TDS and pH meters. (The meter probes are in the river. Water temperature was also read from the two meters).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Measurements of water quality parameters and fauna diversity revealed that there were major changes that had occured in the river. The water quality and fauna diversity were not constant along the river.

4.1 WATER QUALITY

Seven water quality parameters were measured and all seemed to change along the gradient of the river. There was evidence of some external influence or allochthonous discharges into the river which could cause changes in the water quality. This is discussed in more details in subsequent sections of this chapter.

4.1.1 TOTAL DISSOLVED SOLIDS (TDS).

There were notable variations in TDS along the river gradient (Mean = 533.34; range =46.0 - 1148.0 Mg/l; n=42). This is shown in table 2 and appendix 1.

Table 2. Mean monthly TDS changes along river Gatharaini (Values in Mg/l).

	STATIONS					
Months	A	B	C	D	E	F
March	49.8	116	125.6	146.8	1104.8	557
April	46	59.4	103.6	120.2	297.8	263.8
May	54.4	56	112	128.6	1148.6	890.2
June	54.4	54.8	108.8	139.2	277.4	459.8
July	48.4	57	99.4	146	340.8	337.6
August	50.6	55.6	95.6	125	399.6	370.2
Sept.	46.8	58.2	196	164.8	1004.2	854.8
Mean TDS	**50.06**	**65.29**	**120.14**	**138.66**	**653.31**	**533.34**

A two factor ANOVA was carried out to determine whether monthly and between site variations were significantly different.

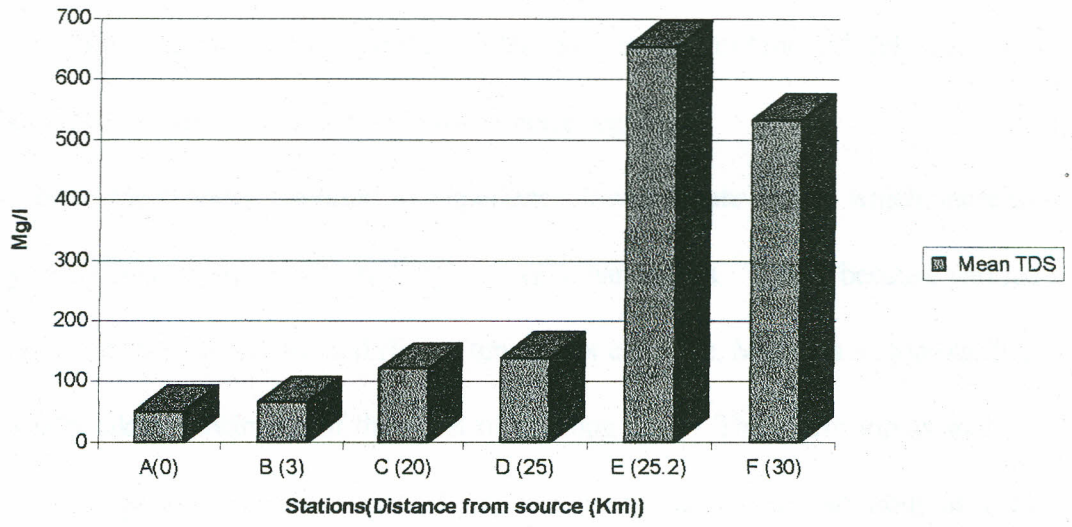
Between site variations were significantly different ($F_{(5,30)}$= 15.55, P<0.001). This shows that land use changes along the river are responsible for introducing allochthonous wastes into the river. L.S.D test showed that the greatest changes occured between station D (below coffee estates) and station E (below Kamiti Tannery factory) indicating that the tannery introduces huge toxic waste load into the river.

Between months variations were also significantly different ($F_{(6,30)}$=2.433, P<0.05). This shows that presence of chemical wastes into the river was intermittent, that is, some months had higher solute concentrations discharged into the river than others. L.S.D. test showed that significant monthly variations occured between March and April, April and May and also between August and September. High TDS values in March coincided with the rainy season (Waters and Odero, 1986) and crop planting season when there was a lot of leaching and erosion of fertilisers from the cultivated farms. A gradual increase was also noted in station C and D in September. This coincided with the beginning of coffee harvesting season when coffee berry juices and husks were discharged into the river from the coffee processing factories.

The tannery factory is greatly responsible in causing tremendous monthly variations in TDS. Those months with high L.S.D. values coincide with periods of highest levels of TDS from the tannery factory (above 1000Mg/l). This clearly shows that discharge of these wastes into the river was deliberate.

Figs.1a, b, and c shows trends in TDS changes along river Gatharaini during the sampling period.

Fig. 1a: Trends in TDS along river Gatharaini.



The graph shows that mean TDS levels increase downstream. The Tannery factory (station E) however has the greatest values of TDS. Five kilometres downstream from the tannery had lower solute load suggesting occurrence of self purification process whereby some pollutants are removed.

Fig. 1b: Mean monthly TDS changes along river Gatharaini.

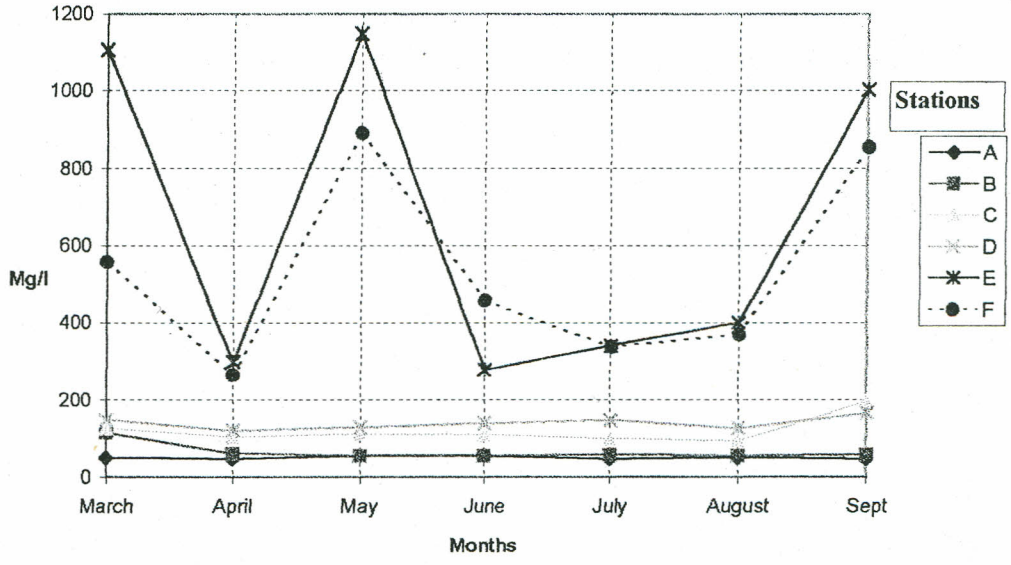


Fig. 1b shows that station E and F have the highest monthly TDS levels. The results also suggest that discharge of these pollutants into the river is intermittent and deliberate and thus make the river experience alternating disturbance regimes.

Stations above the tannery continue to experience lower solute levels which increase gradually. However, some months had higher levels than others. This is because various land use activities are carried out at different times. For example, March is a crop planting season usually taking advantage of the onset of the long rains. Thus farm inputs such as fertilisers and organic manure are leached into the river causing the variations in TDS levels observed. TDS levels were also high in station C and D. This could possibly be due to the start of coffee harvesting season and subsequent release of wastewater from coffee factories.

Fig. 1c: Trends in TDS along river Gatharaini using monthly means.

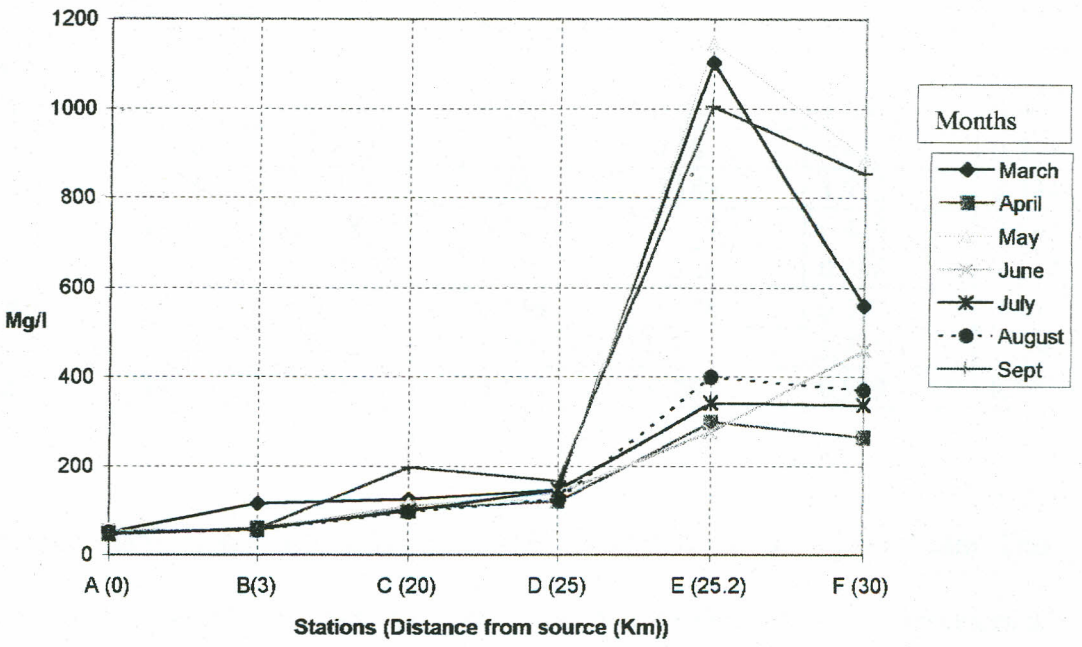


Fig. 1c shows that there was a successive increase in TDS along the gradient of the river during the sampling period. A major difference was noted between station D and E which are situated only 200 metres apart. TDS values of station E and F were unusually high. TDS levels in station E were 8.9 times higher in March, 7.5 times higher in May and 6.09 times higher in September. This shows the tannery is a major pollution point. Indeed this was also clearly reflected in the water odour which was strong and the black colour of the water, river banks and the riverine vegetation. Station F shows signs of recovery whereby TDS levels are lower.

4.1.2 ELECTRICAL CONDUCTIVITY (E.C)

EC varied along the gradient of the river (Mean = 0.793; range = 0.06Ms to 1.74Ms; n=42) as shown in Table 3 and appendix 2.

Table 3: Mean monthly EC changes along river Gatharaini (Values in Ms)

	STATIONS					
Months	A	B	C	D	E	F
March	0.074	0.168	0.182	0.232	1.652	0.82
April	0.066	0.084	0.152	0.18	0.45	0.394
May	0.076	0.078	0.16	0.188	1.712	1.334
June	0.07	0.08	0.162	0.208	0.428	0.688
July	0.07	0.08	0.146	0.226	0.508	0.502
August	0.07	0.076	0.136	0.178	0.592	0.546
Sept.	0.064	0.08	0.288	0.24	1.438	1.266
Mean EC	**0.07**	**0.09**	**0.175**	**0.207**	**0.969**	**0.793**

Electrical conductivity was low at the source but it increased gradually downstream. This shows that as the river flows downslope it becomes more loaded with ionic substances of various kinds.

A two factor ANOVA test showed that monthly variations were not significantly different. However between stations variations were highly significant ($F_{(5,30)} = 15.83$, $P<0.001$) as shown in Fig 2a and b.

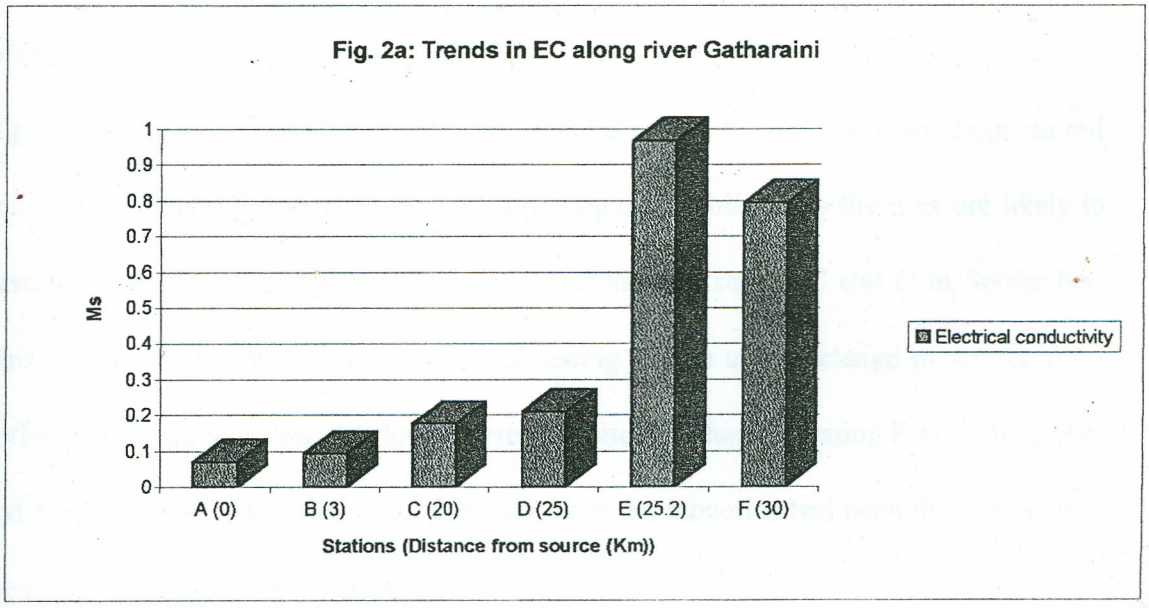
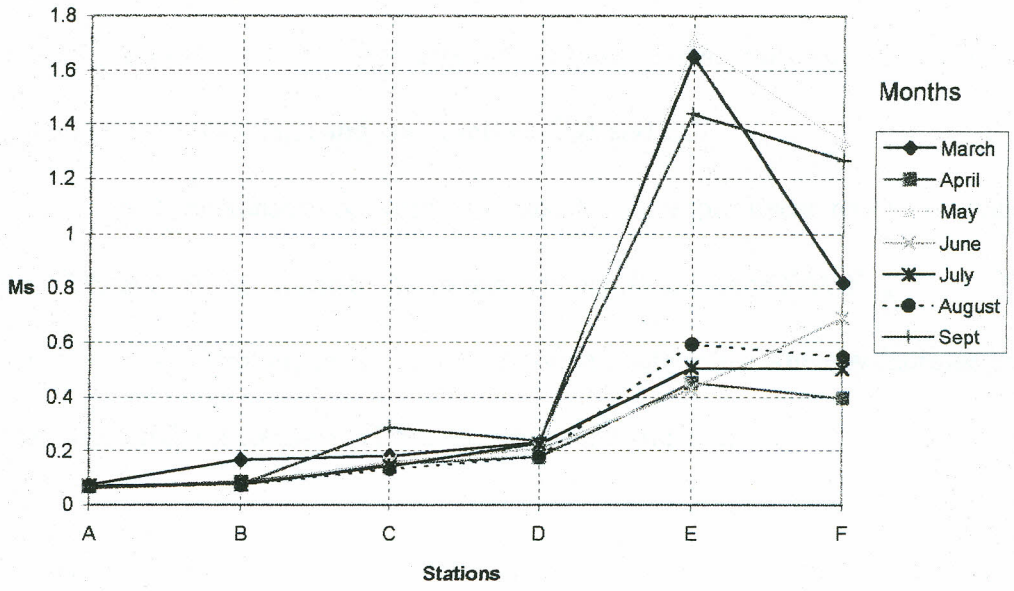


Fig: 2b: Trends in EC along river Gatharaini using monthly means.



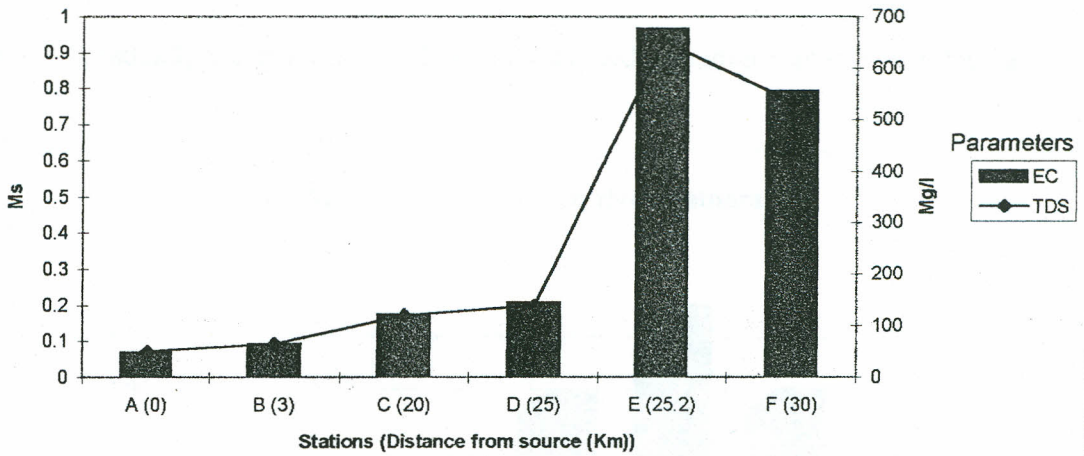
L.S.D. test showed that the greatest changes occured between station D (above the tannery) and station E (below the tannery). The ionic load in station E doubles and sometimes quadruples when compared with station D due to discharges from the tannery factory. Station F located about five kilometres downstream recorded a lower ionic load as compared to station E suggesting that the river experiences a self purification process whereby some ions are removed .

High EC values were recorded in station A, B and C in March coinciding with high rainfall and planting season whereby erosion and leaching of fertilisers into the river are likely to have occured. Elevated levels of EC were also noted in station C and D in September. This coincides with the onset of coffee harvesting season and discharge of wastes from coffee processing factories. EC levels were exceptionally high in station E in March, May and September, and this shows that effluents from the tanneries had been discharged into the river a few days prior to sampling.

The great variations in TDS and EC in station E and F rules out possibility of water quality disturbance by natural means. The trends clearly indicate that human activities in the tannery factory are strongly responsible for the water quality deterioration observed. This also clearly indicates that this discharge of pollutants was deliberate as reflected by intermittent exceptionally high and low levels of TDS and EC.

There was a great relationship between TDS and EC. Simple linear regression analysis between TDS and EC shows that the trends are significant (ANOVA $F_{(1,4)} = 18295.72$, $P<0.001$, $r^2 = 0.94$). This suggests a highly positive relationship whereby increase in EC coincides with similar increase in TDS as shown on the graph Fig. 2c.

Fig. 2c: Comparison between mean values of EC and TDS along river Gatharaini.



The graph shows that increase in TDS coincides with increase in EC of the water. This suggests that most of the discharges into the river were ionic.

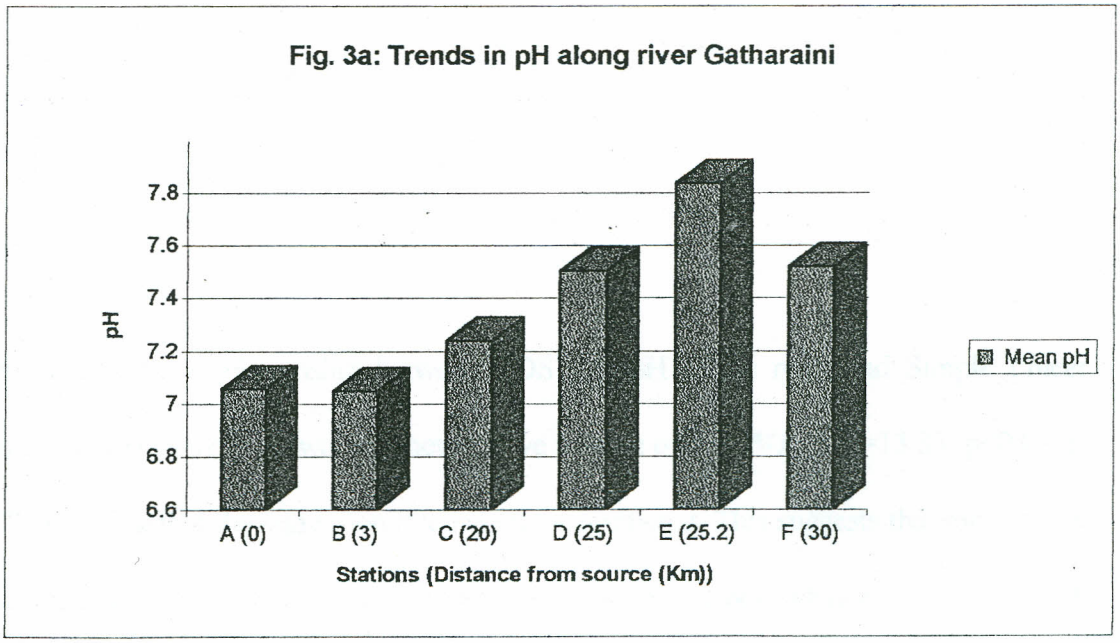
4.1.3 pH

Variations in pH were noted (Mean = 7.5; range = 6.4 - 8.8; n=42) as shown in Table 4 and appendix 3.

Table 4: Mean monthly changes in pH along river Gatharaini

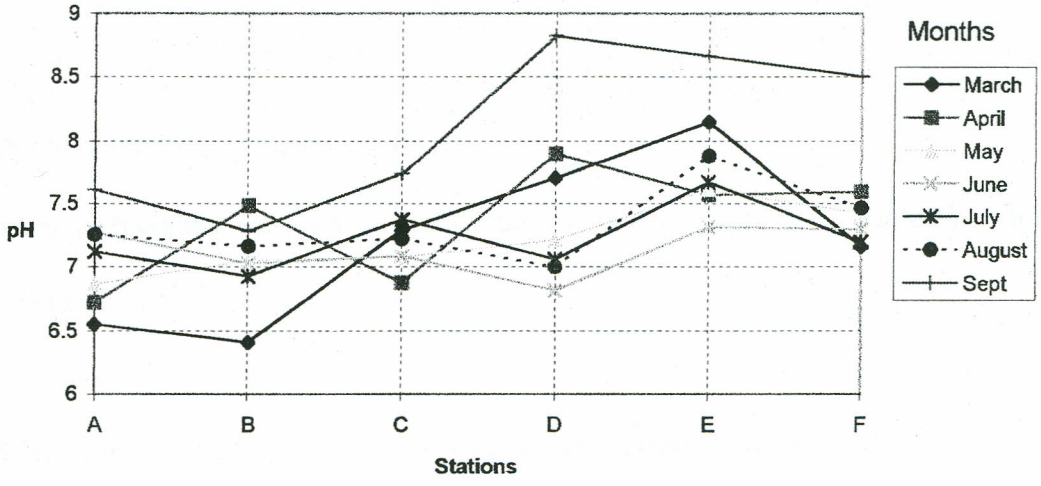
	STATIONS					
Months	A	B	C	D	E	F
March	6.55	6.41	7.29	7.70	8.15	7.16
April	6.72	7.49	6.88	7.9	7.57	7.59
May	6.86	7.05	7.08	7.21	7.61	7.43
June	7.27	7.03	7.09	6.82	7.32	7.3
July	7.12	6.93	7.37	7.06	7.67	7.196
August	7.26	7.16	7.23	7.0	7.88	7.47
Sept.	7.61	7.28	7.74	8.82	8.67	8.5
Mean pH	**7.06**	**7.05**	**7.24**	**7.50**	**7.84**	**7.52**

pH increased gradually along the river although it declined in station F as shown in Fig 3a.



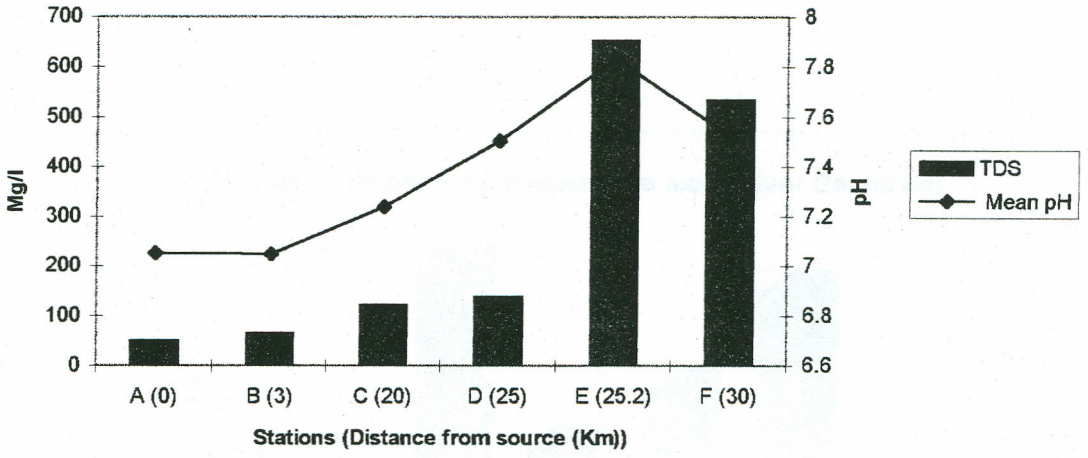
The graph shows that pH differed along the river. A two Factor ANOVA test showed that between stations variations were highly significant ($F_{(6,30)} = 5.98$, $P<0.001$) as shown in Fig 3a and b. L.S.D. test showed that great variations occured between station D and E and also between station E and F. This suggests the possibility of the discharges from the tannery factory being basic thus causing an elevation of pH. Differences in pH between station E and F could possibly be due to self purification causing a decline of pH.

Fig. 3b: Trends in pH along river Gatharaini using monthly means.



There was a close relationship between TDS and pH in the river and Simple Linear Regression analysis of the two parameters gave a value of ANOVA $F_{(1,4)}=13.33$, $p<0.05$, $r^2 = 0.71$ showing that the regression line is highly significant. This suggests that most of the dissolved solutes are basic. Thus TDS and pH rankings are not independent. This shows that there is a positive relationship such that TDS and pH increase together. This is illustrated in Fig. 3c.

Fig. 3c: Comparison between mean values of TDS and pH along river Gatharaini



4.1.4 ATMOSPHERIC TEMPERATURE

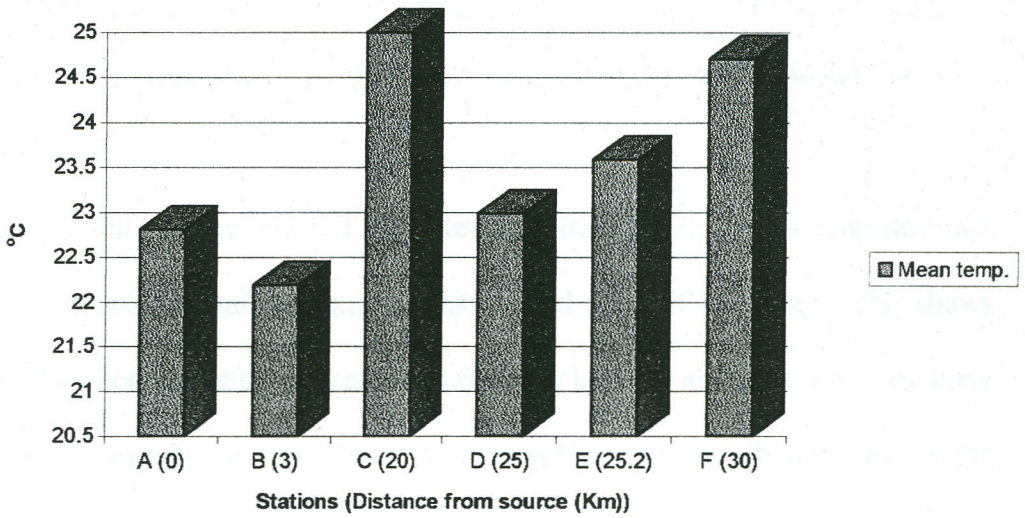
The highest temperature recorded was 29^{0}C and the lowest was 17.4 ^{0}C (Table 5). This gives a range of 11.6^{O}C.

Table 5: Monthly atmospheric temperature changes along river Gatharaini (^{o}C).

	STATIONS					
Months	A	B	C	D	E	F
March	23.2	24.9	26.4	21.4	24.9	22.2
April	28	20.4	28	28.4	23.9	24.1
May	24.1	25.5	25.8	25	29	29
June	19.2	19.4	24.5	22.7	22.4	22.2
July	24.5	21.7	27	21.5	17.4	26.7
August	20.5	22	21.3	20.9	22	24.1
Sept.	20.2	21.4	22	21	25.5	24.6
Mean temp.	**22.8**	**22.2**	**25**	**23**	**23.4**	**24.7**

There were no significant variations in atmospheric temperatures along the river. A two Factor ANOVA test showed monthly variations were not significant while station variations were significant ($F_{(5,30)} = 3.526$, $P<0.001$) as shown in Fig. 4.

Fig. 4: Trends in atmospheric temperature along river Gatharaini



LSD test shows that greatest variations occur in between station B and C, C and D and also between station E and F. These station variations were as a result of variations in weather conditions at the time when sampling was done. Thus some days had early morning sunny conditions whereby high temperatures were recorded while low temperatures were recorded for cloudy mornings.

4.1.5 WATER TEMPERATURES

Only slight changes in temperatures were noted along the river. The lowest temperature reading was 16.64°C while the highest was 22.88°C. This gives a range of 6.24°C (Table 6)

Table 6: Mean monthly water temperature changes along river Gatharaini (°C).

	STATIONS					
Months	A	B	C	D	E	F
March	19.6	22.1	17.8	19.7	17.7	20.7
April	18.5	19.7	22.9	17.6	22.3	20.7
May	19.7	21.7	21.5	20.8	21.2	16.6
June	19.1	19.3	21.3	19.7	19.4	19.3
July	19.0	18.5	20.1	19.1	18.8	17.9
August	19.2	19.2	18.2	22	16.8	20.6
Sept.	20.3	18.7	20.5	18.7	21.7	18.2

A two Factor ANOVA test showed that there were no significant variations in water temperatures.

These trends in both atmospheric and water temperatures shows that the river does not experience significant thermal fluctuations which could affect it's ecology. This shows that the river does not receive thermal effluents from the land use activities it crosses along it's course. The change in gradient of the river does not have any significant effect on the water and atmospheric temperatures. Thus the whole study area is homogenous in terms of water temperatures. Temperature therefore was not a significant factor affecting macrozoobenthic organisms along this river.

4.1.6 DISSOLVED OXYGEN (D.O.)

DO varied along the river (Mean DO = 3.67 Mg/l; range = 0 - 7.04 Mg/l; n=42) as shown in Table 7.

Table 7: Mean monthly DO changes along river Gatharaini (Values in Mg/l)

	STATIONS					
Months	A	B	C	D	E	F
March	6.52	4.04	5.6	4.64	0.04	0.44
April	5.92	4.6	4.4	7.04	1.12	1.3
May	5.0	4.48	4.24	5.92	0	0.08
June	5.32	5.44	4.92	5.88	0.5	1.1
July	5.24	4.48	4.16	5.8	1.18	1.28
August	5.28	5.04	4.68	5.96	0.24	1.26
Sept	5.6	5.04	4.72	5.6	0	0.08
Mean DO	**5.55**	**4.73**	**4.67**	**5.83**	**0.44**	**0.79**

Areas above the tannery had a mean DO value of 5.195 Mg/l (n=28), while areas below the tannery had mean values of 0.615 Mg/l (n=14). A two Factor ANOVA test revealed significant difference in dissolved oxygen between the stations ($F_{(5,30)}$=142.66, P<0.001) (Fig. 5a and b) but not between months.

Using DO values the river can be divided into two main areas. Areas above the tannery had high DO values the highest value being 6.52 Mg/l. Areas below the tannery had low DO values equal to or just slightly above zero. This is clearly shown on the graphs below (Figs. 5a,b and c).

Fig. 5a: Trends in DO levels along river Gatharaini.

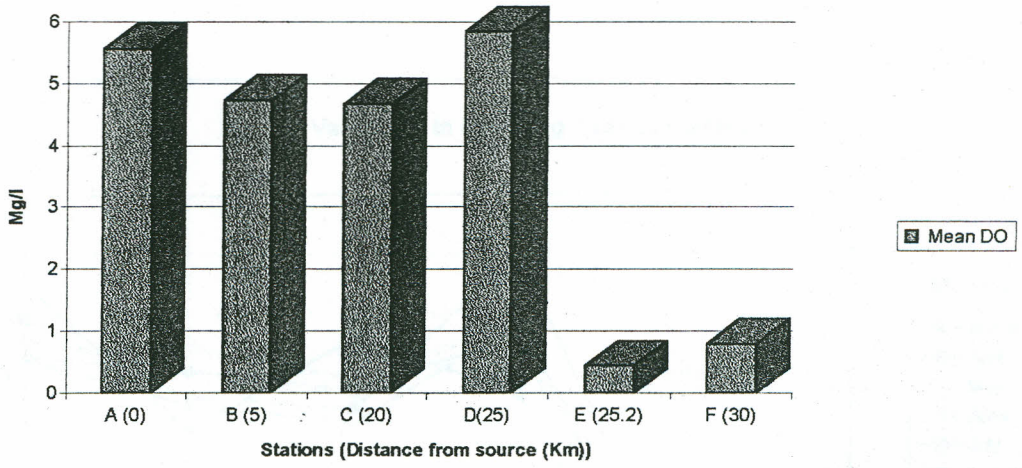


Fig. 5b: Monthly variations in DO along river Gatharaini

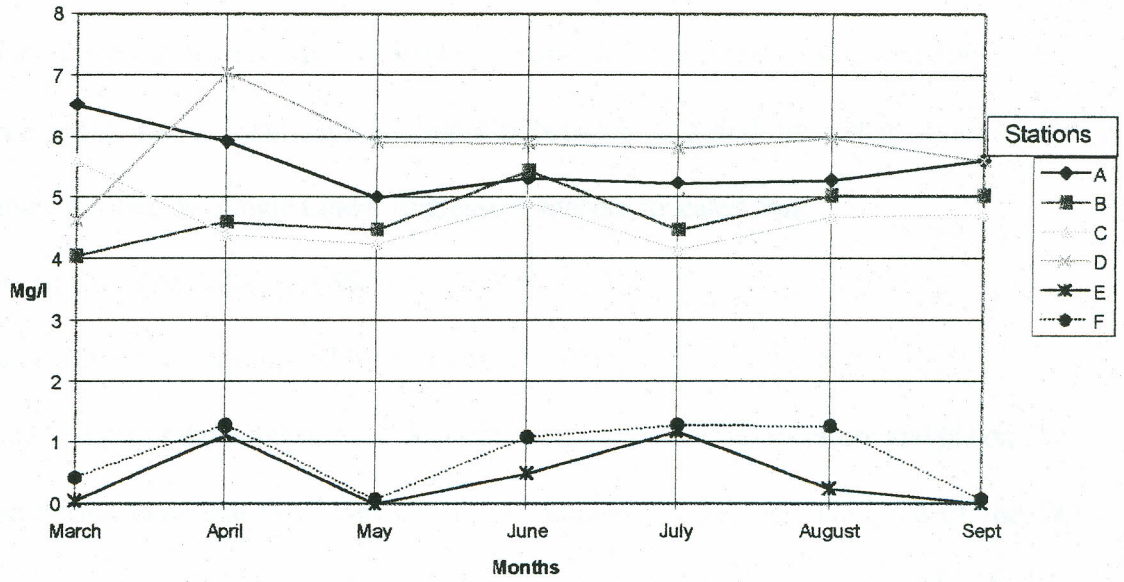
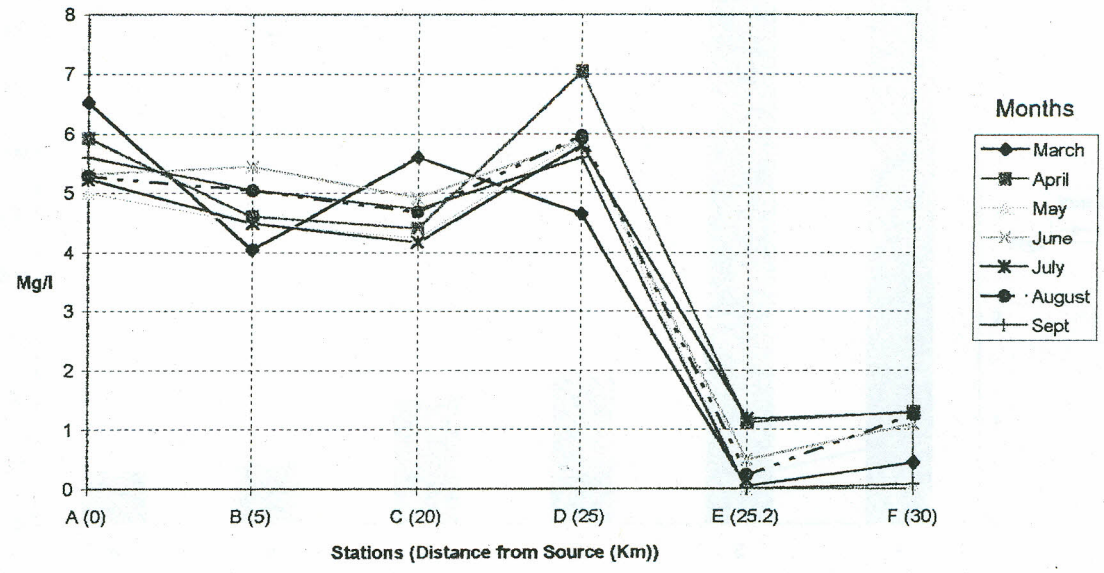


Fig. 5c: Variations in DO along river Gatharaini.



These graphs show that there were great variations in DO above and below the tannery. An L.S.D. test shows that the greatest variations occured between station D and E. The tannery factory effluents can be blamed greatly for this tremendous variation in DO. Indeed there was a significant relationship between DO and the other water quality parameters whereby Simple Linear Regression analysis revealed that;

TDS and DO (ANOVA $F_{(1,4)}= 55.53$, $P<0.05$, $r^2 =0.91$).

EC and DO (ANOVA $F_{(1,4)}= 53.49$, $P<0.05$, $r^2 = 0.91$).

However, this test did not detect the depressing effect of water temperature and pH on DO. These results show that there was an inverse relationship between TDS and EC on DO whereby increase of the former results in decrease in DO as illustrated in Fig. 5d and e.

Fig. 5d: Comparison between TDS and DO along river Gatharaini

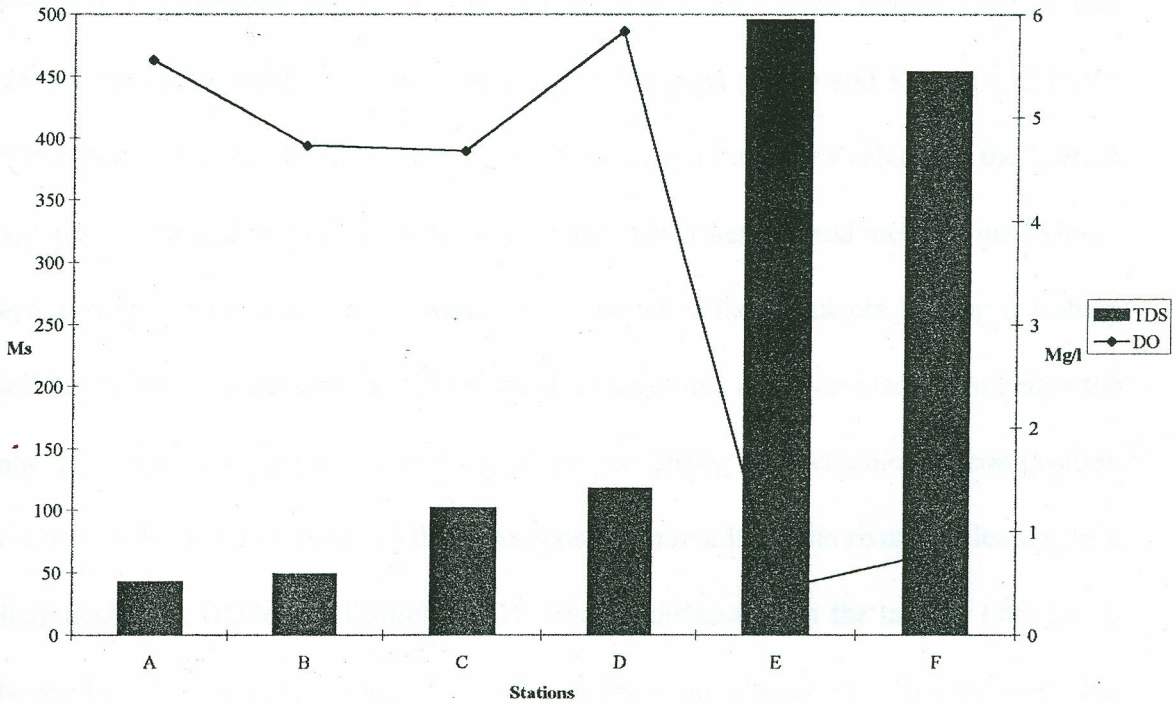
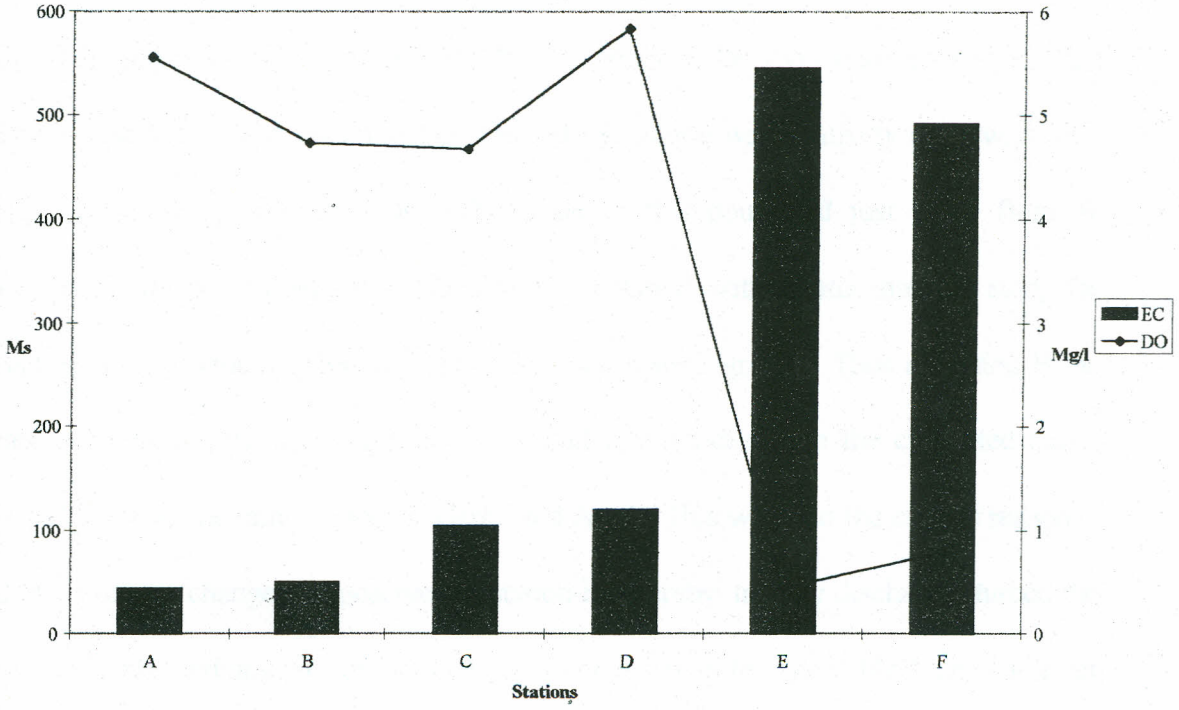


Fig. 5e: Comparison between EC and DO along river Gatharaini



These graphs (Fig 5d and e) show that those stations above the tannery had low levels of TDS and EC but high levels of DO. The results of this study agree with findings in other parallel studies especially in Kenya. A study by Njuguna (1978) and Kinyua and Pacini (1991) discovered that levels of DO in river Nairobi were inversely related to the level of pollution. Thus heavily polluted areas were principally anaerobic and methane gas bubbles were visible on the surface of the water. The sources of the pollutants causing this sharp decline in DO were industrial and domestic discharges just like river Gatharaini below the tannery. These discharges require a lot of oxygen during their chemical decomposition reactions or lead to an increase in the decomposer community in the river thus leading to a sharp decline in DO levels (Daufel, 1972). Further distance from the tannery (station F), the level of DO was a bit higher. The pollutant levels are also lower. This indicates that self purification process was in action. The declined toxin levels lead to increase in oxygen levels in the water (Kinyua and Pacini, 1991).

4.1.7 TURBIDITY

From field observations it was apparent that the water in the river undergoes significant changes as it flows downstream. River water at the source was relatively clear with little traces of silt or suspended solids. The water at this point had just come from an underground aquifer. Downstream, arable farming started, with greater intensity along the banks where arrowroots, green vegetables and maize were grown. Thus at station B the water was nearly brownish in colour due to soil load eroded from the cultivated banks especially during the rainy season in March and April. This was also the case in station C and D. A drastic change was observed in station E whereby tannery discharges turned the river, it's banks and any riverine vegetation in contact with the water blackish. The river was also characterised by a strong odour. These results were also evident when a turbidimeter was used as shown in Table 8 and graphically in figure 6a and b.. Table 8: Monthly turbidity changes along river Gatharaini (Figures in Formazin Turbidity Units (FTU).

	STATIONS					
Months	A	B	C	D	E	F
March	0.4	52	44	23.2	74.1	68.2
April	0.6	46.4	22.3	16.3	54.4	39.1
May	0.7	49	17.1	19.3	68	36.3
June	0.9	38.4	41	37	58	34.2
July	1.2	30	39.3	38.5	48	25
August	0.7	20.8	42.3	33	51	37
Sept	0.8	20	45	20.7	71	53.6
Mean Turbidity	**0.76**	**36.66**	**35.86**	**26.86**	**60.64**	**41.91**

A two Factor ANOVA test showed that between months variations were not significant while between station variations were highly significant ($F(5,30)=24.29$ $P<0.001$). An LSD test showed that great variations occured between station A and B and also between station D and E. This corresponds with intensive agriculture and the tannery factory

respectively. Both are responsible for introducing particulate sediments or coloured complex effluents into the river (section 4.1.1)

Fig. 6a Trends in Turbidity changes along river Gatharaini

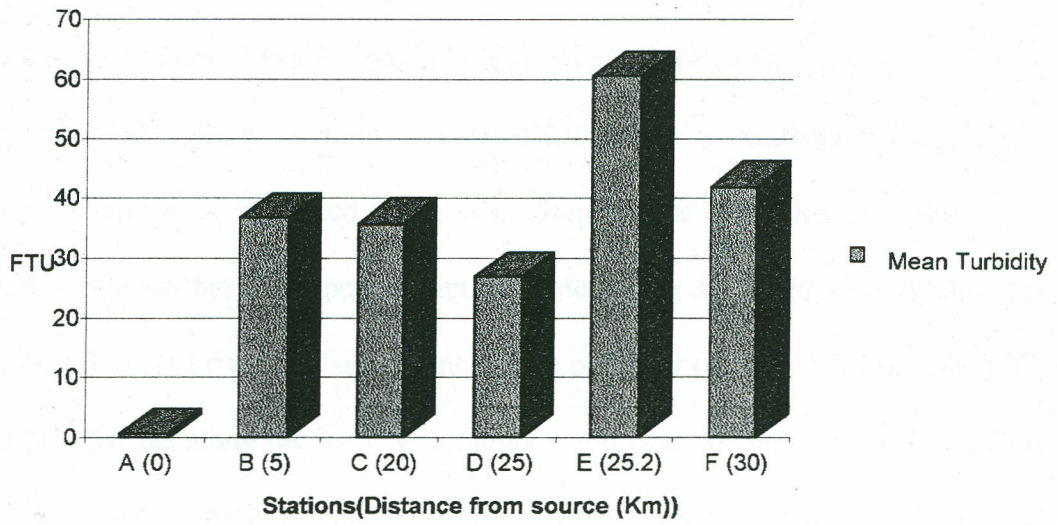


Fig. 6b: Variations in Turbidity along river Gatharaini

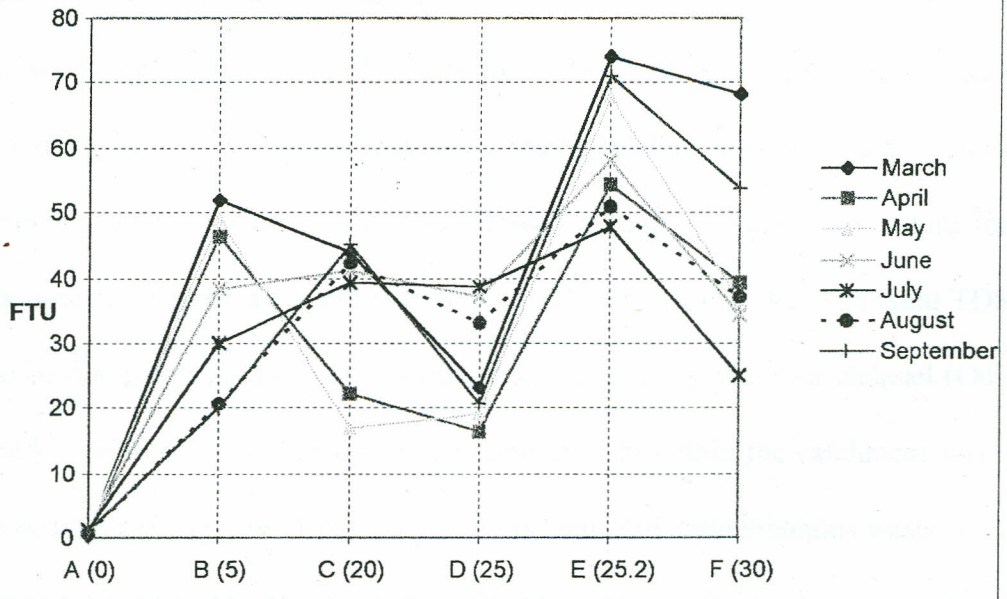


Fig. 6a and b show that turbidity increases drastically with land use. For example, station B was situated below intensively cultivated farms with a lot of soil erosion from the farms and river banks. Station E also had high values of turbidity because of coloured complex industrial (tannery) effluents. Station F showed some recovery or self purification process.

4.1.8 Possible Causes of Water Quality Changes along river Gatharaini

The results of this study (section 4.1) indicated that river Gatharaini experienced significant changes as it flowed along it's 40km course downstream. There was increasing evidence that anthropogenic activities occurring due to the various land uses represented along the river had significant effects on water quality. For example TDS, EC and pH changes along the river were highly significant (section 4.11 to 4.13). This suggests that great variations exists in toxic load inputs into the river. TDS and EC were significantly related suggesting that most of the dissolved solutes were ionic (Fig. 2d). TDS and pH also had a significant relationship suggesting that the bulk of these dissolved solutes in the river were basic.

The sources of these dissolved solutes vary. They could result from geological inputs as a result of solution of rocks and soil minerals along the river valley (Stenzel and Hermann, 1990). Thus as the river flowed a longer distance the solute load was supposed to increase as it met with more soluble substrata. The increased TDS could also be due to breakdown of autochthonous waste along the river channel (Odum and Prentki, 1978) or allochthonous waste coming from within the catchment and its land use activities (Cummins et al, 1980). The presence of autochthonous waste is expected because the riverine ecosystem is a closed system with its own nutrient cycles to maintain it. Hence as water flow downslope it met and transported nutrients downslope leading to an increase in TDS observed. But autochthonous wastes alone

cannot be responsible for the sudden increases in TDS observed in this study. So the third source (allochthonous wastes) are highly suspected in causing these significant increases in TDS.

Types and concentrations of these allochthonous wastes vary with land use type. The mode of discharge into the river could be diffuse or localised at a point. For example from the agricultural land use which covered extensive areas above the tannery, the main allochthonous wastes were pesticides, organic manure and fertilizers from the cultivated farms. The mode of discharge into the river was diffuse. From the coffee processing factories, organic sugary sap from coffee berries discharged into the river can also lead to increased TDS.

A study by Kiithia and Masingi (1991) established that most of the rivers occuring within the Nairobi area sub-catchment are polluted by pesticides and fertilizers. Their study, conducted in many neighbouring rivers such as Kamiti, Ruaka, Gitathuru, Riara and Gatara which pass through similar land use types as river Gatharaini revealed that there was great pollution along the river Nairobi sub-catchment. The main pesticide residues identified are given in Table 9.

Table 9: Pesticide residues in water samples along Nairobi river Sub-catchment

Pesticide residues	Source of sample collection	measured value (Mg/L)
DDT	Gatara River	0.000086
"Ambush"	Gitathuru River	0.0948
"Marathion"	Gitathuru River	0.00014
"Ambush"	Ruaka River	0.255
"Marathion"	Ruaka River	0.00063
"Ambush"	Riara River	0.074
"Ridomil"	Kamiti River	0.147

Source :Kiithia, (1992).

River Gatharaini is unlikely to be an exception since it also passes through similar landuses (Fig.ii, Plate 2,3). Thus these pesticides and fertilizers may be responsible for the observed increase in TDS.

There was a sudden increase in TDS, EC and turbidity below Kamiti tannery factory and these high levels were still maintained in Station F below the housing estates. The possible discharges from the two land uses were heavy metals, complex solutes and also sewage from domestic sources. Kiithia (1992) discovered high organic pollution in Station F using faecal coliforms. He found 460 coliform organisms/100ml of water and 23 faecal coliforms/100ml of water.

This highly exceeded the WHO guidelines limits and the Kenya Standard limits which are 10 coliform organisms or 0 foecal coliforms/100m of water (Kiithia, 1992). This showed that there was great organic pollution by sewage and industrial discharges as

reflected in the high TDS, Turbidity, pH and EC values (Fig 1,2,3,6) and reduced DO values (Fig. 5) observed in this study.

Kiithia (1992), Kinyua and Pacini (1991) also measured high levels of heavy metals in the Nairobi sub-catchment and attributed this to the industrial land use in this region. The levels of suspended solids were also high and they attributed this to agricultural, industrial and residential land uses. Thus the findings of this study are in line with earlier findings in similar land uses. The agricultural, industrial and residential land uses in these regions are the main causes of water pollution in these rivers.

4.2 MACROZOOBENTHIC ORGANISMS

A total of 26 benthic taxa were collected from all the 6 sites in the stream survey (Table 10, Appendix 8). Benthic density and number of taxa at a site ranged from 21 to 3530 organisms per m^2 and the number of taxa ranged from 2 to 9 taxa per site per sampling time. Overall results revealed that species richness in the 6 sites range from 7 to 18 species and mean totals per site range from 1759 to 23287 organisms.

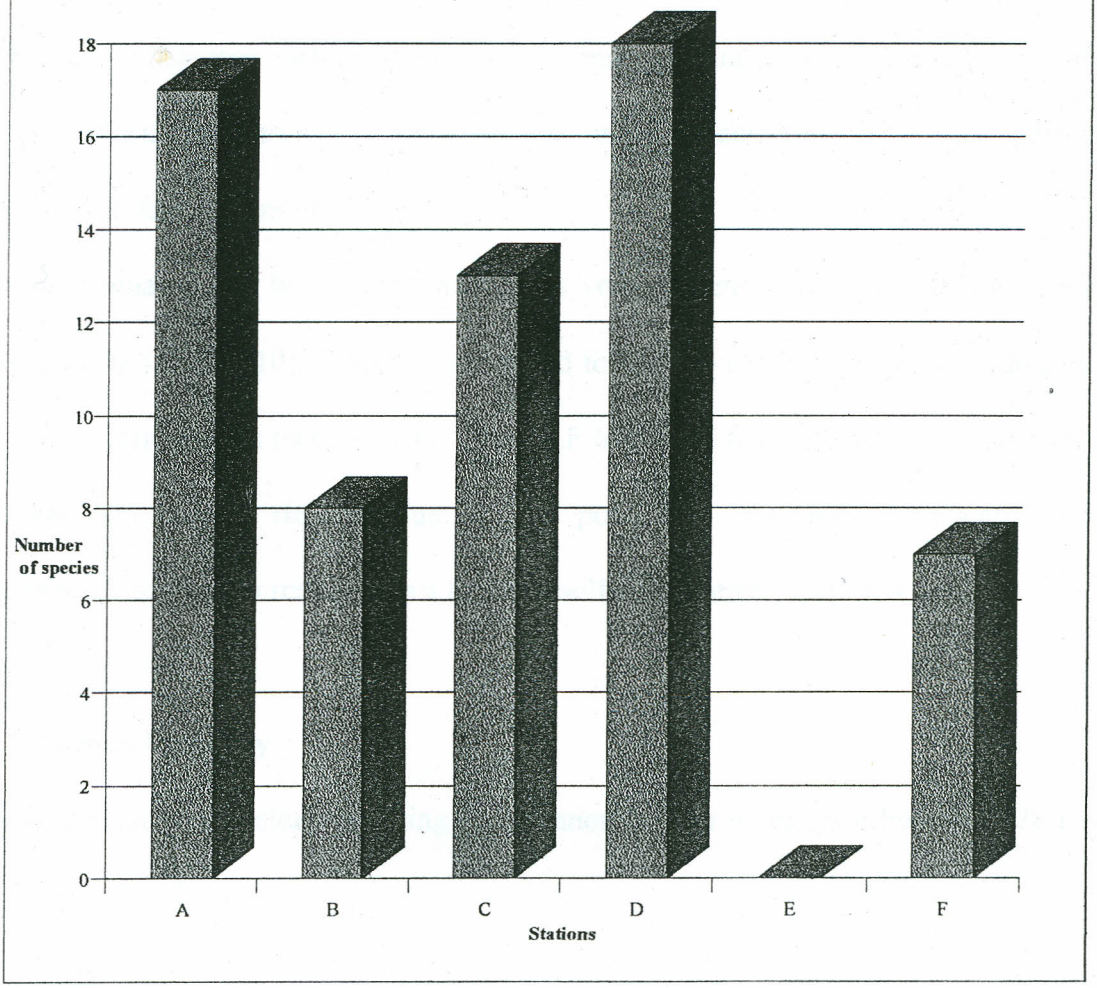
Some organisms only occured at specific sites. For example family Amphizoidea, Elmidae larva and some crustaceans (crabs), only occured in station A. Pseudagrion and Grylotalpa sp only occured in station C. Rotifera only occured in highly polluted waters of station F. Characteristic trends in benthic organisms along the river were noted and discussed in this section.

Table 10: Summary of Macrozoobenthic organisms along river Gatharaini from March to September.									
SAMPLING DATE		March-September 1996.							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	981	753	607	1462		7038
		Tipulidae		440	105	42			
		Sciomyzidae		126	84		104		
		Ceratopogonidae		189	63		63		
		Muscidae		419	105	84	167		209
	Decapoda		*Procambrus clarkii*			84	84		
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*				21		42
		Amphizoidae		42					
		Dytiscidae		21			42		
		Elmidae		63					
	Trichoptera	Hydropsychidae		21			42		
	Orthoptera		*Grylotalpa spp.*				84		
	Hemiptera	Corixidae	*Micronecta scutellaris*	63	63	63	42		
		Napidae	*Laccotrephes afer L.*	42					21
		Lygaiedae					42		
	Ephemeroptera		*May fly*			42	21		
	Odonata	Libellulidae		42		105			
		Coenagriidae	*Pseudagrion spp.*				84		
		Cordulidae		42		21	21		
Crustacea			*Crab*	84					
Annelida	Oligochaeta		*Brachiura sowerbyi*			21	1629		9106
		Almidae	*Alma almini*	251	544	711	4741		6850
	Hirudinea		*Placobdella*	21		294	418		
Rotifera									21
Mollusca			*Melanoides tuberculata*		42	981			
Amphibia			*Phynobatrachus spp*		21		42		21
			Species richness	**17**	**8**	**13**	**18**	**0**	**7**
			Species abundance	**2868**	**1759**	**3097**	**9088**	**0**	**23287**
			Mean Species abundance	**169**	**220**	**238**	**505**	**0**	**3327**
			Species diversity	**2.128**	**1.536**	**1.181**	**1.528**	**0**	**1.155**
			Species evenness	**0.74**	**0.739**	**0.46**	**0.529**	**0**	**0.594**
			Variance of Diversity	**0.000395**	**0.000509**	**0.000896**	**0.000169**	**0**	**1.104E-05**

SPECIES RICHNESS

Table 10 gives a summary of species richness, abundance and diversity along river Gatharaini. Fig. 7 shows the trends in species richness along river Gatharaini. It is apparent that species richness differed significantly along the river.

Fig. 7: Species richness along river Gatharaini



The graph shows that stations above the tannery (station E) have more variety of species than sites below the tannery. There is also a significant variation between station A and B and between station C and D. Suspected causes of these variations was the close proximity to the pollutant source. As shown in plate 2, station B is located in an area with intensive mixed farming. This could cause discharge of various toxins

such as pesticides and fertilisers into the river as suggested by other earlier studies (Kiithia, 1992). This could lead to removal of sensitive species from this area causing a decline in species richness. Stations C and D are located under the same land use type (coffee estates). However station C is located in the heart of this land use while station D is located several kilometres downstream passing through large areas of uninhabited land and a large swamp occurs above it (Plate 4). It is suspected that most of the toxic substances such as pesticides are removed naturally in the swampy section and this encourages survival of sensitive species which could not have survived the high toxic concentrations at station C.

Station E situated just below the tannery was void of benthic life and no organisms were collected (Table 10). This was attributed to high levels of pollution as indicated in water quality results (section 4.1). Station F located a few kilometres downstream also had low species richness due to high pollution. However it indicated the beginning of ecosystem recovery as a result of self purification (section 4.1)

4.2.2 Species Diversity

Species diversity was calculated using the Shannon Wiener Index (Southwood, 1978)

$$H^1 = \varepsilon Pi\ InPi$$

where H^1 = species Diversity

Pi = proportional abundance of the ^{i}th species (=ni/N)

In =natural logarithm

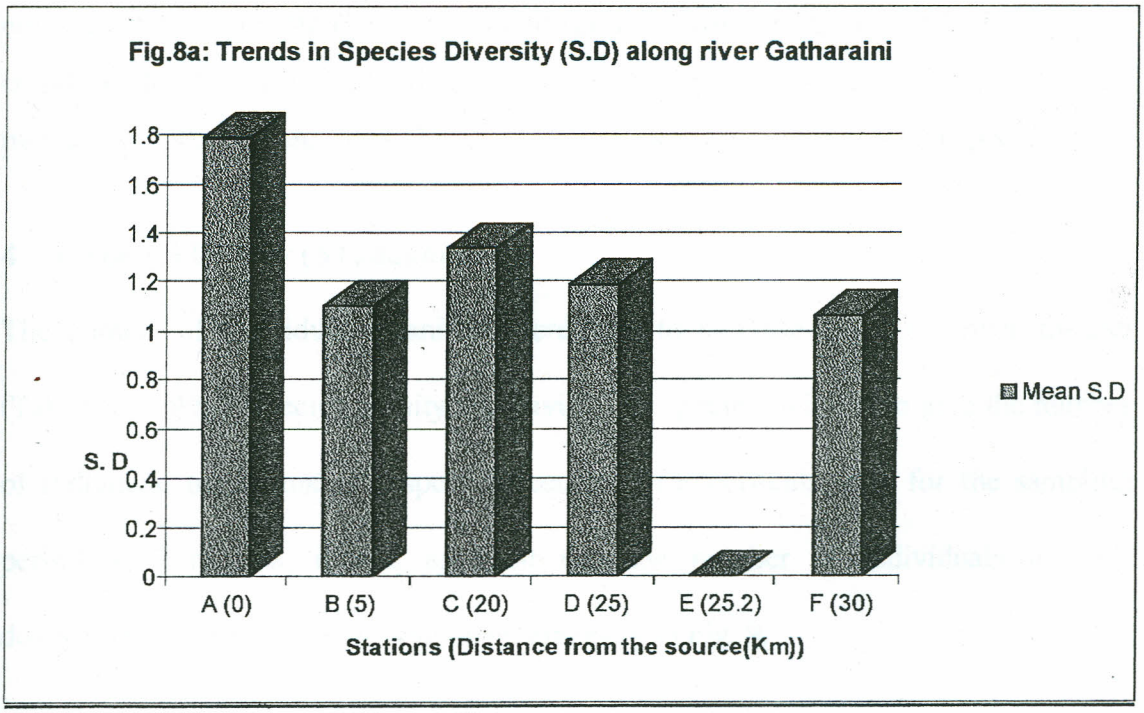
ε = sum of

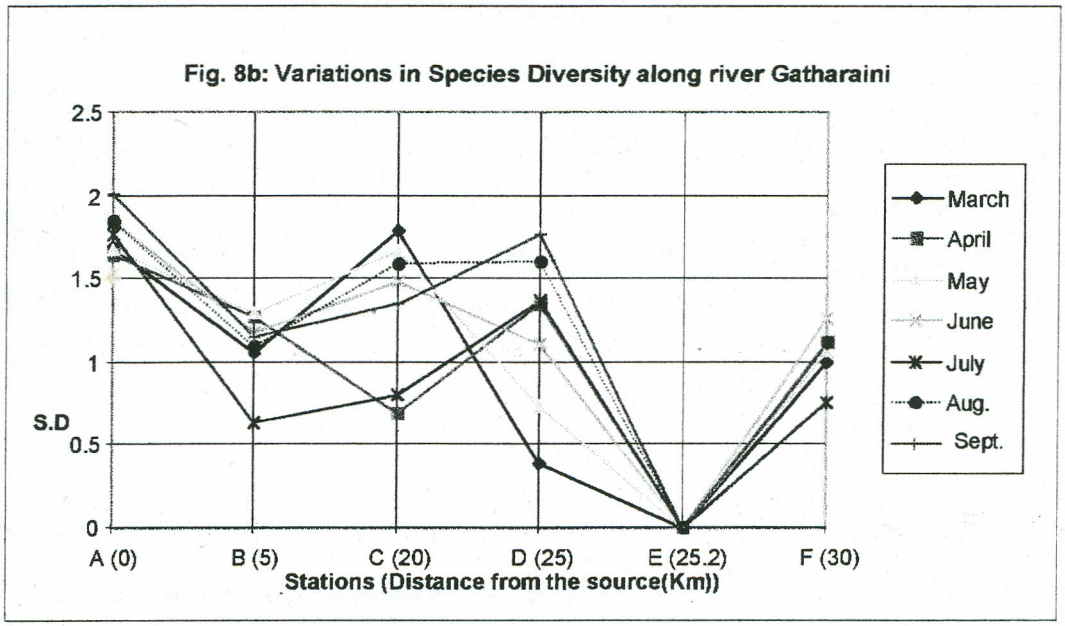
Species diversity was quite high at the source of the river and decreased downslope (Table 10 and appendix 8).

Table 11: Monthly values of Species Diversity along river Gatharaini

	STATIONS					
Months	A	B	C	D	E	F
March	1.687	1.055	1.784	0.383	0	0.999
April	1.644	1.272	0.687	1.344	0	1.12
May	1.683	1.297	1.667	0.739	0	1.068
June	1.846	1.175	1.476	1.103	0	1.256
July	1.768	0.636	0.8	1.376	0	0.756
August	1.846	1.099	1.592	1.596	0	1.119
Sept.	2.003	1.154	1.354	1.764	0	1.108
Mean SD	**1.78**	**1.2**	**1.34**	**1.19**	**0**	**1.11**

A two Factor ANOVA test using monthly values showed that monthly variations in Species Diversity were not significant while between stations variations were highly significant ($F_{(5,30)}$= 26.4; P<0.001). This is shown in figure 8a and b.





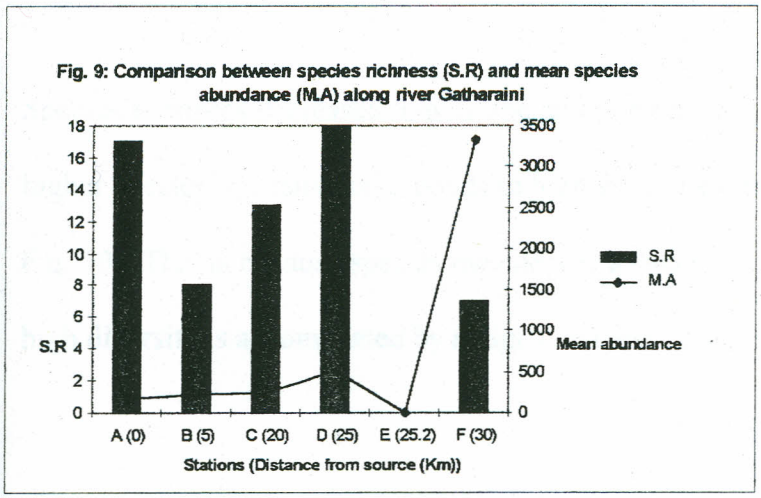
These graphs show that there were great variations in species diversity between the sampling sites. L.S.D. test showed that the greatest variations occured between station A and B, D and E and also between station E and F. As explained in section 4.2.1 variation between station A and B could be due to pollution by fertilisers and pesticides emanating from the intensively cultivated farms. Between station D and E, variation could be due to the tannery effluents while station F marks the beginning of self purification process (section 4.1) and recolonization by pollution tolerant species.

4.2.3 Species Density (Abundance)

The number of individual organisms were seen to increase along the river channel (Table 10). When species density was divided by species richness to give the number of individual organisms of a species occuring in a particular site for the sampling period of 7 months, it was apparent that the number of individuals increase downstream (Table 12). This is shown graphically in Fig. 9.

Table 12: Mean abundance of macroinvertebrates per station along river Gatharaini

Station	A	B	C	D	E	F
Species richness	17	8	13	18	0	7
Species density (all species)	2868	1759	3097	9088	0	23287
Mean density per species	169	220	238	505	0	3327



This information shows that as species abundance increases from the source downslope each species is represented by more individuals with deterioration of water quality status.

The increase in species density shows that species have learnt to adapt themselves to specific environmental conditions. Where the environment is conducive for a particular species, its density is very high. For example *Chironomus* species, *Brachiura sowebyi*, and *Alma almini* are represented by a high density in station F as compared to station D. Thus for *Chironomus* species the density increases 5 times, *Brachiura sowerbyi* increases 7 times and *Alma elmini* density almost doubles its status in station D.

4.2.4 Species evenness

This variable was calculated using the formula $E = H^1/_{\ln S}$ (Batten, 1976).

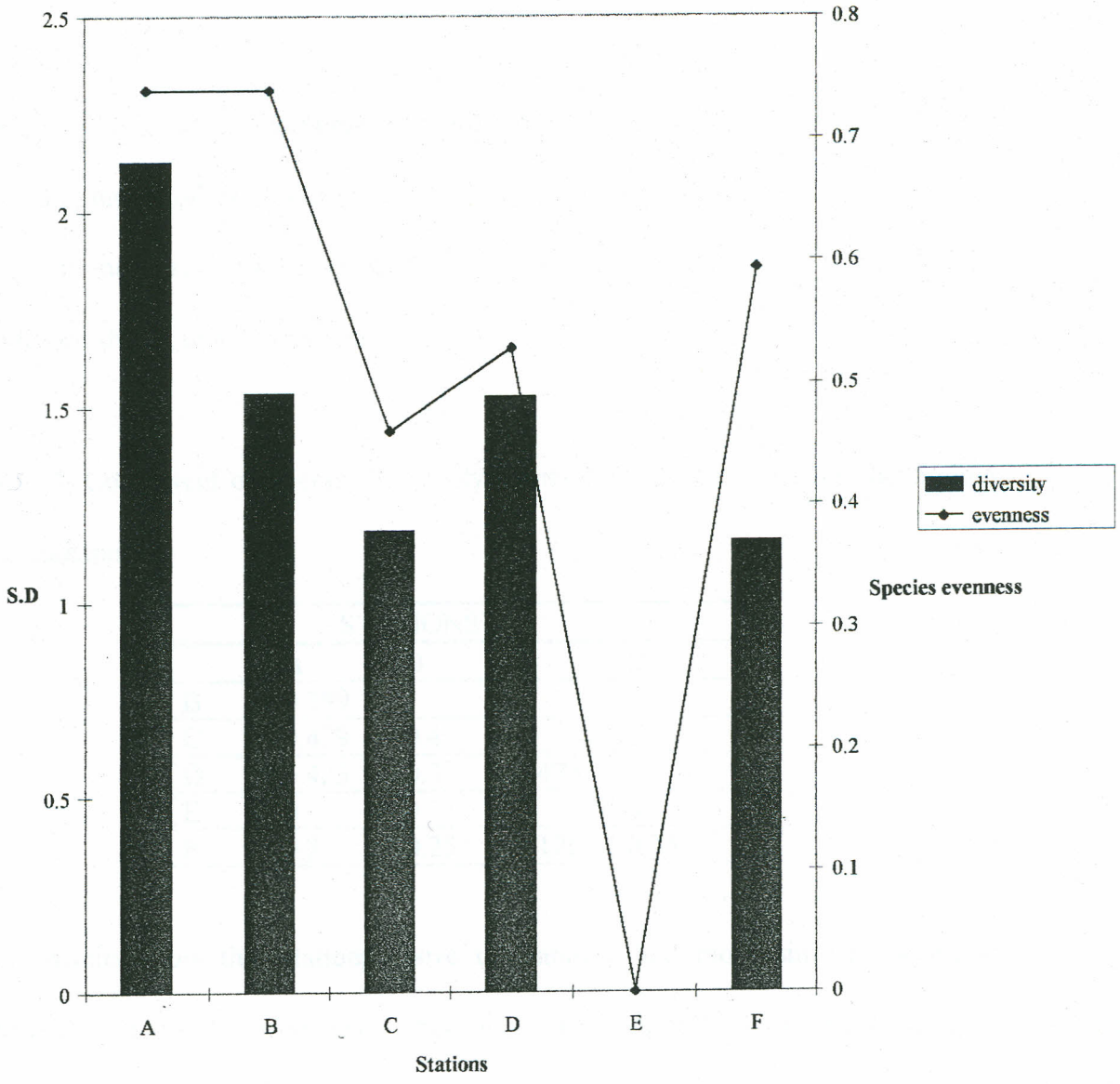
Where E = Species evenness.

H^1= Species diversity of site i.

In S = Natural logarithm of species numbers.

Species evenness decreased downslope and is highly related to species diversity in that higher species diversity corresponds to high species evenness as shown in Table 14 and Fig. 10. This is because species evenness is a function of species diversity such that a high diversity is accompanied by a high evenness

Fig. 10: Comparison between species diversity and species evenness along river Gatharaini



4.2.5 Coefficient of similarity

Comparison between species found in different sites was carried out using Jaccard Equation (Batten, 1976).

$Cj = j/(a + b - j)$

Where j =number of species common to both sites

a =number of species in site A

b =number of species in site B

Results are shown in the table below

Table 15: Coefficient of Species Similarity matrix for macroinvertebrate fauna along river Gatharaini

	STATIONS			
	A	B	C	D
B	0.389			
C	0.429	0.4		
D	0.423	0.3	0.476	
E	0	0	0	0
F	0.2	0.25	0.176	0.25

These results show that stations above the tannery had more similar species as compared to station F downstream. This shows that high pollution levels in station E and F cause changes in species composition leading to colonisation by few pollution tolerant species. Upstream, coefficient of similarity of station A is low when stations compared to station B probably due to few species collected from station B. Thus stations with high species richness also have high values of coefficient of similarity.

Comparison between water quality and species diversity

Species diversity was high in low polluted waters and decreased with increase in pollution. Simple linear regression analysis revealed that there was significant relationship between TDS and species diversity whereby

TDS versus Species Diversity $F_{(1,4)}=8.15$, $P<0.05$, $r^2 = 0.59$

This is shown graphically in Fig 10.

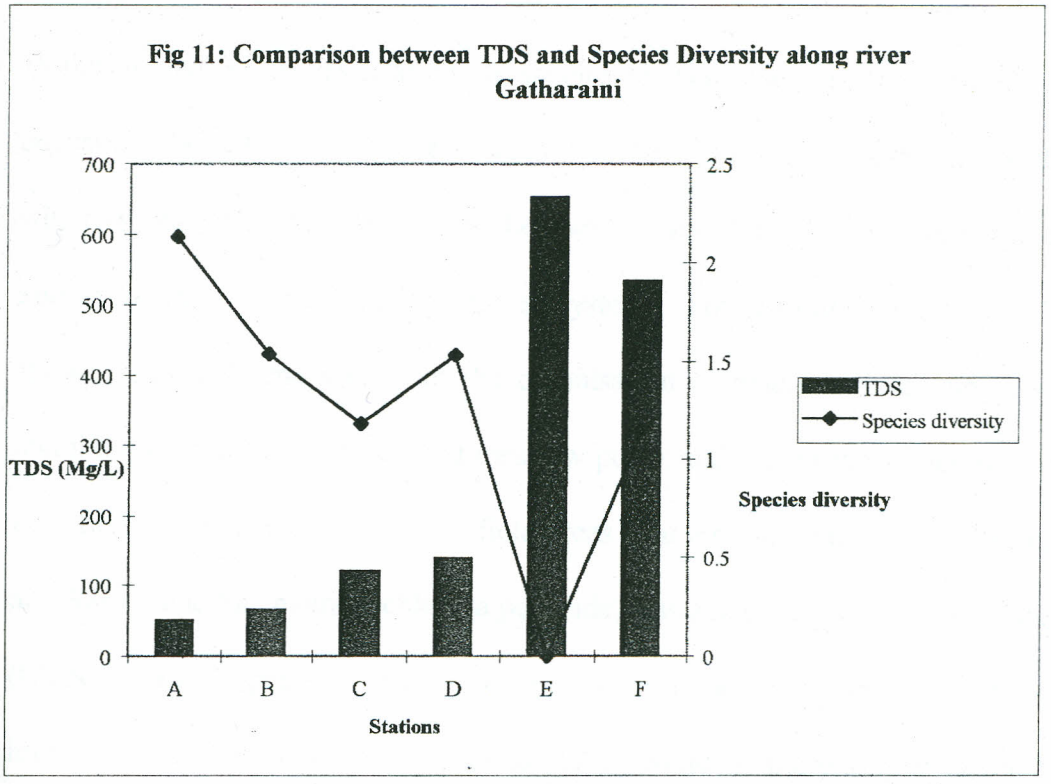


Fig. 11 shows that increase in TDS results in decrease in species diversity along the river.

It was found that species varied along the gradient of the river. The source of the river (station A) had a high species richness of 17 species. However the number of individuals per species was the lowest for all the stations sampled. This is a characteristic of oligosaprobic conditions characterised by a high water quality status

(Kinyua and Pacini, 1991). In the intensively cultivated region (station B) which don't have very adverse water quality status the species richness was quite low. This was quite unusual. However the farming system surrounding this station can be blamed as the one introducing high levels of toxic pesticides into the river which might lead to disappearance of some species. So the pesticides though not in high concentration in the river, had adverse effects on the organisms in the water leading to reduced species richness.

Within the coffee estates (station C), species richness was low and the coffee estates occurring above this station are suspected to have introduced pesticides in the river which wipes out some species from the river. Pesticides and other agrochemicals are known to create havoc in the aquatic ecosystems. For example, Ramade *et al* (1985) showed that differences exist in the organisation of macro-invertebrates and insect communities from field ponds and meadow ponds and linked this difference to water pollution by agrochemicals used in field areas of intensive cultivation. Stephenson et al (1986) found that methoxychlor (a pesticide) was acutely toxic to macrozooplankton (Cladocea and Copepoda) and microzooplankton (Rotifera). So, the high pesticide levels measured by Kiithia and Musingi (1995) could be the one responsible for low species diversity in intensively farmed areas.

The region immediately above the tannery (station D) had the highest species richness of all the stations sampled. This station was located about five kilometres down slope from the nearest coffee estate. Above this station is huge swamp covered with vegetation, reeds (*Cyperrus imensus*) being the dominant vegetation type (plate 4). It is suspected that the swamp played a significant role in purifying the water removing some of its toxic load. However, water quality in this station was still poor as compared to the other stations above it. The high species richness and diversity in

station D agrees with predictions from other studies done elsewhere. Generally, species diversity is predicted to increase with habitat heterogeneity (Townsend, 1989) and to decrease as the frequency of disturbance increases. However diversity may peak at intermediate levels of disturbance (Connell, 1978).

As environmental patchiness increases especially with respect to disturbance frequency and intensity, the colonising ability of species is likely to become more important than competitive ability (Townsend, 1989). As disturbance frequency increases further the ability to move between suitable patches may control community structure. Data from this study agrees with revelations by Armerod *et al* (1994). They studied attitudinal trends in diatoms, macroinvertebrates and fish in Nepalese river system and discovered that aquatic diversity was more concentrated on lower Himalayan slopes where human population density is greatest and risk of catchment degradation is most pronounced. Townsend (1989) predicts that high mobility will be characteristic of species in frequently disturbed habitats and stream communities experiencing high disturbance frequency are predicted to be dominated by "weedy" species. Moreover because sedentary species require stable substrata they should be filtered out of streams having high disturbance frequencies or a lack of stable substratum patches.

The area immediately below the tannery (station E) experienced the greatest environmental disturbance characterised by high TDS, EC, pH and turbidity levels accompanied by low dissolved oxygen levels. Another feature noted was that disturbance in this station was intermittent. So in March, June and August the TDS and EC values were very high as compared to the other months. This can greatly affect the colonising ability of organisms (Townsend, 1989) leading to complete absence of macrobenthos observed.

Lack of biota in highly polluted waters has been reported in other parallel studies done in other parts of Kenya. Several studies done on river Nairobi has revealed absence of riverine biota in highly polluted sections (Kinyua and Pacini, 1991). Industrial and residential land uses have been blamed for this decline. Tanneries have been shown to discharge heavy metal cadmium into the aquatic environments. These heavy metals can have a great impact on the aquatic biota. For example Ngiri (1978) showed that heavy metals especially Copper is poisonous to *Spirulina* and *rofiters* leading to their death.

Further downstream from the tannery (station F), the levels of pollutants have gone slightly down (section 4.1) and colonisation of the habitat by several species was observed (Table 10). However only few species were found here mainly dominated by Diptera, Chironomidae and Oligochaeta. The species abundance was high such that each species was represented by many individuals. This is characteristic of alpha mesosaprobic environments. This suggests that these organisms were adapted to the high pollutant levels. Resh et al (1988) predicted that streams experiencing frequent disturbance will have less epilithic algae and benthic particulate organic matter than more stable streams. Differences in food source availability caused by the disturbance regime will have consequences for community functions feeding group structure. Thus less stable streams are predicted to have fewer specialist grazers, filter feeders and shredders and more generalist feeders (Scarsbrook and Townsend, 1993).

River Gatharaini also portrayed some recovery both in terms of water quality and the benthic diversity in Station F. This suggests that the river underwent a self purification process whereby some pollutants were removed from the water through various

chemical reactions. Other studies have also demonstrated recovery of the aquatic biota after a decline in pollutant levels (Njuguna, 1978; Kinyua and Pacini, 1991).

For the case of the dead river section below the tannery, some action is needed to clean this polluted water. This study has already indicated that this water undergoes self purification process whereby the pollutant levels decline. So the tannery factory should neutralise their discharge chemically to remove these harmful chemicals or construct ponds where this water can stand for some time for self purification to take place before finally joining the main stream.

CHAPTER 5

5.1 CONCLUSIONS AND RECOMMENDATIONS

This study revealed that major changes had taken place in river Gatharaini. The river was found to be highly polluted with major pollutants possibly being fertilisers, pesticides and particulate suspended solids resulting from the intensive agricultural land use (Kiithia, 1992). Industrial and residential discharges also played a great role in influencing water quality.

It was noted that discharge of pollutants into the river occurred at specified times. For example, the agricultural land use was a major pollutant during the wet season and more so if this coincides with the planting or plant growing season (Fig l, 2). This was mainly due to leaching and erosion of these substances from the farmlands onto the river. So, its during the wet season that most of the fertilisers and pesticides get carried to the rivers where they exert their toll on water quality and riverine fauna and flora.

Also from agricultural land use pollution may come about through deliberate discharge of pollutants into the river. For example, the great increase in EC and TDS in September was due to onset of coffee harvesting season which discharges waste water from the coffee factories into the river. These discharges consist mainly of organic sugars found in coffee berries cell sap which is squeezed out in coffee processing factories. The sediments in the river are mainly derived from the eroded landscape and river valleys. Sediments have been shown to retain these pollutants for long periods such that the effect of a pollutant on water quality and organisms may extend for a longer period post pollutant introduction into the water (Ward et al, 1986).

From the Industrial land use great havoc was realised. It seems that release of pollutants was deliberate and was done without minding about its toxicity levels to the recipient habitats. As can be seen from this survey a section of the river had been

completely devastated to a point of being devoid of fauna life (Section 4.2). But a close look at the levels of for example TDS which in this study had been identified as a pollution predictor, shows that sometimes the levels of TDS falls even to a lower level in Station E (below the tannery) than Station F situated 5 km downstream. So this study therefore suspects that it's because of the differences in magnitude of the disturbance regimes that made this place uncolonisable even by *Chironomidae, Brachiura*, and *Almidae* species which have been shown to be abundant in highly polluted waters (Roback 1974, Kinyua and Pacini 1991).

This study also revealed that it is hard to predict the effect of a pollutant indirectly by using pollutant levels. For example in station B (situated in the intensively cultivated farms) the species diversity was low as compared to other stations above the tannery. Looking at the pollutant levels indirectly using TDS, EC, pH shows this station to have excellent conditions for supporting a high diversity. But the opposite is true. This shows the need for research being more comprehensive to identify the levels of various specific pollutants such as pesticides which was highly suspected to be involved here.

But because of the hardships involved in procuring enough funds to carry out comprehensive physical chemical studies it is now advisable that more research should be geared towards identifying an indicator species. The presence or absence of an indicator species should tell us much about the general status of the habitat. In this study this objective was not clearly realised mainly due to the fact that the study was carried out within only a short period of seven months. So a whole cycle of events over maybe a year was not observed. Another handicap to this study was lack of enough funds to carry out a comprehensive survey where each specific pollutant was isolated and identified. So much of what was discovered was as a result of indirect deductions. These indirect deductions deal with interactions of many factors. For example TDS

could incorporate fertilizers, pesticides, organic nutrients, and dissolved rock minerals. From the industrial land use TDS could incorporate heavy metals and other organic and inorganic substances. This makes it hard to have an unbiased judgement of an appropriate indicator species. However its worth noting that this study found out several species confined to particular stations only. For example *rotifers* were only found in the highly polluted sections in station F further downstream from the tannery. *Amphizoidae* and *Crustacea* were only found in the unpolluted waters of the stream source. These two cases are the extremes which could form a good starting point in search of an indicator species.

But abundance may also be a good indicator of polluted waters if used together with other species diversity measures. For example in this study, though the species diversity vary, the mean abundance per species continued to increase as the water quality deteriorated (Table 12). So one can deduce the water quality status of a habitat if comparative studies are done. Thus highly polluted waters will either be void of life or have few species represented by many individuals. Moderately to low polluted waters will have a high diversity but individuals will increase with the level of pollution.

5.2 Recommendations

Relating the water quality measurements to land use activities taking place along river Gatharaini, it is clear that human activities along the channel have influenced the water quality status of river Gatharaini. The overall result has been an increase in pollutant load of the river to a climax level where no animal can survive in the riverine habitat.

The issue of environmental pollution has been a critical issue of concern especially now that there is imminent danger of collapse of natural life sustaining systems as a

result of external human induced manipulations (Zaden, 1995). In river Gatharaini, a section of the riverine habitat had been made lifeless. This study, therefore is timely because it clearly displays what is to be expected in future if necessary actions are not taken to monitor, assess and reduce discharging toxic wastes into the aquatic habitats.

So this study recommends the great need for evaluation of impact of pollutants on the environment and more so the aquatic environment. Thus for example this study has already revealed that the tannery has a great negative impact on the riverine water quality and biodiversity. The tannery here makes the water unsuitable for human use and as a habitat for organisms. So similar studies should be done for other industries and land uses in order to have complete information on pollution hazards to ecosystems caused by various pollutants emanating from the various land uses.

Because the various land uses undertaken by man are economically supporting his well being, something should be done with regard to their production procedures, treatment and discharge of wastes. This should be done to ensure that there is no interference with the natural environment on which the landuse ultimately depends on. So every discharge to the environment should conform to the external environment in both physical and chemical aspects.

The problem however in most countries is not lack of knowledge on adversities of pollution, but ignorance by the parties concerned. So the government of the day should install automatic water quality monitoring stations at strategic places to monitor discharges into the rivers. In the industries, every industrial discharge drainage outlet should be installed with an automatic water quality devise or recorder to ensure that no illegal wastes are discharged into the rivers system or other natural ecosystems. For this action to work effectively it should be strengthened by instituting hard legal penalties against defaulters who discharge harmful effluents to the natural environment.

Some discharges such as fertilisers and pesticides are hard to control. Their application including amounts and types should be monitored by Kenya Pesticides Board from the Ministry of Agriculture in order to avoid a major environmental deterioration.

On waste disposing, there is need to evaluate the present procedures in use by both industrial and residential land uses to avoid disposing wastes especially into rivers. County Councils together with other relevant government ministries should provide their people with guidelines to be followed in dumping waste. These guidelines should be reinforced by a kind of legislation comprising both punitive and rewarding mechanisms.

5.3 Further areas of Research

There is need to establish the detailed status of river Gatharaini habitat both in terms of water quality and biodiversity. Complete and detailed analysis of the water is necessary so as to know how much allochthonous waste of various types come from each land use. This study should be conducted for a longer period of several years inorder to give a clear picture of the habitat. Specific inorganic and organic substances should be identified and quantified over the whole stretch of the river.

The biological status of the river should also be studied in greater detail and over a longer time so as to identify the different organisms, their respective niches together with their seasonal variations. This study should be conducted for both macro and micro-organisms for both plants and animals.

The interactions of the living organisms with the pollutants or physical and chemical conditions should be analysed with more detail over an extended period. Scientists should relate the levels of pollutants in the water to that in the living organisms along

the river to see whether there are any possibilities of bioaccumulation of the pollutant in the living organisms.

Relating the pollutant levels to organisms diversity, their distribution and their physiological status would help us to come up with an indicator species. This indicator species would help us in predicting the nature and levels of pollution in the freshwater environments even before field experiments are conducted on their water quality status.

Because of the complexity of the natural environments there is need for ex-situ studies on pollutants and their effects on living organisms. These studies should act as controls against which in-situ interactions between organisms and their physical chemical environments can be compared.

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Appendix 1: Monthly TDS changes along river Gatharaini (Values in Mg/l)

		STATIONS				
Months	A1	A2	A3	A4	A5	Mean
MARCH	47	52	50	51	49	49.8
APRIL	49	48	48	34	51	46
MAY	51	54	59	50	58	54.4
JUNE	57	57	50	52	56	54.4
JULY	49	47	47	51	48	48.4
AUGUST	51	52	50	51	49	50.6
SEPTEMBER	47	47	47	46	47	46.8
Months	B1	B2	B3	B4	B5	Mean
MARCH	115	116	114	120	115	116
APRIL	60	59	59	61	58	59.4
MAY	56	58	56	55	55	56
JUNE	54	59	50	53	58	54.8
JULY	56	56	55	59	59	57
AUGUST	54	56	55	55	58	55.6
SEPTEMBER	55	57	59	59	61	58.2
Months	C1	C2	C3	C4	C5	Mean
MARCH	121	123	124	129	131	125.6
APRIL	104	104	104	104	102	103.6
MAY	112	112	111	112	113	112
JUNE	108	109	109	109	109	108.8
JULY	98	102	99	100	98	99.4
AUGUST	91	84	101	101	101	95.6
SEPTEMBER	190	196	196	199	199	196
Months	D1	D2	D3	D4	D5	Mean
MARCH	140	151	148	147	148	146.8
APRIL	118	120	120	121	122	120.2
MAY	123	128	130	132	130	128.6
JUNE	134	137	143	143	139	139.2
JULY	163	163	150	130	124	146
AUGUST	118	119	126	131	131	125
SEPTEMBER	170	155	158	182	159	164.8
Months	E1	E2	E3	E4	E5	Mean
MARCH	1097	1105	1111	1114	1097	1104.8
APRIL	313	300	300	289	287	297.8
MAY	1126	1139	1158	1152	1168	1148.6
JUNE	267	277	279	283	281	277.4
JULY	341	343	340	341	339	340.8
AUGUST	390	398	400	405	405	399.6
SEPTEMBER	992	1008	1002	1008	1011	1004.2

Months	F1	F2	F3	F4	F5	Mean
MARCH	524	567	563	567	564	557
APRIL	262	264	265	265	263	263.8
MAY	880	887	896	893	895	890.2
JUNE	462	460	458	458	461	459.8
JULY	323	343	340	341	341	337.6
AUGUST	367	375	375	372	362	370.2
SEPTEMBER	850	852	860	856	856	854.8

Appendix 2: Monthly EC changes along river Gatharaini (Values in Ms)

		STATIONS				
Months	A1	A2	A3	A4	A5	Mean
MARCH	0.06	0.08	0.08	0.08	0.07	0.074
APRIL	0.07	0.06	0.07	0.06	0.07	0.066
MAY	0.07	0.08	0.08	0.07	0.08	0.076
JUNE	0.08	0.08	0.04	0.07	0.08	0.07
JULY	0.07	0.07	0.06	0.08	0.07	0.07
AUGUST	0.07	0.07	0.07	0.07	0.07	0.07
SEPTEMBER	0.06	0.07	0.06	0.07	0.06	0.064
Months	B1	B2	B3	B4	B5	Mean
MARCH	0.17	0.17	0.17	0.17	0.16	0.168
APRIL	0.09	0.08	0.08	0.09	0.08	0.084
MAY	0.08	0.08	0.08	0.08	0.07	0.078
JUNE	0.08	0.09	0.07	0.07	0.09	0.08
JULY	0.08	0.08	0.07	0.09	0.08	0.08
AUGUST	0.08	0.07	0.07	0.08	0.08	0.076
SEPTEMBER	0.08	0.09	0.07	0.08	0.08	0.08
Months	C1	C2	C3	C4	C5	Mean
MARCH	0.18	0.18	0.18	0.19	0.18	0.182
APRIL	0.16	0.15	0.15	0.15	0.15	0.152
MAY	0.16	0.16	0.16	0.15	0.17	0.16
JUNE	0.15	0.16	0.17	0.16	0.17	0.162
JULY	0.14	0.15	0.15	0.14	0.15	0.146
AUGUST	0.13	0.12	0.14	0.15	0.14	0.136
SEPTEMBER	0.28	0.29	0.29	0.29	0.29	0.288
Months	D1	D2	D3	D4	D5	Mean
MARCH	0.19	0.22	0.22	0.25	0.28	0.232
APRIL	0.18	0.18	0.18	0.18	0.18	0.18
MAY	0.18	0.19	0.19	0.19	0.19	0.188
JUNE	0.2	0.21	0.21	0.21	0.21	0.208
JULY	0.25	0.27	0.23	0.19	0.19	0.226
AUGUST	0.17	0.17	0.17	0.19	0.19	0.178
SEPTEMBER	0.25	0.23	0.23	0.26	0.23	0.24
Months	E1	E2	E3	E4	E5	Mean
MARCH	1.65	1.64	1.65	1.67	1.65	1.652
APRIL	0.47	0.45	0.45	0.44	0.44	0.45
MAY	1.69	1.69	1.72	1.72	1.74	1.712
JUNE	0.4	0.42	0.42	0.46	0.44	0.428
JULY	0.51	0.51	0.5	0.51	0.51	0.508
AUGUST	0.56	0.6	0.59	0.61	0.6	0.592
SEPTEMBER	1.15	1.51	1.51	1.5	1.52	1.438

Months	F1	F2	F3	F4	F5	Mean
MARCH	0.77	0.84	0.83	0.84	0.82	0.82
APRIL	0.39	0.39	0.4	0.4	0.39	0.394
MAY	1.32	1.33	1.34	1.35	1.33	1.334
JUNE	0.69	0.69	0.68	0.69	0.69	0.688
JULY	0.48	0.51	0.51	0.5	0.51	0.502
AUGUST	0.54	0.55	0.55	0.55	0.54	0.546
SEPTEMBER	1.21	1.29	1.25	1.29	1.29	1.266

Appendix 3: Monthly pH changes along river Gatharaini

	STATIONS					
Months	A1	A2	A3	A4	A5	Mean
MARCH	6.98	6.41	6.53	6.57	6.25	6.548
APRIL	7.13	6.81	6.55	6.62	6.5	6.722
MAY	6.62	6.58	6.88	7.16	7.08	6.864
JUNE	7.98	7.65	7.23	6.83	6.66	7.27
JULY	7.55	7.36	7.07	6.91	6.7	7.118
AUGUST	8.02	7.48	7.13	6.9	6.75	7.256
SEPTEMBER	8.24	7.63	7.37	7.48	7.32	7.608
Months	B1	B2	B3	B4	B5	Mean
MARCH	7.16	6.22	6.21	6.2	6.25	6.408
APRIL	7.76	7.42	7.53	7.38	7.34	7.486
MAY	6.8	7.04	7.11	7.18	7.12	7.05
JUNE	7.27	7.05	7.04	6.9	6.89	7.03
JULY	6.9	6.9	6.89	6.98	6.98	6.93
AUGUST	7.02	7.21	7.23	7.18	7.17	7.162
SEPTEMBER	7.21	7.3	7.33	7.28	7.27	7.278
Months	C1	C2	C3	C4	C5	Mean
MARCH	7.22	7.16	7.23	7.39	7.45	7.29
APRIL	6.94	6.91	6.87	6.96	6.71	6.878
MAY	7.23	7.14	7.05	6.99	6.98	7.078
JUNE	7.45	7.13	7.03	6.97	6.85	7.086
JULY	7.52	7.41	7.3	7.3	7.32	7.37
AUGUST	7.25	7.3	7.24	7.19	7.15	7.226
SEPTEMBER	7.91	7.91	7.69	7.63	7.56	7.74
Months	D1	D2	D3	D4	D5	Mean
MARCH	7.75	7.56	7.63	7.87	7.7	7.702
APRIL	8.05	8	7.92	7.86	7.67	7.9
MAY	7.27	7.22	7.28	7.17	7.11	7.21
JUNE	6.78	6.83	6.83	6.83	6.82	6.818
JULY	7.28	7.22	6.93	7	6.86	7.058
AUGUST	7.21	7.08	6.89	6.91	6.93	7.004
SEPTEMBER	9.24	8.9	8.75	8.67	8.56	8.824
Months	E1	E2	E3	E4	E5	Mean
MARCH	8.14	8.15	8.15	8.15	8.16	8.15
APRIL	7.54	7.57	7.57	7.62	7.55	7.57
MAY	7.57	7.61	7.63	7.63	7.62	7.612
JUNE	7.32	7.32	7.32	7.32	7.31	7.318
JULY	7.67	7.66	7.66	7.66	7.68	7.666
AUGUST	8	7.92	7.82	7.8	7.84	7.876
SEPTEMBER	8.7	8.83	8.63	8.56	8.61	8.666

Months	F1	F2	F3	F4	F5	Mean
MARCH	7.12	7.12	7.23	7.2	7.14	7.162
APRIL	7.83	7.62	7.52	7.5	7.48	7.59
MAY	7.36	7.47	7.47	7.47	7.36	7.426
JUNE	7.14	7.34	7.33	7.35	7.34	7.3
JULY	7.14	7.18	7.25	7.21	7.2	7.196
AUGUST	7.6	7.43	7.44	7.42	7.44	7.466
SEPTEMBER	8.5	8.5	8.5	8.5	8.5	8.5

Appendix 4: Monthly Water temperature changes along river Gatharaini (Values in ^{0}C)

		STATIONS				
Months	A1	A2	A3	A4	A5	Mean
MARCH	19.6	19.7	19.5	19.5	19.5	19.56
APRIL	20.2	20.4	20.4	20.2	20.1	20.26
MAY	19.5	19.4	19.5	19.9	20	19.66
JUNE	19.1	19.1	19.1	19.1	19.1	19.1
JULY	19.2	19	19	18.6	19	18.96
AUGUST	19.3	19.3	19.1	19.1	19.1	19.18
SEPTEMBER	18.2	18.8	18.2	19.2	18.2	18.52
Months	B1	B2	B3	B4	B5	Mean
MARCH	22.1	22.1	22.1	22.2	22.1	22.12
APRIL	19.6	19.6	19.4	20	19.9	19.7
MAY	22.4	21	21.5	21.6	22	21.7
JUNE	19.3	19.2	19.3	19.3	19.4	19.3
JULY	18.5	18.6	18.6	18.5	18.4	18.52
AUGUST	19.2	19.2	19.3	19.2	19.2	19.22
SEPTEMBER	18.6	18.8	18.8	18.6	18.6	18.68
Months	C1	C2	C3	C4	C5	Mean
MARCH	20.6	20.5	20.5	20.5	20.5	20.52
APRIL	22.2	23	23.4	22.8	23	22.88
MAY	21.3	21.4	21.5	21.5	21.7	21.48
JUNE	21.5	21.2	21.3	21.3	21.2	21.3
JULY	20.3	20.2	20.1	20.1	20	20.14
AUGUST	18.4	18.2	18.2	18.2	18.2	18.24
SEPTEMBER	17.8	17.8	17.8	17.6	18	17.8
Months	D1	D2	D3	D4	D5	Mean
MARCH	19.6	19.6	19.6	19.8	19.9	19.7
APRIL	21.8	21.8	22	21.9	22.3	21.96
MAY	20.9	20.9	20.8	20.8	20.7	20.82
JUNE	19.7	19.7	19.7	19.7	19.7	19.7
JULY	19.2	19.1	19.1	19.1	19.2	19.14
AUGUST	17.8	17.6	17.6	17.5	17.5	17.6
SEPTEMBER	18.8	18.6	18.7	18.7	18.6	18.68
Months	E1	E2	E3	E4	E5	Mean
MARCH	21.6	21.8	21.6	21.8	21.8	21.72
APRIL	22.2	22.3	22.4	22.3	22.3	22.3
MAY	21.2	21.2	21.2	21.2	21.2	21.2
JUNE	19.4	19.4	19.4	19.4	19.4	19.4
JULY	18.8	18.8	18.8	18.8	18.8	18.8
AUGUST	17	16.8	16.8	16.8	16.8	16.84
SEPTEMBER	18	17.7	17.7	17.6	17.7	17.74

Months	F1	F2	F3	F4	F5	Mean
MARCH	20.7	20.6	20.7	20.7	20.7	20.68
APRIL	20.7	20.7	20.7	20.7	20.7	20.7
MAY	20.6	20.6	20.6	20.6	20.5	20.58
JUNE	19.3	19.3	19.2	19.4	19.2	19.28
JULY	18	17.9	17.9	17.9	18	17.94
AUGUST	16.7	16.7	16.7	16.6	16.5	16.64
SEPTEMBER	18.2	18.7	18.1	18.1	18.1	18.24

Appendix 5: Monthly DO changes along river Gatharaini (Values in Mg/l)

		STATIONS				
Months	A1	A2	A3	A4	A5	Mean
MARCH	6.2	6.4	7	6.2	6.8	6.52
APRIL	5.8	6	6	6	5.8	5.92
MAY	4.8	5.2	5.2	4.8	5	5
JUNE	5.2	4.6	5.2	6.2	5.4	5.32
JULY	5.6	5.4	5.6	5	4.6	5.24
AUGUST	6.6	5.8	5.2	4.4	4.4	5.28
SEPTEMBER	6.4	5.6	4.8	5.2	6	5.6

Months	B1	B2	B3	B4	B5	Mean
MARCH	3.8	3.8	5.6	3.6	3.4	4.04
APRIL	5.2	4.4	4.6	4.6	4.2	4.6
MAY	4.4	4.6	4.4	4.6	4.4	4.48
JUNE	4.8	6	5.6	5.6	5.2	5.44
JULY	4.4	4.6	4.6	4.6	4.2	4.48
AUGUST	4.8	4.6	5.2	5.4	5.2	5.04
SEPTEMBER	5	4.6	5.2	5.2	5.2	5.04

Months	C1	C2	C3	C4	C5	Mean
MARCH	6	5.6	4.8	6.4	5.2	5.6
APRIL	4.6	4.2	4.2	4.4	4.6	4.4
MAY	4.6	4	4.2	4	4.4	4.24
JUNE	4.6	5.2	5.2	4.8	4.8	4.92
JULY	3.6	4.2	4.6	4.2	4.2	4.16
AUGUST	5	4.6	4.6	4.4	4.8	4.68
SEPTEMBER	4	4.8	5.2	4.8	4.8	4.72

Months	D1	D2	D3	D4	D5	Mean
MARCH	4.8	5.2	4.4	4.4	4.4	4.64
APRIL	6.4	7	7.4	7.2	7.2	7.04
MAY	5.4	5.8	5	7.6	5.8	5.92
JUNE	7	5.6	5	5.8	6	5.88
JULY	6	5.8	5.4	6.2	5.6	5.8
AUGUST	6.2	6	6	5.8	5.8	5.96
SEPTEMBER	5.6	5.8	5.8	5.4	5.4	5.6

Months	E1	E2	E3	E4	E5	Mean
MARCH	0.2	0	0	0	0	0.04
APRIL	1.4	1.4	1	1	0.8	1.12
MAY	0	0	0	0	0	0
JUNE	0.3	0.5	0.6	0.8	0.3	0.5
JULY	1.3	1.2	1	1.2	1.2	1.18
AUGUST	0.6	0.4	0	0.2	0	0.24
SEPTEMBER	0	0	0	0	0	0

Months	F1	F2	F3	F4	F5	Mean
MARCH	0.4	0.4	0.4	0.4	0.6	0.44
APRIL	1.4	1.1	1.4	1.2	1.4	1.3
MAY	0	0	0	0.4	0	0.08
JUNE	1.1	1.2	1	1	1.2	1.1
JULY	1.6	1.2	1.4	1.2	1	1.28
AUGUST	1.4	1.4	1.2	1.2	1.1	1.26
SEPTEMBER	0.4	0	0	0	0	0.08

Appendix 6: Monthly Macrozoobenthic organisms status along river Gatharaini									
SAMPLING DATE		Mar-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	355		21			1692
		Tipulidae		167		21			
		Sciomyzidae		42					
		Ceratopogonidae		84					
		Muscidae		63	21				
	Decapoda		*Procambrus clarkii*			21			
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						
		Amphizoidae							
		Dytiscidae							
		Elmidae		21					
	Trichoptera	Hydropsychidae							
	Orthoptera		*Grylotalpa spp.*				21		
	Hemiptera	Corixidae	*Micronecta scutellaris*	42	42				
		Napidae	*Laccotrephes afer L.*						
		Lygaiedae							
	Ephemeroptera		*May fly*						
	Odonata	Libellulidae							
		Coenagriidae	*Pseudagrion spp.*						
		Cordulidae							
Crustacea			*Crab*	21					
Annelida	Oligochaeta		*Brachiura sowerbyi*				439		3530
		Almidae	*Alma almini*	104	42	84	982		1253
	Hirudinea		*Placobdella*			42	84		
Rotifera									
Mollusca			*Melanoides tuberculata*			84			
Amphibia			*Phynobatrachus spp*						
			Species richness	**8**	**3**	**7**	**4**		**3**
			Species abundance	**857**	**105**	**315**	**1526**		**6475**

SAMPLING DATE		Apr-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	146	272		773		1587
		Tipulidae		21	63				
		Sciomyzidae					63		
		Ceratopogonidae					63		
		Muscidae		63	42		104		
	Decapoda		*Procambrus clarkii*						
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						42
		Amphizoidae							
		Dytiscidae							
		Elmidae							
	Trichoptera	Hydropsychidae							
	Orthoptera		*Grylotalpa spp.*						
	Hemiptera	Corixidae	*Micronecta scutellaris*	63	21		21		
		Napidae	*Laccotrephes afer L.*						
		Lygaiedae							
	Ephemeroptera		*May fly*				21		
	Odonata	Libellulidae							
		Coenagriidae	*Pseudagrion spp.*						
		Cordulidae							
Crustacea			*Crab*						
Annelida	Oligochaeta		*Brachiura sowerbyi*				84		1002
		Almidae	*Alma almini*	21	146	104	1399		940
	Hirudinea		*Placobdella*	21		84	146		
Rotifera									
Mollusca			*Melanoides tuberculata*						
Amphibia			*Phynobatrachus spp*	21					
			Species richness	**7**	**5**	**2**	**9**		**4**
			Species abundance	**356**	**544**	**188**	**2674**		**3570**

SAMPLING DATE		May-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	146	251	84	543		1525
		Tipulidae		63	21	21			
		Sciomyzidae		21	42		21		
		Ceratopogonidae			42				
		Muscidae		63		21			
	Decapoda		*Procambrus clarkii*			21	21		
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						
		Amphizoidae		21					
		Dytiscidae							
		Elmidae							
	Trichoptera	Hydropsychidae							
	Orthoptera		*Grylotalpa spp.*						
	Hemiptera	Corixidae	*Micronecta scutellaris*						
		Napidae	*Laccotrephes afer L.*						
		Lygaiedae							
	Ephemeroptera		*May fly*						
	Odonata	Libellulidae				42			
		Coenagriidae	*Pseudagrion spp.*						
		Cordulidae							
Crustacea			*Crab*	21					
Annelida	Oligochaeta		*Brachiura sowerbyi*						835
		Almidae	*Alma almini*	21	21	21	1170		1065
	Hirudinea		*Placobdella*						
Rotifera									
Mollusca			*Melanoides tuberculata*		42	125			
Amphibia			*Phynobatrachus spp*						
			Species richness	**7**	**6**	**7**	**4**		**3**
			Species abundance	**356**	**419**	**335**	**1755**		**3425**

SAMPLING DATE		Jun-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	42	167	418			313
		Tipulidae		63					
		Sciomyzidae			21				
		Ceratopogonidae		21	21				
		Muscidae		42	21				63
	Decapoda		*Procambrus clarkii*			21			
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						
		Amphizoidae							
		Dytiscidae							
		Elmidae							
	Trichoptera	Hydropsychidae							
	Orthoptera		*Grylotalpa spp.*						
	Hemiptera	Corixidae	*Micronecta scutellaris*						
		Napidae	*Laccotrephes afer L.*						21
		Lygaiedae							
	Ephemeroptera		*May fly*						
	Odonata	Libellulidae		21		63			
		Coenagriidae	*Pseudagrion spp.*				63		
		Cordulidae							
Crustacea			*Crab*	21					
Annelida	Oligochaeta		*Brachiura sowerbyi*				251		439
		Almidae	*Alma almini*	21	188	272	418		606
	Hirudinea		*Placobdella*			42	63		
Rotifera									
Mollusca			*Melanoides tuberculata*			146			
Amphibia			*Phynobatrachus spp*			21			
			Species richness	**7**	**5**	**7**	**4**		**5**
			Species abundance	**231**	**418**	**983**	**794**		**1441**

SAMPLING DATE		Jul-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	84	21		84		292
		Tipulidae		42					
		Sciomyzidae					21		
		Ceratopogonidae							
		Muscidae							
	Decapoda		*Procambrus clarkii*						
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						
		Amphizoidae							
		Dytiscidae							
		Elmidae							
	Trichoptera	Hydropsychidae		21			21		
	Orthoptera		*Grylotalpa spp.*						
	Hemiptera	Corixidae	*Micronecta scutellaris*						
		Napidae	*Laccotrephes afer L.*	21					
		Lygaiedae							
	Ephemeroptera		*May fly*						
	Odonata	Libellulidae		21					
		Coenagriidae	*Pseudagrion spp.*				21		
		Cordulidae		21		21	21		
Crustacea			*Crab*						
Annelida	Oligochaeta		*Brachiura sowerbyi*			21	292		292
		Almidae	*Alma almini*	21	42	63	292		1650
	Hirudinea		*Placobdella*						
Rotifera									
Mollusca			*Melanoides tuberculata*			313			
Amphibia			*Phynobatrachus spp*						
			Species richness	**7**	**2**	**4**	**7**		**3**
			Species abundance	**231**	**63**	**418**	**752**		**2234**

SAMPLING DATE		Aug-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	104	21				773
		Tipulidae		21					
		Sciomyzidae		63	21				
		Ceratopogonidae		63					
		Muscidae		146		63			
	Decapoda		*Procambrus clarkii*			21	63		
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*				21		
		Amphizoidae							
		Dytiscidae		21					
		Elmidae							
	Trichoptera	Hydropsychidae							
	Orthoptera		*Grylotalpa spp.*				42		
	Hemiptera	Corixidae	*Micronecta scutellaris*			21	21		
		Napidae	*Laccotrephes afer L.*						
		Lygaiedae					42		
	Ephemeroptera		*May fly*						
	Odonata	Libellulidae							
		Coenagriidae	*Pseudagrion spp.*						
		Cordulidae		21					
Crustacea			*Crab*						
Annelida	Oligochaeta		*Brachiura sowerbyi*				272		1107
		Almidae	*Alma almini*	42	21	104	355		752
	Hirudinea		*Placobdella*			84	84		
Rotifera									21
Mollusca			*Melanoides tuberculata*			146			
Amphibia			*Phynobatrachus spp*						
			Species richness	**8**	**3**	**6**	**8**		**4**
			Species abundance	**481**	**63**	**439**	**900**		**2653**

SAMPLING DATE		Sep-96							
CLASS	ORDER	FAMILY	GENUS/SPECIES	Station A	Station B	Station C	Station D	Station E	Station F
Insecta	Diptera	Chronomidae	*Chironomus spp.*	104	21		63		856
		Tipulidae		63	21				
		Sciomyzidae							
		Ceratopogonidae		21					
		Muscidae		42	21		63		146
	Decapoda		*Procambrus clarkii*						
	Coleoptera	Hydrophilidae	*Helochares mediastinus Orch*						
		Amphizoidae		21					
		Dytiscidae					42		
		Elmidae		42					
	Trichoptera	Hydropsychidae					21		
	Orthoptera		*Grylotalpa spp.*				21		
	Hemiptera	Corixidae	*Micronecta scutellaris*						
		Napidae	*Laccotrephes afer L.*	21					
		Lygaiedae							
	Ephemeroptera		*May fly*			42			
	Odonata	Libellulidae							
		Coenagriidae	*Pseudagrion spp.*						
		Cordulidae							
Crustacea			*Crab*	21					
Annelida	Oligochaeta		*Brachiura sowerbyi*				292		1900
		Almidae	*Alma almini*	21	84	63	146		585
	Hirudinea		*Placobdella*			42	42		
Rotifera									
Mollusca			*Melanoides tuberculata*			167			
Amphibia			*Phynobatrachus spp*			21	21		
			Species richness	**9**	**4**	**5**	**9**		**4**
			Species abundance	**356**	**147**	**335**	**710**		**3487**