THE EFFECTS OF LAND USE TYPES ON THE HYDROLOGY AND WATER QUALITY OF THE UPPER-ATHI RIVER BASIN, KENYA

By

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A Thesis submitted in fulfilment of requirements for the degree of Doctor of Philosophy (Ph.D) in Hydrology of the University of Nairobi.

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This thesis is dedicated to the late Prof. George S. Ongwenyi who was my supervisor, dear friend and my academic mentor. His kindness, encouragement and wisdom helped me to shape and sharpen my ideas throughout my academic research and career. May God Almighty rest his soul in peace.

My dear wife, Virginia and two daughters, Anne and Miriam, my parents; Nzilani and Kithiia, friends and to all my dear colleagues in the Department of Geography and Environmental Studies, College of Education and External Studies, Kikuyu.

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LIST OF ABBREVIATIONS

ASS: Atomic Absorption Spectrophotometry

BOD: Biological Oxygen Demand

COD: Chemical Oxygen Demand

DO: Dissolved Oxygen

JTU: Jackson Turbidity Units

NTU: Nephelometric Turbidity Units

PCA: Principal Components Analysis

TDS: Total Dissolved Solids

TSS: Total Suspended Solids

COND: Conductivity

TURB: Turbidity: The state, condition or quality of opaqueness or reduced clarity of a fluid due to the presence of a suspended matter, Morgan (1990).

WHO: World Health Organization

$Qm^3 s^{-1}$: Discharge in meters per second

Plant Species 1: *Sphaeranthus napierae* (Compositae)

Plant Species 2: *Commelina benghalensis* (Commilinaceae)

Plant Species 3: *Pennisetum purpureum* (Graminae)-Napier grass

Plant Species 4: *Xanthium pungens* (Compositae)

Quality: This refers to the suitability of water for its intended use. So the quality standards for different uses do vary (i.e.) Water suitable for irrigation may not be suitable for domestic purposes (IAWPRC, 1991).

Key Words: Land use changes, Water quality, Riverine vegetation, Storm-water.

ABSTRACT

The Athi/Sabaki River basin harbours two of the major urban and industrial centres in Kenya, namely, Nairobi city on the upper catchment areas and Malindi in the south-eastern outlet of the basin. Nairobi city is the heart of the industrial production in Kenya.

In the upper catchment areas (headwaters) land has been extensively used for urban settlement, transport and industrial activities while in the south-eastern parts agricultural production especially livestock keeping dominates.

The study on land use changes focuses on the city of Nairobi and its environs drained mainly by Nairobi, Mathare and Ngong rivers. These streams drain areas of diverse land use activities. The land use changes in a spatial manner from the rich agricultural system through residential cum urban to industrial. The contribution of these land use activities to pollutants generation and hence water pollution and quality degradation is quite enormous.

Water, river sediments and riverine vegetation from all the 10 sampling stations on the Ngong, Nairobi and Mathare Rivers were analysed to find the extent of water pollution and quality degradation downstream the rivers. The results of the study indicated a downstream increase in water pollutants and water quality degradation for the three rivers investigated. Water quality and hydrology of all the three rivers indicated a seasonal trend in variability. Water quality degradation was more physical during the rains (wet season) and chemical during the dry season. Nairobi River which drains most

of the city centre and upper parts of the catchment had mean values of Total Suspended Sediments (TSS) of 158 mg l^{-1} (1001t year^{-1}) at Muthangari and 256 mg l^{-1} (6317 t yr^{-1}) at Outering Road Bridge after passing through the city and Gikomba areas. A TSS concentration value of 33 mg l^{-1} (37 t year^{-1}) was measured at Mutoine tributary (Ngong forest), 88 mg l^{-1} (188 t year^{-1}) at Langata road bridge (downstream Nairobi dam) and 160 mg l^{-1} (1733 t year^{-1}) after industrial areas at Embakasi in the Ngong River. In the Mathare River, TSS concentration of 71 mg l^{-1} (1194 t year^{-1}) was measured at Thika Road Bridge and 251 mg l^{-1} (2987 t year^{-1}) at Outering Road after passing through the Mathare slums. Organic pollution detected was due to frequent sewer bursts and un-sewered slum areas with a five day measured value of Biological Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) exhibiting an increasing trend in the three streams. A value of 7.8 mg l^{-1} and 123 mg l^{-1} in BOD_5 were recorded in Nairobi River at Muthangari and Outering Road Bridge, respectively. Heavy metals were detected in water samples but most of them were found to be adsorbed in the river sediments. Concentration values of 1.0 mg l^{-1} and 0.1 mg l^{-1} for Zinc and Lead in water were measured but river sediments had the highest adsorption levels of 700 ppm (700 mg l^{-1}) and 51 ppm (51mg l^{-1}) for Zinc and Lead respectively. The dissolved metal ions in water appeared to surpass the recommended WHO and Kenya standards limits for drinking water.

Heavy metal concentration in the tissue of riverine vegetation was found to be significant. *Sphaeranthus napierae (spp 1)*, *Commelina benghalensis* (*spp*, 2) and *Xanthium pungens (spp*, 4) had the highest absorbed values of Zinc, Copper and Nickel and these varied with the part of the vegetation tissue. High Zinc concentration values were recorded in the root system with a value of 0.68 ppm recorded in sampling point Njiru 2 (10) for plant species 1 (*Sphaeranthus napierae*) and 0.66 ppm in species 2 (*Commelina benghalensis*) at Njiru 1 (9) and 0.55 ppm for species 4 (*Xanthium pungens*). In Mathare River, Zinc values of 0.85 ppm were recorded in the root system of species 1, 0.52 ppm in species 2 and 0.53 ppm in species 4. The stem and leaf had the least heavy metal concentration with some metal ions not being detected in the leaves. Generally, heavy metal concentration decreased upward the plant system (i.e.) from the roots to the leaf system. The study recommends the use of storm rain water (natural purification after heavy storm down fall) and *Commelina benglensius*, *Sphaeranthus napierae* and *Xanthium pungens* plant species in cleaning the heavily polluted river water and restore its aesthetic quality in the basins studied. Species 3 (*Pennisetum purpureum*-Napier grass) was commonly found along the river profiles where it is harvested as folder for cattle feeding in and around Nairobi.

Generally, pollution and pollutant levels varied with season and distance away from the city in the three rivers. In addition, the streams were found to be less polluted chemically (less ionic concentration) away from the city due to dilution effect and self-purification of the river waters during the wet season.

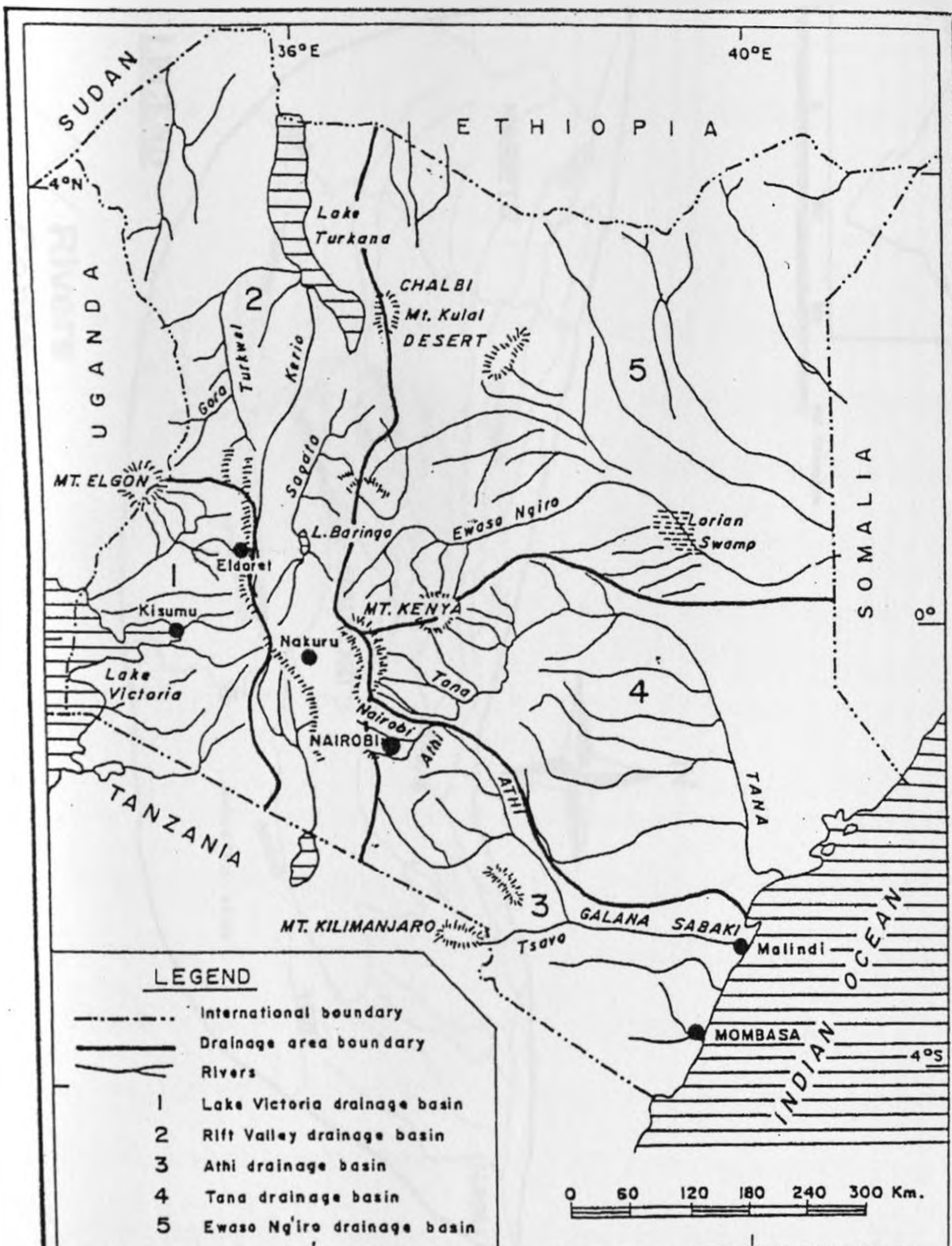
The study revealed that storm rainwater can be used to clean up the dirt, foul smelling and highly polluted waters of the rivers passing through the city. Riverine vegetation along the streams proved useful in adsorbing some of the pollutants especially heavy metals. In addition, strategic and well constructed ponds along the rivers would be useful in reducing the water quality degradation problem in the stream investigated.

CHAPTER 1-STUDY INTRODUCTION

1.0. GENERAL INTRODUCTION

The Athi River drainage basin is the second largest basin after the Tana River drainage basin. Further the River traverses agro-ecological zones of diverse climatic characteristics and land use activities. The River draws most of its headwaters from the Kenya Highlands (Kikuyu and Ondiri springs) flowing through the dry and semi-arid lands of Kenya and discharging its waters into the Indian Ocean, north of Malindi.

In addition, the Kenya highlands are endowed with vast water resources. In addition, land use activity changes in these areas have led to water quality degradation in addition to affecting the flow characteristics of the rivers. Within the basin are found two of the major urban and industrial centres in Kenya. Nairobi city lies at the upper catchment areas while Mombasa is located on the southern outlet of the basin. Most of the upper-Athi river tributaries and indeed the three main streams investigated (Ngong, Nairobi and Mathare) drain the Kikuyu escarpment through the city and joining before the Kilimambogo hill (Donyo Sabuk) to form the main Athi River as shown in Figs. 1 and 2.



Source: Survey of Kenya, Atlas, 1970.

Figure 1: Study area location and Principal towns in Kenya

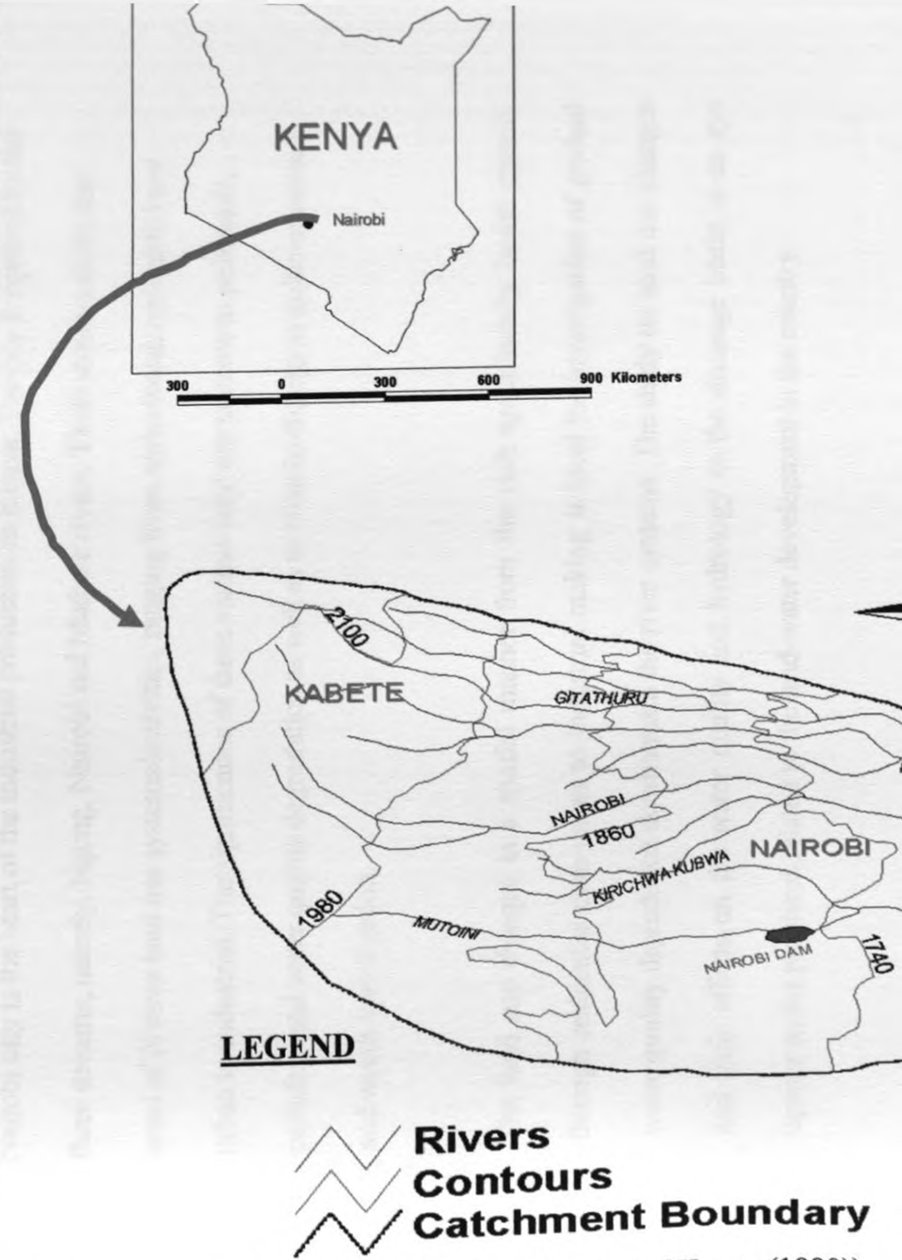
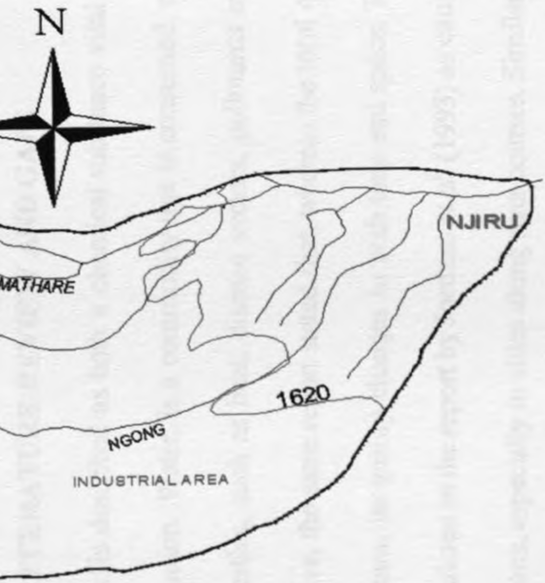


Figure 2: Location of the study Area (Survey of Kenya (1980))


N
NJIRU
MATHARE
1620
NGONG
INDUSTRIAL AREA

Nairobi city is the heart of the industrial production in Kenya. The city is drained by the three streams, namely, Ngong, Nairobi and Mathare rivers. These streams drain also areas of diverse land use systems/activities, ranging from agricultural, residential and urban to industrial. The significance of these various land use systems to pollutants, pollution and water quality degradation as well as to river hydrology is quite enormous and worth investigation.

The land use changes in a spatial manner from the rich agriculturally based system, through residential cum urban to industrial making it ideal for investigation of gradual water quality degradation downstream the river systems. The study on land use changes and their effects on the water quality and hydrology in the drainage basin is an eye opener to the problems related to the land-water development in the country.

1.1. LITERATURE REVIEW AND GAPS

Water is described as both a chemical substance vital to life on earth and a means for navigation. Water, is a commodity that is consumed, and carrier of other substances or properties, such as heat, disease vectors, pollutants and energy (Jordaan *et al.* 1993). Further, the same report stated that, whereas the total quantity of water on earth remains constant, its quality changes in both time and space. The problem of water quality was articulated in the report by Jordaan *et al.* (1993) as causing a great strain on water supply systems, especially in cities along river courses. Similarly, in 1985, at the midpoint of the international water supply and sanitation decade, it was pointed out that although 870 million people lived in urban areas of the developing world, roughly 1.6 million were rural inhabitants and approximately 22% of the urban group were without a water supply service and 40% were without sanitation. The population represented 64% and about 85% of lack of water supply and sanitation services to the rural population, respectively (Jordaan, *et al.* 1993). In essence, the rural inhabitants are faced with a great threat of using low quality water compared to the urban counterparts. This explains the eminent problem of water quality degradation not only in the urban areas but also in the rural set areas.

Giambelluca (1991), while considering drought as a main factor determining groundwater recharge and the land use planning systems in Central Oahu, Hawaii, stated that agricultural and urban land uses in the basin have large impacts on recharge rates by altering run-off and evaporation characteristics and irrigation by extension. The most obvious effect of urbanization on the water balance is the increase in surface run-off while paved surfaces reduce the evaporative surface area and tend to focus rainfall into smaller areas. The result is that urbanization may either decrease or (in the drier areas of Oahu, Hawaii) increase groundwater recharge. Giambelluca (1991) concluded that as greater amounts of land are taken out of agriculture, both water demand and the ratio of groundwater recharge to withdrawal would diminish. He, however, did not explain the factors attributed to either that phenomenon or what effects they have on the environment in general.

Generally, urbanization increases run-off, but good agricultural practice reduces it by increasing infiltration, depending on the soil texture, type and porosity. While urbanization may reduce sediment production by reducing the exposed soil surfaces, agricultural activities tend to increase sediment loads in water depending on the crop grown and land management practices undertaken. The changes in land use within the study are therefore of immense importance to river flow variations and water quality changes.

Wurbs and James (2002) explored the impact of urbanization process in relation to sediment yields and water quality degradation. He mentions three phases of urbanization that affect the water quality of storm water runoff as:-

a) During the initial phase of urbanization, the dominant source of pollution is sediments from bare soil areas at construction sites,

b) During the intermediate phase of urbanization, sediments from construction sites declines, but sediments from stream bank erosion increases because of the increased runoff rate and volume,

c) During the mature phase of urbanization (when the stream channels have stabilized and there is limited new construction), the primary source of pollution is from wash off of accumulated deposit on pervious surfaces.

The city of Nairobi can be categorized as to fall within the second and third phase of urbanization because most of its sediment loads emanate from construction sites or from urban storm water runoff. These are compounded by the variation in land use activities within the city and its environs.

Stephenson (1981) stated that erosion of soil in catchments, in the form of sheet erosion, or rill and gully erosion, is a complex phenomenon with the amount of sediment detached by rainfall based on kinetic energy of the rain drops. He asserts that there are many theories in use for predicting silt loads in channels. But most theories for the transport of silt in open channels are based on uniform flow where the silt in suspension is in equilibrium with the bed, the rate of settling out being equal to the rate of re-suspension from the bed due to turbulence.

Linsley (1982) found that, as water moves across the land surface during or after a strom, it transports dissolved and suspended materials which have been picked up along the path of flow and that these are major contributors to water pollution. He indicated the wash off materials of most concern as to include sediments, mineral salts, heavy metals, nutrients, pesticides, biodegradable organics, and microbial pollution. These are some of pollutants investigated in the present study. He adds further that, there can be no doubt that land use profoundly affects the quality of water in streams, rivers, lakes, and shallow aquifers. However, the task of finding specific cause-effect relationship between land uses and water quality problems is seldom easy for several reasons:

i) Water courses usually assimilate materials from widely dispersed land areas;

ii) Land areas drained by a common waterway nearly always have mixed uses;

iii) Soil supporting given land uses vary significantly in properties affecting infiltration, chemistry, and the quality of drainage flows;

iv) Movement of materials from land areas to waterways vary greatly with time and local precipitation pattern.

These were the main tasks of the investigations based on the land use activities within the three rivers investigated and the corresponding water quality status. The deposition of silt and groundwater recharge was not accounted for in the study by Stephenson (1981), but gives a clear account of soil erosion problem. Soil erosion depends mainly on the storm water run-off relationship assuming other factors remain constant, but of course, with changes in land-to-water relationship soil erosion becomes severe. This contributes significant amounts of suspended sediments, thereby reducing water quality in terms of water turbidity.

Nordin (1985) argued that rivers convey in their flows the dissolved and solid products of weathering and erosion from basins they drain. Quoting from Colby (1963), he defines sediments as fragmental material that originates from disintegration of rocks and is transported by, suspended in or deposited by water or air, or is accumulated in beds by other natural agencies. He stated further that sediments become fluvial sediments when they are entrained in flowing water as when un-consolidated sediments are eroded by sheet flow or by channel flow. This enlightens on the concentration of sediments in water in terms of water quality degradation.

Nordin (1985) further stated that the term 'sediment load' generally is used in a quantitative sense to refer to the solid inorganic material being transported by river. Quantitatively, sediment loads are described by their discharge or transport rates, by the densities and size distributions of the particles and their chemical and mineralogical compositions. He concluded that the rates at which sediments are transported by streams are determined by either the ability of the flow to move the individual particles or by the rates at which the sediments are made available for transport. Sizes of particles are important in relation to the rates of deposition which was well explained in the study, giving an insight to the understanding of the sediment deposition and water resources exploitation, conservation and management with more emphasis on the semi-arid areas. He, however, did not make an evaluation of these effects of sediment loads and river discharge on the water quality degradation and the environment in general, a situation pursued in the study.

Trudgill (1991) characterized an environmental problem as "a resource or life-damaging situation which is not universally recognised or is difficult to improve". He enlisted three groups of environmental problems as; **air**: which involves pollution of air, acid rain, climatic change and global warming-linked to energy production, industrial and agricultural processes; **water**: pollution of water and scarcity of water resources-linked to agriculture, drinking water, human health and industrial processes, and with aquatic ecosystems; **land**: degradation of forest resources, bio-mass availability for fodder and wood fuel-linked with agriculture, food resources and land degradation. Major problems identified facing mankind include provision of food and shelter, land rehabilitation, control of atmospheric inputs, control of water quality and quantity and conservation of nature. All these are environmentally related, but cautioned that scientific knowledge about the way in which the environment functions is a necessary but not sufficient prerequisite to tackling the problems involved. There is, the need to understand the proper characteristics of sediment production rates and process in relation to changes in land use and rainfall patterns and the activities taking place.

The following measures in solving environmental problems were recommended by Trudgill (1991);

a) Deciding on environmental goals

b) Identifying the situations which fall short of these goals

c) Specifying the situations, the problems, their causes and their significance

d) Proposing resolutions

e) Evaluating the relative merits of courses of action

f) Identifying the barriers which hinder the formulation of goals, the recognition of damaging situations, the exact specification of problems, the acceptance of a problem, the formulation of resolutions and their implementations

g) Attempting to overcome the barriers and thereby to implement solutions. This approach is more suited to the study area especially in the evaluation of water quality degradation and sediment loads transport control and management.

This is in line with the main objectives of the present study that seeks to evaluate and understand the main environmental problems involved in the soil and water conservation and management practices in use in the particular drainage area. This strategy can be applied in other basins with similar problems in the country and the world in general.

Water quality and environment issues cause growing concerns to water resources management. Their impacts are best resolved on a local scale. The United Nations, (1992) states that "The river basin is the most practical hydro-geographic unit within which the quality of rivers, lakes, reservoirs and aquifers can be effectively controlled". The same UN (1992) report observed that water quality is fundamental to the health, efficiency and well-being of individuals and societies in all countries of the world. It is, however, threatened by almost all modern interactions of man with nature. Jordaan *et al.* (1993) observed that water quality degradation is an unpleasant side effect both of unchecked industrial development and of uncontrolled urban growth, a case more pronounced in the study area where water is being used in many industrial activities such as food processing and for the production of metals, chemicals, textiles and paper. The resultant effect has been water quality degradation as noted by Kithiia (1992). This implies that unless a compensating link is established between environment and development, degradation of water quality is inevitable.

Hydrological processes are the decisive factors that affect the fate of pollutants in aquatic systems as documented by Jolankai (1992). They provide the main transport pathways as well as the media, e.g. water, for most of the chemical and biological transformation processes. Erosion and leaching provides the natural or geological background of particulate and dissolved matter contained in surface and subsurface waters. In reviewing the main processes that affect pollutants in land run-off, Jolankai (1992) concluded that: surface and subsurface run-off, erosion, and sediment transport and a large variety of chemical, biological and biochemical processes taking place in the soil-plant-water system are significantly important. This is an approach found suited for this study in combining land-water systems and their interactions with man's activities.

Stream water quality was described by EPA (1986) and MacDonald *et al.* (1991) as a function of a variety of parameters, including temperature, sediment loads, inorganic chemistry, toxic metals and organic compounds while Binkley and Thomas (1993) observed that increases in suspended sediment concentrations may degrade water quality for a variety of uses. High suspended sediment concentration (or high turbidity) degrades the quality of drinking water. Increased suspended sediment concentration may be associated with sedimentation of gravel stream beds, lowering permeability of the gravel beds. The general conclusion was that most streams draining forests have relatively low (< 5mg l^{-1}) annual average concentration of sediments with stream flow peaks of up to 100mg l^{-1}. Generally suspended sediments have a degrading effect on water quality in physical terms.

Yu-Sheng and Shamin (1993) discussed in great detail the relationship between trends of water quality constituents over time. Its quantification by use of principal component analysis technique was attempted. In that paper, a detailed account of the use of principle component analysis in relating water quality variations over time was given. However, this study covered only a short period of time. The present study used the same method in trying to analyse water quality variations over the study period and within the selected streams. Mass loadings of the different water quality constituents were computed in relation to the land use changes.

Engelmann and Leroy (1993) asserted that deteriorating water quality is a particular threat in developing countries, where hundreds of millions of people lack access to clean drinking water. Further, the vast majority of sewage is discharged into surface waters without waste-water treatment. In addition, drinking and bathing in polluted water are among the most common routes for the spread of infectious disease and nearly half of the world's population suffers from water related diseases. This study takes no exception to this fact, given the mushrooming of informal housing units (slums) along the river courses, partly to act as sewage (raw human waste) disposal sites.

Water is needed in all aspects of life; the general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water related diseases as it was stipulated in Agenda 21, endorsed by leaders of 178 nations at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil (UNCED, 1992).

Jonlankai (1992) described the dissolved oxygen (DO) content as one of the most characteristic quality parameters of surface water bodies. The existence of various aquatic life forms, and thus the existence of the entire aquatic ecosystem depend on the supply of oxygen to the water, its presence and availability in the water. The dissolved oxygen content of water is depleted by the oxygen used for multiple chemical, biological and biochemical processes that take place within the water body. In aquatic environments receiving substantial organic waste loads the most important "consumer" of oxygen is the biochemical decomposition of organic matter. This depletes the DO level of water by the amount of oxygen utilized by micro-organisms for their metabolic activity when decomposing or feeding on organic substances. Thus, the most widely used measure of the organic material content of water is the Biochemical Oxygen Demand (BOD_5) which is the amount of oxygen utilised by micro-organisms in unit volume of water for decomposing organic matter during a specified period of time. Detailed models for the simulation and quantification of specified water quality constituents in a river stream course were given in the study by Jonlankai (1992). The present study used both BOD_5, Chemical Oxygen Demand (COD) and DO as measures of organic pollution in the urban areas and as a cause for water quality degradation and an indicator of areas of high pollution levels along the courses of Ngong , Nairobi and Mathare rivers downstream the city of Nairobi.

United Nations Education Science and Cultural Organization (UNESCO, 1974) stated that the hydrological changes caused by converting a previous un-inhabited region to subsistence farming can take place very rapidly and are difficult to reverse. The magnitude and distribution of river flows as well as the quality of water can be altered radically. The study, however, did not determine their effects on the sediment load characteristics and water quality as a result of these environmental changes; a case reviewed in the study.

Linsley *et al.* (1985) stated that the hydrological cycle is visualized as beginning with the evaporation of water from oceans. The resulting vapour is transported by moving air masses. Under the proper conditions, the vapour is condensed to form clouds, which in turn may result in precipitation. The precipitation which falls upon the land is dispersed in several ways. The greater part is temporarily retained in the soil near where it falls and is ultimately returned to the atmosphere by evaporation and transpiration by plants. A portion of the water finds its way over and through the soil surface to stream channels, while other water penetrates farther into the ground to become part of the groundwater with the balance forming the stream flow.

Davis (1966) correlated both the stream flow and runoff when he wrote that the term "runoff" is considered synonymous with "stream flow". It is the sum of surface runoff and groundwater flow that reaches the streams. Surface runoff is noted as a function of precipitation intensity, permeability of the groundwater surface, duration of precipitation, type of vegetation, area of drainage basin, distribution of precipitation, stream channel geology, depth to water table, and the slope of land surface. These factors significantly affect runoff characteristics and the same were used in this study to relate river flow characteristics with sediment load production in relation to land use changes.

On the same line of thinking, Moore *et al.* (1969) suggested that the rates of runoff depends on the size and shape of the watershed, surface slopes, nature and amount of vegetation, character of the soil as regards permeability, saturated condition of the soil due to previous rains, arrangements and character of drainage channels, evaporation, storage and underground conditions, and the duration and intensity of rainfall. These are very vital inputs and closely linked to the present study.

Dunne and Leopold (1978) envisaged that understanding of storm runoff production indicates the processes by which pollutants reach streams and the management techniques that might be used to minimize the discharge of these materials into surface water. In particular, an appreciation of runoff processes allows the planner to recognize present constraints, to predict the consequences of some form of development, and to avoid possible problems.

Boyd *et al.* (1994) stated that in urban drainage basins, storm runoff is generated on impervious surfaces such as roads and roofs, and may also be generated on pervious surfaces if antecedent wetness is high or if rainfall intensities or total rainfall depths are large. This becomes a major source of sediments and hence water quality degradation in the urban areas.

Newson (1994), while assessing efforts being made to control and manage water quality status of rivers in the European Union and by extension in the developing countries, identifies the main sources of pollution as industrial, urbanization, and agricultural human activities. He mentions further that, with increasing quest for economic development, many countries will have to content with the problem of water pollution. The major pollutants mentioned include; heavy metals from industries, faecal wastes from human settlements and pesticides from agricultural activities. These are the same causes and pollutant sources in the study area.

Barrow (1987) asserts that land use changes especially forest clearance in a river basin, affects the microclimate of that basin. In addition, removal or change of the vegetation cover of a watershed also affects overland flow and infiltration rates altering quantity, timing and quality of stream flow and river flow. He further notes that the management of watershed land use is especially important in the upper and middle portions of a river basin because these are usually the portions where overland flows can be strong and soils are more easily eroded. The same view was held by Linsley (1982) when he wrote that, as a rule, passage of water through the soil profile results in purification of water because of adsorption, volatilization, decomposition or degradation, nitrification, denitrification, and plant uptake. He added that, soils with heavy vegetal cover, the major mechanisms for removal of inorganic nitrogen and phosphorus is uptake by plants. This fact was investigated in the current study to find out the role of riparian vegetation in cleaning the polluted waters of Nairobi River and its tributaries.

Chapman (1990) articulates that water bodies are characterised by three major components: hydrology, physico-chemistry and biology and that spatial variation in water quality is one of the main features of different types of water bodies, and is largely determined by the hydrodynamic characteristics of the water body. He further noted that most plant groups, such as macrophytes, filamentous algae, mosses, periphyton and phytoplankton can be used as indicators of water pollution and eutrophication.

Whitton (1987) found that plants can be used to monitor heavy metal contamination in rivers in four main ways:-

i) Analysis of metal composition in whole or selected part of the plant;

ii) Toxicity assays;

iii) Analysis of species and community composition;

iv) Assessment of genetic adaptation.

Whitton (1987) further noted that, the rationale for the use of metal composition in plants is that most, if not all, species show elevated concentrations in at least some part of the plant when concentrations in the environment are elevated. Similarly, Satake (1987) found accumulation of heavy metals within the tissues of certain bryophytes in Japan. This is also used to monitor and locate a pollution source. This is the strategy employed in the investigations undertaken on various vegetal species within the studied Nairobi River sub-basins. Strategy number one (i) as mentioned by Whitton (1987) was applied in the investigations.

Water quality in the downstream reaches of a river is a summation of all the inputs along the course of the river. The cleaning up of a polluted river, bay or part of an ocean is a major task that involves large numbers of people and many communities, and it can only be accomplished if most of the pollution along the river can be stopped (United Nations, 1992). This can be achieved through an investigation of the relationship between land use changes, river flow characteristics and the water quality status as carried out in the study.

Quemer *et al.* (1997) explains that changes in land use, climate and groundwater abstractions have an impact on river flows. This may result in hydrological droughts or a decrease in water availability. Generally, natural variation in stream flow and additional effects of land use or climate change affect the low flows and associated droughts. He further asserts that a drought occurs when stream flow is below a prescribed threshold discharge or mean.

Nouh (1997) argues that proper design of urban water management and control schemes require identification of runoff heavy metal loads and their spatio-temporal variability. He further adds that basically metal loads are introduced into urban runoff from three sources; namely, the land surface, catchment basins and the sewers in combined sewer system. In addition, heavy metals from land surfaces are caused by streets and sidewalk sweepings, pollutants deposited on or washed into streets from yards and other indigenous open areas, wastes and dirt from building and demolition, dirt-oil-tyre and exhaust residue contributed by automobiles and fall out of air pollution particles.

Goldyn *et al.* (2001) underscores that overland flow is an effective method of decreasing the loads of nutrients and other pollutants received by surface waters. The method makes use of sedimentation, filtration uptake by plants, adsorption on soil particles, microbiological biodegradation, denitrification, oxidation and chemical precipitation according to EPA (1986, 1992) manuals. These manuals indicate that one of the most important processes in this method is uptake by plants (mainly grasses) which accumulate nutrients and other compounds responsible for pollution of surface waters.

This conforms very well with the current study which tries to use riverine vegetation as both pollution indicators as well as cleaning agents. In addition, the EPA manual (1992) indicates that little is known about the removal of heavy metals from water by vegetation uptake. However, some results confirm that concentrations of heavy metals are greatly reduced by overland flow. This is one of the recommended methods of cleaning the three streams investigated in the Study.

Siva and Masuda (2001) postulates that protecting global freshwater resources is a basic issue for the 21st century to achieve the key aim of sustainable development set for the millennium. This is a major challenge for the people and the politicians. In the same report, it is noted that industrialization, population growth and upward social mobility in the system will continue to demand more and more energy and resources leading to several ecological and environmental problems. One such problem is the contamination of natural waters due to anthropogenic processes affecting the global biochemical cycling of many elements as mentioned in other reports (Fyfe, 1981, Nriagu and Pacyna, 1988 and Nriagu, 1990 and 1996).

Rumyantser *et al.* (1995) stipulates that pollution of stream water is a major problem in every country. In addition, stream water quality is influenced by both natural and human factors. The natural factors can be viewed as a product of climatological, geochemical, physiographic, edaphic and forest influences. The human factors can be viewed as a product of agricultural, urban and industrial influences. These are basically the three land use systems investigated in the study and their relationships to changes in water quality and river flow characteristics.

Smith (1995) described the demographic transitions and changes in diseases transition as being intertwined with a shift of disease patterns from traditional to modern due to underlying risk factors for the various forms of ill-health. The distinction between risk and ill-health is important for another category of hazards, pollutants that make their way slowly through the environment, eventually reaching humans via food, air or water. The release of the pollutant represents the creation of the risk (i.e. commitment to the health effect), even though there may be many years between the release and the disease, due to environmental and physiological latencies. He further adds that urbanization has been one of the most important influences in the transition from traditional to modern risks. The tendency has been to focus on the terrible modern risks imposed by the mega-cities of the developing world; the air and water pollution, the traffic jams, the garbage dumps and unfettered pollution of all sorts, although it may seem contradictory, however, the admittedly poor evidence is that cities in general bring health.

He further notes that in many countries, urbanization now seems to be taking on a different character called "Kotadesasi", which is a combination of the Indonesian words meaning "town" and "village". This new process results in widespread increases of peri-urban areas, often linked to an urban centre but themselves not being urban in the usual sense. "Kotadesasi" regions are characterised by rapid increases in the variety and insensity of work places and land uses intertwined within traditional farming areas.

This can lead to releases of toxic materials from small-scale industrial activities like electro-plating. This is a characteristic more evident in the study area.

In the same report by Siva and Masuda (2001), it is also noted that water and soil in and around urban areas are increasingly being contaminated with a variety of toxic elements by anthropogenic activities, for example, automobiles emit a variety of metals into the environment including platinum and palladium from catalytic converters, lead from petrol, nickel from diesel fuel, zinc and cadmium from tyre, copper from brake linings and wiring and chromium from plating. This underscores the sources of pollutants along the river courses in the study dented with *Jua-Kali* automobile garages without any proper waste disposal systems.

In support of a rapidly growing population, Bruijnzeel (1993) argued that people in most warm humid regions are forced to manipulate their natural surroundings at an increasing pace. Land use practices that proved stable for centuries under low to moderate population pressures are breaking down; large numbers of landless people invade forested areas to practice "slash-and-burn" agriculture, thereby jeopardizing chances for the land's regeneration and sustainable use. Recent estimates of tropical forests depletion cover a figure of 17million Ha/year which is substantially higher than the global acceptable figure of 11.5million Ha/year. Such changes in land use may be accompanied by more or less dramatic changes in the flow quantity and quality of streams. The effects of land use changes on the magnitude of flood peaks in large rivers was pointed out to be very difficult to evaluate because such changes are rarely very fast and consistent and normally compounded by climatic variation. Thus, in relatively medium streams, these changes are bound to be significant and worth investigating as it was found in Kerichwa Kubwa stream downstream Kawangware Market.

Mudiare (1990) asserted that there was total lack of studies relating land use changes and water quality in Nigeria and recommended an investigation into the studies of land use hydrology in Nigeria. These are necessary in the planning and management of water resources. The study presented in the paper was done mainly on irrigation set up where the source of pollution was mainly fertilizer application. Other sources of pollutants were from gasoline storage tanks and petroleum leakage and spills and sewage disposal all contributing a significant amount of pollutants into both groundwater and surface water resources.

Dharam (1991) observed that concern with environment is not a recent phenomenon in Africa and postulated that after a period of benign neglect in the early years of independence, African governments have become increasingly alarmed by the state of environment and are now setting in motion wide ranging measures to arrest and reverse its degradation. In the 1920's and beyond, there has been a tendency to view the environmental problem in physical, ecological and technical terms with the problem defined as soil loss, disappearance of forests, extinction of wildlife and plant species, spread of deserts, pollution of water ways and sedimentation of dams and irrigation facilities. The measures devised to cope with the problem were focused on technical solutions involving land use and alleviation of human and animal pressure on resources but are, however, imposed upon the rural inhabitants. Thus, all these should involve the rural inhabitants who should decide on the best methods.

Dharam (1991) pointed out that from all counts, the environmental crisis in Africa is serious and getting worse. The available indicators point to dramatic deterioration in the quality and quantity of natural resources. For example, Africa's 703 million hectares of forests are being cleared at the rate of 3.7 million hectares (0.6%) each year. Soil erosion has assumed dramatic proportions with the affected areas experiencing soil loss at the rate of 10- 200 tons per hectare. There is also growing pollution of waterways and sediment levels in rivers which have been increasing at 5% per annum in countries like Nigeria, Tanzania and Zimbabwe. In Ethiopia, annual loss of top soil is estimated at 3.5 billion tons.

The essence of the environment problem in Africa is to ensure resources and livelihood security through effective management of the change from an extensive to intensive system of production. The fate of the environment in Africa, (even more than elsewhere), will be determined by the interactions between hundreds of millions of peasants, herders, nomads, forest dwellers and fisherfolk and the natural resources from which they derive livelihood. This is a totally changed scenario and with emphasis on intensive agriculture and sedentary life this has added a new dimension onto the environmental degradation in the continent, and more so to Kenya as a country.

It is this interactions coupled with changing agricultural production methods and technological know-how that relate to other economic production techniques such as land terracing, pesticide application, population settlement and patterns and land use activities which lead to environmental degradation.

Amuzu (1997) indicated that the impact of urbanization and industrialization on the water quality of some surface waters in Ghana by the uncontrolled discharge of domestic effluents and industrial emissions has worsened since 1983 when the Government introduced the Economic Recovery Programme (ERP). These resulted to increased volumes and amounts of domestic solid wastes and industrial effluents. The implication of this was noted to be pollution of surface waters of rivers passing through Accra city, notably, Korle lagoon and its tributary the Odaw River which have since been heavily polluted. This is one major reason of undertaking the present investigations arising from the fact that Kenya also adopted a policy of industrial diversification in 1986 as outlined by Kithiia and Ongwenyi (1997).

Gash *et al.* (1999) exclusively analysed the problems affecting freshwater resources in Africa and management strategies for sustainable use of water resources in the continent. The main issues addressed included the impact of population increase, industrial growth, climate change, water use conflict, and economic development. These have a degrading effect on water quality and human health. These are some of the issues investigated in the present study.

In Kenya the main objective for water development is to provide water to rural population within reasonable walking distance (NWMP, 1978, 1992). In achieving this objective, balance between human needs, requirements for livestock development, rural industrialization and minor irrigation will need to be maintained.

A prominent problem observed almost everywhere is soil erosion in watershed areas. It occurs usually in the form of gully, rill and sheet erosion. Nationally, the areas which experience the highest erosional risk coincide with most productive areas of the country. These areas include the Kenya highlands, the eastern districts of Machakos, Kitui and Embu, the Lake Victoria basin and some parts of the coastal zone (Ongwenyi *et al.*, 1993) and Kithiia (1997).

Soil erosion in Kenya is mainly due to surface water run-off from "bare" soil surface. The problem is more pronounced in the marginal lands as a result of intensive cultivation and overstocking, a phenomenon evidenced in the southern parts of the study area. Soil erosion in the arid and semi-arid lands which are less productive is more controllable by adopting conservation and management practices as compared to the high productive areas where there is intensive agriculture and the land tenure system cannot allow for land recovery.

The problem of soil erosion has a long history in Kenya and had been identified as a major environmental problem by 1935. It is also reported by Dunne and Ongwenyi (1976), Dunne and Leopold (1978), Ongwenyi (1978, 1979), Edwards (1979), Wain (1983) and Ongwenyi *et al.* (1993) to have been increasing in rates and proportions. Ongwenyi *et al.* (1993) reported that Machakos district is one of the districts experiencing soil loss due to running water above the permissible amounts of 10 t ha^{-1} $year^{-1}$. The rate of erosion increases under agricultural conditions. It is even much greater under grazing and overstocking in semi-arid and arid parts of the country.

The National Water Master Plan (NWMP, 1992) draft report concluded that soil erosion in the country is bringing about a number of problems, particularly; decrease of fertile soils in agricultural lands, deterioration of water retaining and infiltration capacity of soils, infilling of reservoirs and irrigation canals, and turbidity of river water causing burden to water treatment works. The same report mentioned that to prevent the erosion hazards, some types of counter measures such as terracing, cut-off drains and check dams have been provided at many places. Because of soil erosion problems in many river basins, the total suspended load carried by most rivers is very high, especially in the middle and lower reaches. This is a pronounced condition in the lower reaches of rivers in both Machakos and Makueni districts. It reported that in terms of river water use, most rivers in Kenya are characterized to have relatively large imbalance of discharges between the dry and rainy seasons, which makes steady water abstraction difficult.

Archer (1996) observed a marked increase in downstream concentration of sediment yields in the upper-catchment areas of Mount Kenya, but these declines towards the drier south and east. This is attributable to changes in rainfall regimes and intensities. The same trend was observed within the study area.

In Kenya, the problem of water quality degradation was first exposed in the Ministry of Water Development (MOWD, 1976 a&b) reports containing case studies of three rivers; Nzoia, the Nyando and Kerio. These reports contain the chemical characteristics of the water shortly before and after establishment of factories along their courses. Nzoia River which drains into Lake Victoria carries the effluent discharged from Pan Africa Paper Mill in Webuye upstream and from Mumias Sugar Factory downstream; Nyando River which also discharges the water into Lake Victoria receives molasses effluent from sugar factories Chemilil and Muhoroni. In the early 1970's Nyando River was polluted on about 30 km of its course by molasses effluents. Kerio River drains the Kerio Valley with intermittent flow into Lake Turkana. This is now periodically polluted by effluent from Fluorspar factory established three decades ago. All these three reports indicate the adverse effects industrial growth has on the quality of water courses. In general their effluents are a major contributing factor to water quality degradation at the vicinity of industrial activities.

In the Odingo (1978) report on Kamburu/Gitaru ecological survey, an attempt was made to study the quality of the water within the dam area, not only in terms of the amount and nature of the sediment contained in the water and finally being deposited in the dam, but also its chemical quality which may affect the biotic life within the dam. The effects of land use especially cultivation was also considered as it relates to sediment transport and production. The water was found to be of soft and neutral character. It is largely of excellent chemical quality and could be put to a variety of good uses. However, it was polluted with organic wastes from coffee factories, highly coloured and turbid during the rains thus posing a potential danger to the biotic life within the reservoir. At present pollution within the reservoir could be a critical problem particularly considering the hydro-power generating machinery which has so far been installed, high thermal heat production and the increased rates of cultivation along the river course downstream Mount Kenya slopes.

Agricultural effects on water quality were investigated in the Gucha catchment and found to have profound effects in reducing the quality of water compared to the WHO and the Kenya guideline standards in a study by Nyangaga (1993). Most streams in the catchment were found to carry excessive "man-induced" levels of soil losses, sediment and suspended load. All were found to reduce the quality of water physically. The study found that sheet and rill erosion were much more dominant in Riana catchment with 6412.7 t km^{-2} $year^{-1}$ of sediment than gully erosion (153.3 t $km^{-2}year^{-1}$) and cultivated and grazing fields were major sources of sediment production in the catchment.

Sediment transport in the catchment varied with discharge with large values during rainy seasons and low discharges leading to smaller amount of sediment in the rivers during the dry season. Animal production was noted to play a significant role in degrading the quality of water as well as pesticide application in cultivated fields. There was lack of evidence of soil and water conservation and management practices in the catchment area. Unfortunately, the study failed to give a proper account of the effects of these on the water quality but only generalized the water quality *status quo* of the water resources in the catchment *vis-à-vis* agricultural practices. There is therefore a need for a study harmonizing the agricultural effects on the water quality and other land-use changes on one hand and then conservation and management practices on the other hand, a case pursued in the present study. Mwamburi (2003) found that, river sediments in several rivers within the Lake Victoria basin carry substantial amounts of heavy metals emanating from industrial, municipal wastes, atmospheric emissions, metal corrosion products and leached agricultural chemicals. The results indicated the presence of heavy metals in the sediments although low in concentrations except for River Kasat.

Pioneering work relating to groundwater quality was done by Gavaerts (1964) and Arunga (1972) in the various geological units in the Nairobi area. At the time of this investigation, groundwater in Nairobi was of good quality except for its fluoride content which was in excess of the desirable limits of 1.5 ppm over a large part of the area. A more recent study by Kithiia (1992) found that the surface water was highly contaminated with high concentration values of fluoride content of 2.0 ppm well in excess of the required WHO value of 1.5 ppm. This was attributable to the industrial activities which have since been established in the area. A study on integrated water resources of the Athi river basin by the Ministry of land Reclamation, Regional and Water Development (MLRRWD, 1997) revealed that groundwater quality in the upper-Athi river drainage basin is of good quality but the surface water resources are highly polluted mainly by human activities. These studies did not in any way attempt an evaluation of the effects of land use changes on the water quality and river flow characteristics, an objective of the present study.

The MOWD (1976 a&b) report surveys, all make the past works on the Nairobi-Athi river system on the water quality. Their results indicated increasing trends in concentration of pollutants in sites located within and in the vicinity of Nairobi. Nairobi River pollution was chiefly attributed to domestic waste, industrial wastes and runoff (both rural and urban) as indicated in the study by Njuguna (1978) of the effects of pollution on a tropical river in Kenya while Kithiia (1992) attributed the problem of water pollution within the same basin to different land use systems especially industrial and agricultural. There was more heavy metal pollution in the streams passing through the mainly industrial area as compared to the more agricultural upstream areas which exhibited high values of pesticide residues. The water was found to degrade in quality in the entire area in which the investigation was carried out.

Ongwenyi (1979) reported that the Athi drainage basin experienced both flooding and drought problems while other problems included alkalinity, salinity, contamination and sedimentation but receiving less attention then. Water samples obtained from the Athi River had alkalinity values of 149 mg l^{-1} and Sabaki 340 mg l^{-1} at low flows. The high alkalinity of the Sabaki was attributed to the influence of Mzima springs, the main sources of dry weather flow in the Tsavo. Pollution of streams passing through Nairobi was attributed to inadequately treated sewage, illegal discharges of solid and effluent wastes to the main storm drains, direct discharges in un-sewered areas and frequent blockage in the sewers.

An on-going investigation of the Nairobi River (1992) by a group known as the Nairobi Clean-up Organisation found that Nairobi River is heavily polluted and further that the trend of pollution is worsening. The river is dirty, gives a foul odour and cannot sustain any life. Solid waste dumped into the river, raw sewage, industrial effluent and surface runoff are the main sources of pollutants. Thus an investigation into the COD and BOD_5 levels along the river course will be revealing as to the status of water quality degradation. This was investigated in this present project to enable formulation of better conservation and protection methods to control the rates of pollution of the river.

Study of storm water quality in the Nairobi city centre was done by Abwao (1993) based on consecutive storms within the city centre. The study investigated the quality parameters in general without considering their effects on the water use. The main focus of the study appeared to be methods of storm water storage and control rather than water quality *per se*. There was no attempt to relate the different land uses in the city to the water quality degradation, river flow characteristics and the sediments in the storm water. The study, however, recommended an investigation into the water quality characteristics of storm runoff generated from other urban land use types within the city (e.g. residential, industrial and recreational) with a view to developing an integrated storm drainage system for the whole city and also an analysis of rainfall water quality and the sources of pollutants. These are some of the approaches adopted in the present study.

Studies conducted by (Okoth and Otieno, 2000) and (Mavuti, 2003) found degrading trends in water quality of the Ngong River, a major tributary of the Nairobi River drainage basin and attributed this to increasing population density, industrial activities and other human activities. This was found in the investigations as the same trend in water quality deterioration along the river course with high pollution and deterioration rates downstream the industrial areas and measured at Embakasi sampling point. The literature review identified the following research gaps:

1). Lack of research studies in Kenya and the study area which tried to link land use changes with sediment transport and water quality was revealed. Only studies focusing on the problem of soil erosion *per se* and reservoir sedimentation were identified, but without due attention to the changes taking place within the different watersheds. All were concentrated on the Tana River drainage basin.

2). There are few studies which have examined the flow characteristics of the major rivers in the country and the three sub-basins investigated and thus the significance of the present Study. The present Study tries to examine and evaluate the effects of spatial land uses in the upper-Nairobi-Athi River drainage basin on the water quality and river flow hydrology in relation to sediment load as a water quality parameter. The role of riverine vegetation has not been investigated in the basin and in the country as a means of purifying water pollutants as well as the importance of stream water run-off. In addition, no attempts have been made in tracing bio-magnification levels in Africa and in Kenya as well. The present study, however, investigated the role played by riparian vegetation in the uptake of heavy metals and hence cleaning the polluted waters in the investigated streams.

1.2. STATEMENT OF THE PROBLEM

The Literature Reviewed showed that there is lack of a detailed study that relates changes in land-use with river flow characteristics and water quality changes over time and space. This is more so in the specific area relevant to this study. The Upper Athi River basin drained mainly by Ngong, Nairobi and Mathare rivers has experienced tremendous development in terms of agricultural, human settlement and industrial development. The overall effect has been water quality degradation and increased peak flows. Many parts of the catchment have environmental conditions conducive to accelerated soil erosion and sediment production. Cultivation and population settlement on the steep slopes resulting from the population pressure on the land enhances rapid soil erosion and sediment production. These have profound effects on the water resources development and management within the watershed. The immediate effect is environmental degradation relating to soil erosion, sediment production and water quality.

A close monitoring of land use changes over time and space is geared towards a revelation of their relationships with river flow characteristics and water quality in parts of the upper Athi River basin. The main land use activities in the basin namely agricultural, human settlement and industrial development are examined in trying to relate river flow characteristics and water quality with land use changes. The role of riparian vegetation in water quality restoration has not been investigated in the country and within the streams under investigation and hence the reason for its inclusion in the work.

1.3. JUSTIFICATION OF THE STUDY

It is evident from the literature review that most research works in Kenya relate to sediment production and basically has been focused on the problem of soil erosion in general and mostly within the Tana River drainage basin. Past studies in the study area have also tended to concentrate on the general water quality status in relation to pollutant sources and their effects on micro-organisms living in the river water courses. More recent studies have also tended to focus on the water quality status without checking on the causes and sources of pollutants. This is without taking into account the land use activities taking place in the drainage basin. To the best of my knowledge, there has never been any study that has focused on the river flow characteristics in Kenya. Hence, there is a need for an investigation which tries to link the effects of land use changes on the water quality degradation in general, sediment loads transport and river flow characteristics. This is the primary objective of the study.

Assessment and evaluation of the sediment production sources, total sediment load in the urban storm water is an enlightening tool to the understanding of the course of urban floods mainly in Nairobi city as a result of sediment choking and blocking of the urban storm water drainage systems. Construction of buildings and other concrete structures increases paved areas and reduces land under agricultural activities hence reducing the infiltration capacity but increasing the overland flow. This increased overland flow has profound effects on the pollutants, soil and sediment load production in the basins under study.

The study of land use changes and their effects on the river flow characteristics and water quality aims at evaluating the compounded effect of land use changes on the river flow characteristics and water quality. Spatial changes in land-use and other hydro-geomorphic activities have a profound effect on the flow of water in river courses and determine the available water resources in a catchment in addition to influencing the human activities. The study in parts of the upper-Athi river basin is of great significance to the drainage basin since it will evaluate the available water resources in amounts in relation to the activities taking place in the basin *vis-à-vis* demands and population.

1.4. SIGNIFICANCE OF THE STUDY

This study once completed will provide important information on water quality in which Kenya and the water policy makers can look at the land-water resource relation (land-water use) as a guide to establishing sediment source areas and both environment and water quality degradation for proper planning, development and management of the water resources in the drainage basin and Kenya in general. The results are expected to provide fundamental guidelines for future water pollution control, management and conservation policies, water quality and river flow data and characteristics. The focus of the study on land use changes and their effects on the river flow and water quality characteristics is justifiable in three ways:

1) The need to compare river flow changes and suspended sediment load changes.

2) The need to compare river flow characteristics and water quality degradation in terms of suspended load transport in the selected sub-basins and other quality parameters.

3) The need to compare river flow changes against rainfall characteristics over time.

Such a study is of great significance to upper-Athi drainage basin which experience intensive land-use changes. It can also be of use in planning the methods of water utilization, management and soil conservation in the more productive areas of Kenya occupying 19% of the total land area. The results will be of use to other humid and arid and semi-arid areas of the country and to the economic development of the country. It also provides a source of data for sediment load production, discharge rating curves, water-land utilization, water quality status and hence water supply and management. It is of purposeful use to the policy makers and water resource development planners and to the country in general.

1.5. OBJECTIVES OF THE STUDY

The study aims at looking at spatial land use changes and activities and their effects on water quality degradation status along the river courses of the three sub-basins of Ngong, Nairobi and Mathare Rivers. These are related to sediment losses and rainfall characteristics (bimodal) in assessing the seasonal variations of river flow characteristics and water quality parameter concentration in the evaluation of water quality. This is to ascertain the usefulness of the river waters within the drainage basin and their implications on sustainable water and land development as natural resources.

To achieve the main objective, the following specific issues were addressed:-

(a) To examine spatial land use changes and total suspended sediment loads in the river courses in relation to river discharge (Q) in terms of water quality concentration variation along the river courses.

(b) To investigate sources and levels of the various water pollutants and their longitudinal variations along the river courses against distinct land use activities.

(c) To investigate the use of riverine vegetation and storm water flood in the uptake of pollutants and cleaning process of the river water.

The study aims to achieve the above objectives by: assessing the land use activities, rainfall patterns, water quality degradation parameters and discharge rates of the rivers. Methods of water quality conservation, control and management strategies in the Athi-Nairobi river drainage basin are also considered. In addition the study tries to ask the following specific research questions:-

1) What are the effects of land use activities on the water quality degradation status?

2) Which major land use activity(ies) have significant effect(s) and to what extent? And on what?

3) What role is played by the riverine vegetation in water pollution control?

4) Which remedial measures (strategies) are needed to abate this problem(s)?

5) How is this achievable or which methods are applicable in solving this problem(s)?

This aims at ensuring continued water resources development without adverse effects on the environment and proper management methods of both soil and water resources for sustainable development of basically the study area and the country in general.

1.6. STUDY AREA CHARACTERISTICS

The study area includes some parts of the upper-Athi River drainage basin drained by rivers Ngong, Nairobi and Mathare. The area covers lower parts of Kiambu district and Nairobi city as indicated in figures 1 and 2 shown earlier in section 1.0 of the introduction part of this study. It encloses a total area of 2,435 km^2 within latitudes 0° 45' S and 1° 38' S and longitudes 36° 15' E and 37° 15' E. To the north-west side it is bordered by the contour line 2300m above sea level and contour line 1500m to the south-east. Generally, the area slopes in a south-east direction with distinct hills dissecting the landscape. The highest contour line of 2400m is at Kikuyu escarpment while the lowest, 1400m at Donyo Sabuk, the outlet of the investigated upper-Athi drainage streams. From contour line 1500m just outside Nairobi to contour line 1400m at Donyo Sabuk, the land appears gentle or plain with just one contour line of 1560m above sea level (a.s.l.).

1.6.1. Geological Characteristics

The geology of any particular land surface determines the drainage patterns of the area in addition to influencing land use systems. The geology of the study area consists mainly of Tertiary trachytic lava of Pleistocene age. The area lies between the Plio-Pleistocene trachytes of the Kikuyu escarpment and the Late Miocene phonolite of the Kapiti plains as indicated in figure 3. The trachytes of Longonot, Kiambu and Nairobi occupy the upper parts. The middle and lower Kerichwa valley tuffs lie close to the city of Nairobi. On the south-eastern side are the Nairobi phonolites and Athi tuffs. The underlying rocks are Tertiary and younger sediments, volcanic lavas, tuffs and the basement complex. The Tertiary trachytic lava which covers most of this area is derived from the ancient fissures on the eastern flank of the Rift Valley. In the southern end, most parts are the Athi tuffs and lake beds with chert band. Generally, the hydrogeology of the study area is controlled by the nature of the various volcanic lava flows and the configuration of the old land surface of the basement system. The area is good for groundwater resources and is in fact said to have a high groundwater potential (NWMP, 1992). The area can be referred to as volcanic plateaux in reference to landforms in Kenya.

Dunne and Leopold (1978) stated that geology controls the drainage pattern of any given area due to the nature of the rocks, their texture, type and chemical composition, and their susceptibility to erosion. They influence the relief of the given area in respect to erosion. The topography of the study area is more variable, from gently undulating to flat, with a number of small hills protruding above the general land surface (Kithiia, 1992). The geology of the study area plays a significance role in determining water quality. In the study by Kithiia (1992) it was found that the upper areas exhibit high concentrations of manganese and calcium while in the southern parts, high fluoride content were detected which surpasses the recommended WHO 1.5 ppm value. This is attributable to both the geology of the area and the industrial activities. The same findings were found to be true in the data obtained for this study as shown in Table 1

.

Table 1: Mean concentration values of Sodium, Chloride, Calcium and Fluoride compared to WHO values and Kenya guideline standards.

River/ parameter	Magnesium (mg) mg l-1	Calcium (Ca) mg l-1	Fluoride (F) Mg l-1	Sodium (Na)mgl-1	Chloride (Cl) mg l-1
Nairobi	7.1	18.6	2.0	48.8	52.9
Mathare	8.2	18.5	0.6	42.7	39.4
Ngong	8.2	25.8	2.3	64.0	49.1
WHO (1995)	0.1	200	1.5	200	250
Kenya guideline Standards Value	0.1	200	1.5	200	250

Source: Researcher field data (1998-2000), WHO (1993, 1995) & Kenya Standards (1985).

Table 1 indicates that except for Fluoride within Nairobi River with a value of 2.0 mg l^{-1} which is in excess of both WHO guideline value and the Kenya Standards value of 1.5 mg l^{-1}, the others are within the acceptable limits in drinking water.

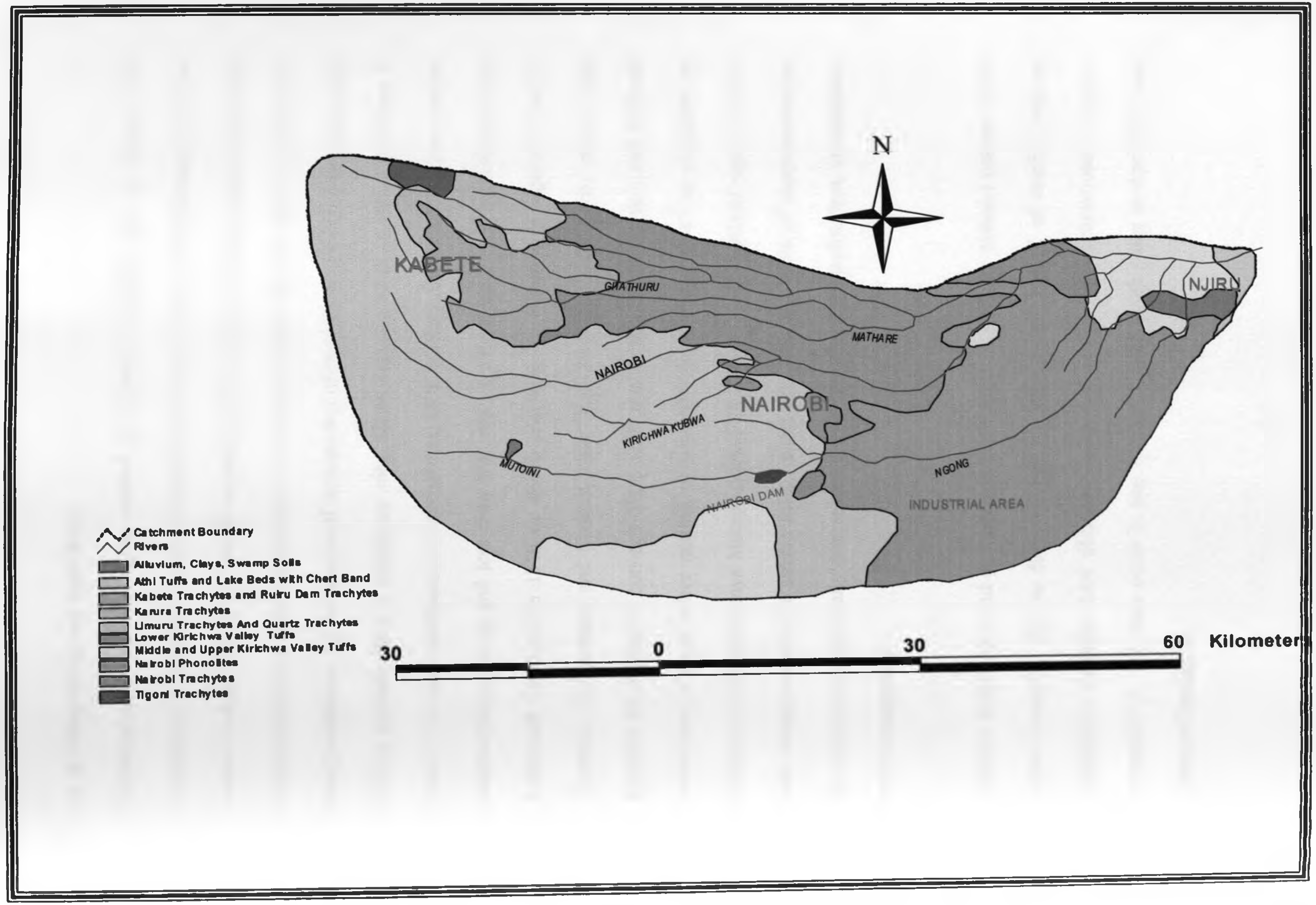


Figure 3: Geological units of the Study Area (Survey of Kenya (1980))

1.6.2. Climatology and Hydrology

Hydrological events are highly related to climatic variables such as rainfall and evaporation. Climatically and ecologically, the upper-Athi river drainage basin lies within Ecological zone IV which experiences two distinct rain seasons; March-May designated as long rains and October-November as short rains. In addition to the rains being influenced by the bi-annual movements of the inter-tropical convergence zone (ITCZ), altitude plays a significant role. Mean annual rainfall of above 1000 mm is received in areas north-east of contour line 1620 m, between 1000-1200 mm west of contour line 2100 m and less than 800 mm of annual rainfall is received in areas southward contour line 1740 m above sea level as indicated in figures 2 and 4. Generally the northern and western areas (high altitude or highlands) receive high amounts of rainfall of between 1000-1200 mm $year^{-1}$, while the east and southern areas have a much lower rainfall of between 700-800 mm $year^{-1}$ as explained by Griffins (1972) and Kenya Meteorological Department (1984) annual report. This in turn relates more to the stream flow; runoff and pollutant wash off characteristics in the study area, and finally determines the water resources development, conservation and management.

Rainfall distribution and patterns within the basin exhibit the bimodal pattern of the whole country. This is demonstrated by figures 5, 6 and 7 of rainfall stations Dagoretti, Uplands Lari (Limuru) and Jomo Kenyatta International Airport, respectively. The rains occur in two distinct seasons, with peaks in April-May and October-December.

Temperature essentially affects the rates of evaporation and evapo-transpiration. This is, however, more related to altitude and sunshine duration in a day. The daily temperature range is small at about 5°C with seasonal variations. In terms of water loss, temperature is quite insignificant in the highlands as opposed to the lowlands.

In hydrological terms, the upper Athi River catchment area is drained by the main Athi River with tributaries Koma, Ndarugu, Ruiru, Ruaraka, Mathare, Mutoine, Mbagathi, Ngong and Nairobi, all joining together downstream to form the main Athi upstream River Gauging Station (RGS) 3DA2 at Fourteen Falls (Donyo Sabuk). The streams under investigation in the current study are Ngong, Nairobi and Mathare joining together to form the main Nairobi river at Ruai and further down forming the main Athi River. The sub-streams in the upper-catchment are running in a north-east direction in Kiambu District while past the Nairobi city they run in a south-east direction. The upper parts, and indeed, Kiambu district, the streams exhibit a high drainage density as opposed to the lower reaches as indicated in figures 4 and 8 for rainfall distribution and stream density according to Strahler (1998). The drainage density ranges from high to medium (6:4), i.e., 1.59 through 0.63 to 0.40 m km^{-2} in parts of Kiambu district with a stream order 6 at the outlet point in Ruai. Kiambu district is basically the main source of water for the Nairobi and Ngong forest for the main Athi River, with streams originating mainly from the springs of Ondiri, Tigoni falls, Kabete and Karura forests. This implies that upper areas are well drained as compared to the lower reaches of these streams where stream density declines drastically. The implication of this is that the upper catchment areas are well endowed with water resources relative to the lower areas.

Thus, any land-use changes in regard to agricultural productivity, urbanization, and industrialization and population settlement density have adverse effects on the water resources and subsequently on the environment, mainly water quality in general. In overall, Kenya is listed as a country with water scarcity by the year 2025 according to Engeman and Leroy (1993) as indicated in Table 2.

Table 2: Kenya's renewable freshwater available against projected population and per capita water availability.

Country /Yr	Total annual renewable freshwater available (million m^3)	1955		1990		2025					
		Pop^n 000's	Per capita available water m^3	Pop^n 000's	Per capita available water m^3	Low 2025 pop^n	Per capita	Medium popn	Per capita	High popn	Per capita
Kenya	15,000	7,189	2,087	23,585	636	60,800	247	63,826	235	66,870	224

Source: Adapted from Engelman and Leroy (1993)

The implication of table 2 is that water resources in Kenya and in particular catchment areas must be well managed and conserved. This is to reduce the adverse effects of environmental degradation and subsequent water resources. Stringent measures should be adopted to deal with any land use activity likely to cause environmental degradation and hence water quality deterioration. The fact that by the year 2025, Kenya is likely to experience water scarcity is a cause for concern. Table 2 clearly shows the drastic decrease in per capita available water in cubic meters from 1955 at 2,087, 1990 at 247 and the projected value of 224 m^3 by the year 2025. This represents 90% decrease in the available water resources from a mere 7.2 million in 1955 to 66.9 million by 2025 representing a significant 90% increase. This has put a lot of demand and strain to the policy framework and strategies to address the ever increasing water pollutants resulting to water quality deterioration.

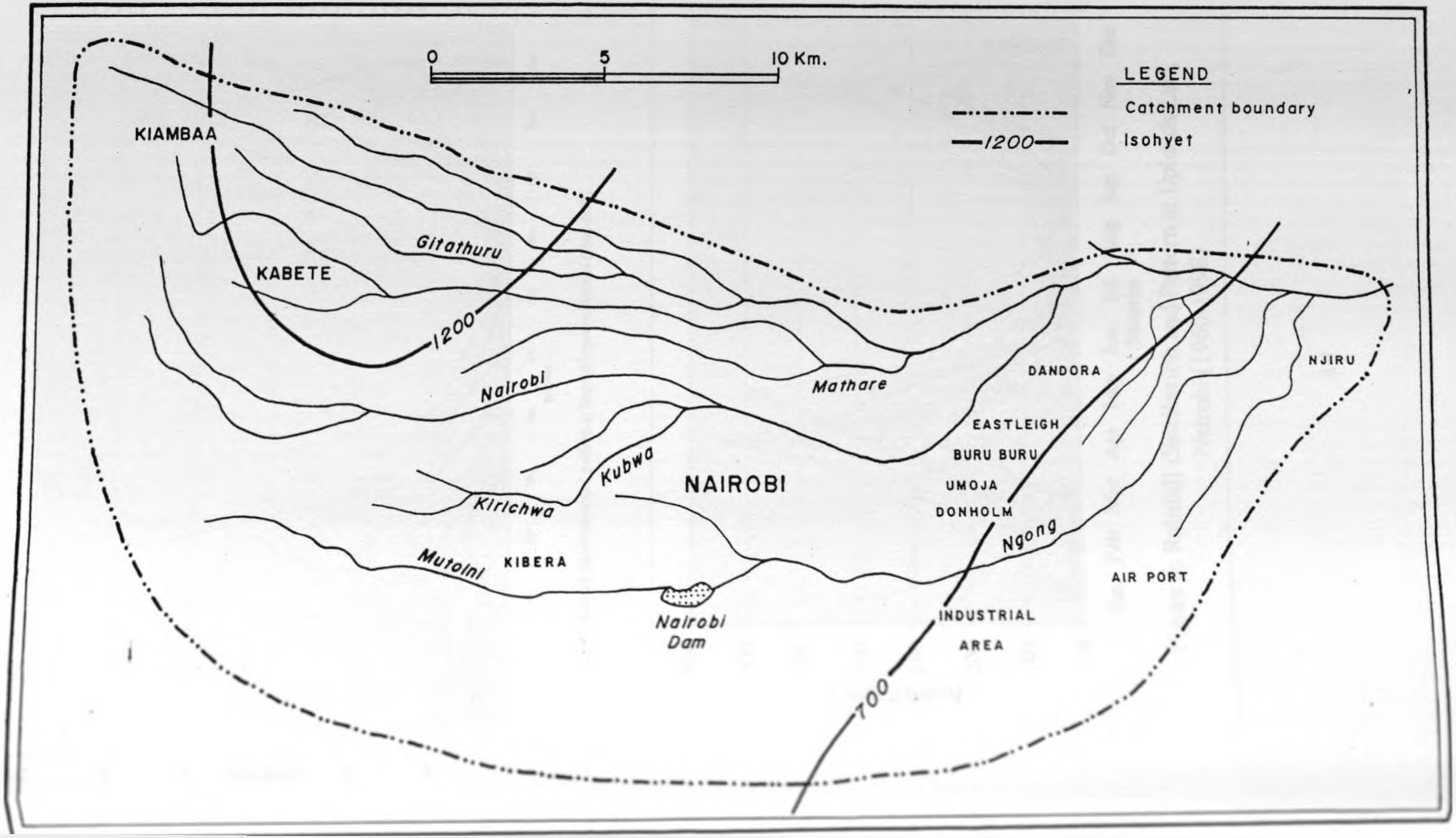
1.6.3. Hydrology of the Athi River Drainage Basin

The Athi River basin is drainage basin number three (3) of the Kenya's drainage basins and is about 540 km long. The river drains has a catchment area of about 70,000 km^2 (66,837 km^2) representing 12% of Kenya's total land area. The mean annual run-off is about 1294 x 10^3 with annual rainfall of 550 mm translating to 19 $m^3 s^{-1}$ mean annual runoff for the whole basin.

The Athi River originates and drains the southern slopes of Aberdare ranges and comprises the southern part of the country east of the Rift valley. It covers large parts of Kiambu, Nairobi, Machakos and Makueni districts. The river flows through a country of basement complex rocks, the areas being mostly semi-arid and subject to long drought periods. Its tributaries from the highlands flow in deep valleys close together, almost forming a parallel drainage system.

The main tributaries are Ruiru and Ndarugu. Other minor tributaries but of great hydrological importance are Ngong, Nairobi, Mathare, Mbagathi, Riara and Gitathuru. Ngong, Nairobi and Mathare which are tributaries in the upstream areas traverse the Nairobi city and its environs and are the main focus of this study. After being joined by its tributaries, the Athi River flows down steeply in a series of falls and rapids in a metamorphic formation. It goes down reducing in capacity due to underground seepage as a result of geological configuration; E.g. 95 $m^3 s^{-1}$ above Kwaa, 65 $m^3 s^{-1}$ at Kibwezi 100miles (161km) downstream, 40 $m^3 s^{-1}$ 70 miles (113km) above the confluence of Tsavo (Republic of Kenya, MOWD, 1997). Further down, it becomes reinforced by Tsavo River from Mt. Kilimanjaro which provides dry weather inflows after where it changes its name into Galana or Sabaki and flows in a series of meanders over sandy beds until it drains its waters to Indian Ocean north of Malindi as was indicated in Fig. 1.

The river carries with it an enormous volume of suspended sediments as a result of erosion and other human activities in its upstream reaches. The total amount of sediments discharged by the river into the Indian Ocean is estimated at 2,057, 487 tonnes/year as indicated in table 8. The heavy sediment loads discharged into the Ocean are responsible to the highly coloured beaches of Malindi which have changed totally to brownish therefore affecting the tourism industry by polluting the sand beaches around Malindi town. The heavy sediment loads may adversely affect marine life by reducing light penetration although they may add food nutrients. This requires proper land use planning, management and conservation in the headwater areas of the Athi River drainage basin in order to sustain the valuable marine organisms and coastal beaches necessary for the tourism industry and the much needed foreign exchange. An increasing trend in water quality degradation was highlighted by Kithiia (1992 and 1997), Aketch and Olago (2000) and Mavuti, (2003). This complimented the findings of the present study.



0
5
10 Km.
LEGEND
Catchment boundary
1200
Isohyet
KIAMBAA
KABETE
Gitathuru
1200
Nairobi
Mathare
DANDORA
NJIRU
EASTLEIGH
BURU BURU
UMOJA
DONHOLM
Kubwa
NAIROBI
Kirichwa
Mutoini
KIBERA
Ngong
AIR PORT
Nairobi
Dam
INDUSTRIAL
AREA
700

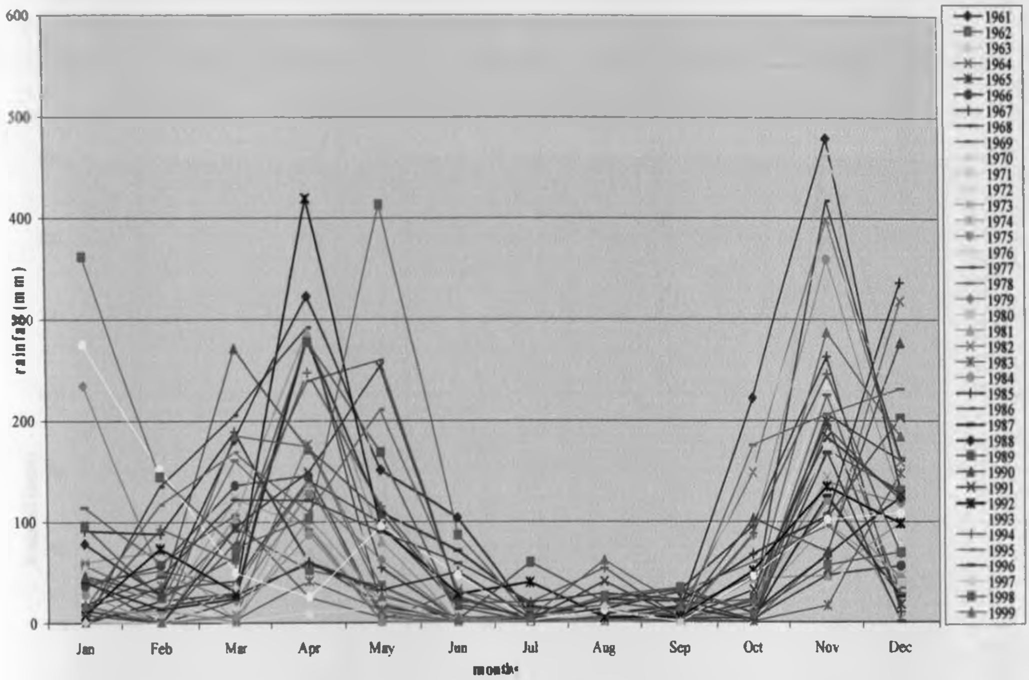


Figure 5: Rainfall distribution and pattern at Dagoretti corner, Nairobi (1961-1999)

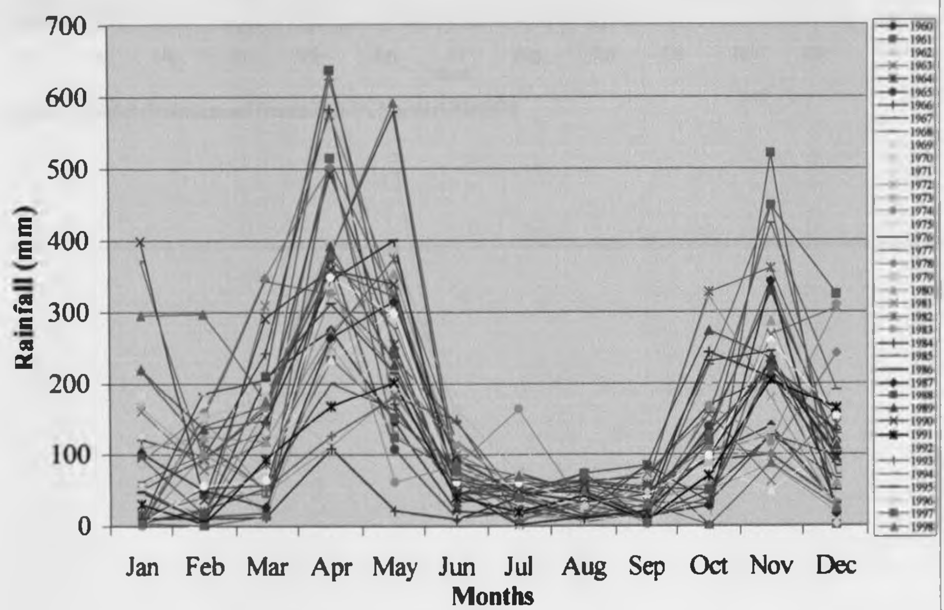
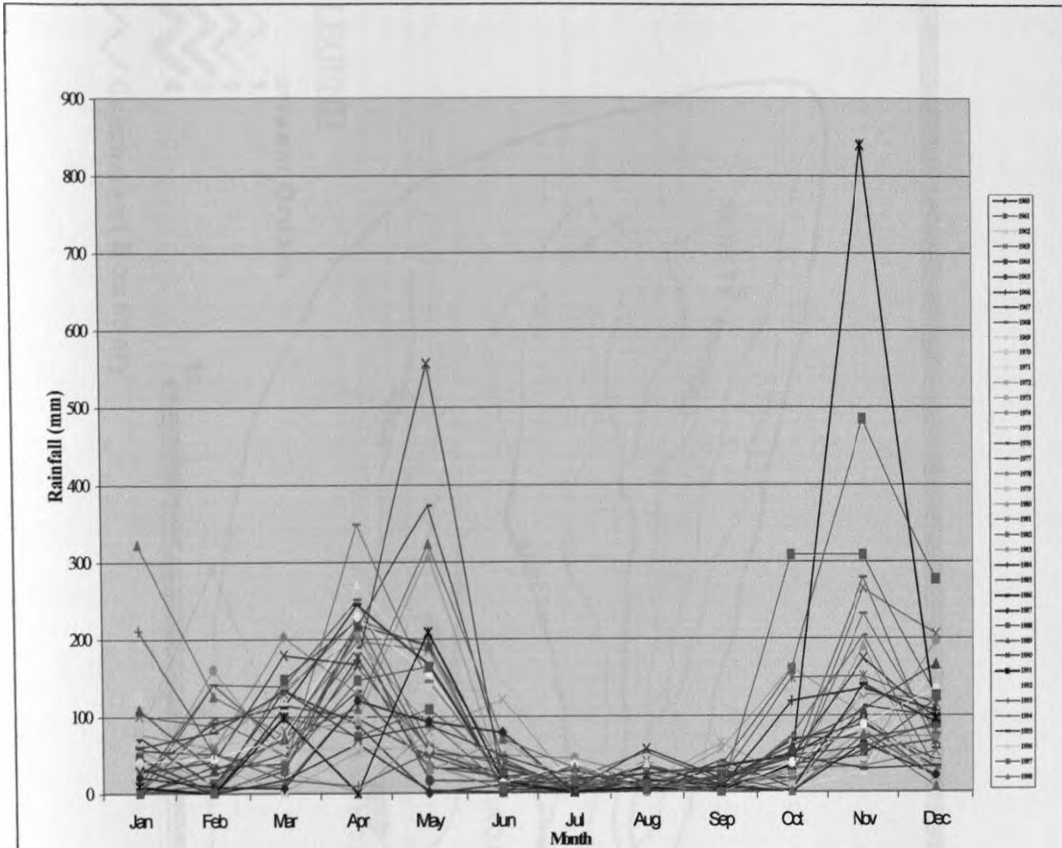


Figure 6: Rainfall distribution and Pattern at Uplands Lari, Nairobi (1960-1998)

Figure 7: Rainfall distribution and Pattern at JKIA, Nairobi (1960-1999)



Rainfall (mm)
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

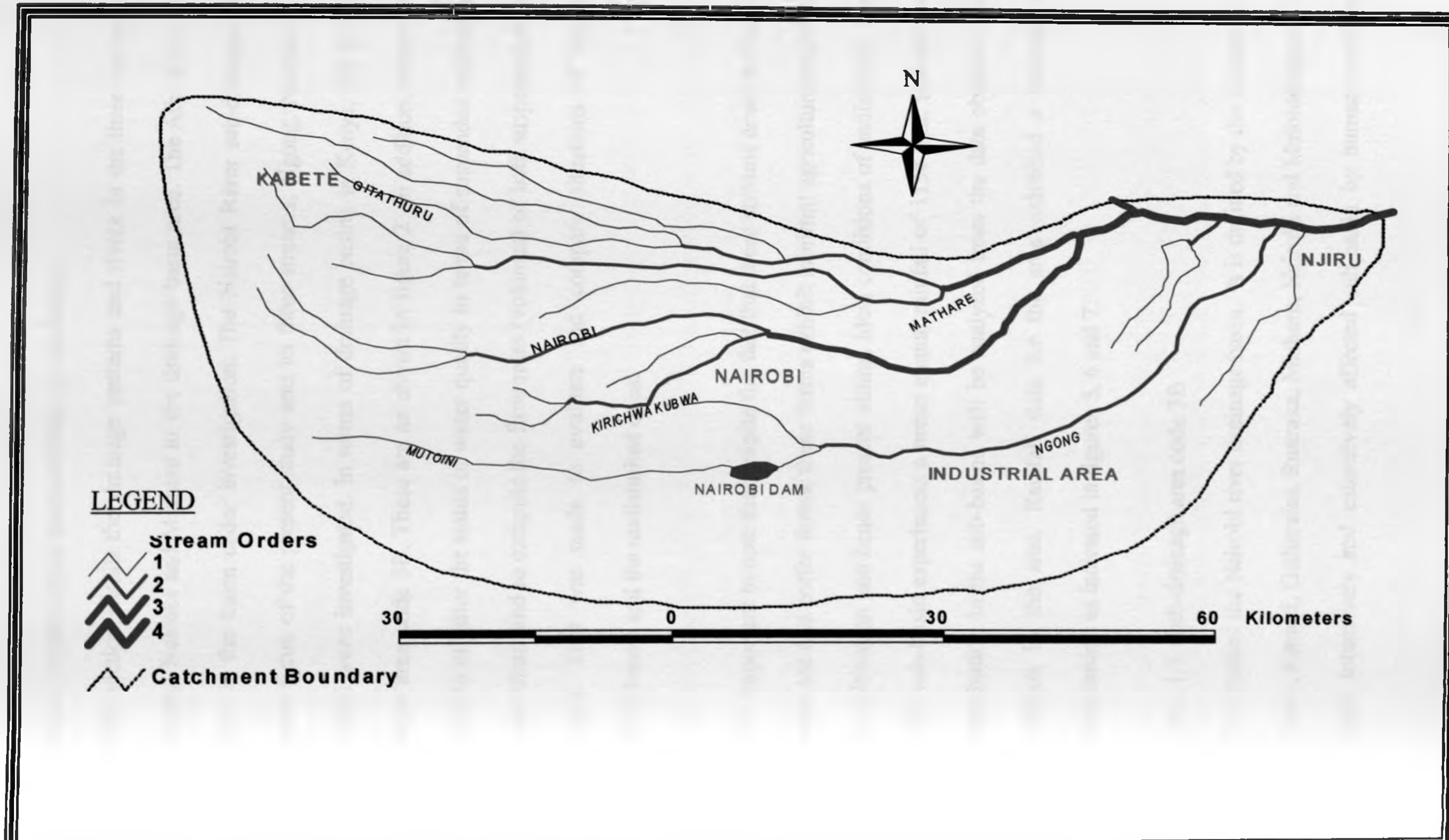


Figure 8: Hydrology and Stream Orders (Survey of Kenya (1980))

1.6.3.1. Hydrological characteristics by sub-basins

This section details the drainage patterns and rivers in the three sub-basins namely Ngong, Nairobi and Mathare in the drainage basin area. The Athi River is the major river in the basin under investigation. The Nairobi River sub-drainage basin is the main focus of the present study and its three streams, Ngong, Nairobi and Mathare which were investigated. In terms of drainage basins in Kenya, this is sub-drainage basin area code 3B. These are as shown in figure 2. In addition, these were streams used to monitor the status of water quality in terms of suspended sediments, turbidity and colour and to compute the flow rates (volumes) of both suspended sediments and water. This was made to evaluate and compare situations of human activity disturbance and the undisturbed ones.

It is important to note that despite the fact that these streams drain the large and small scale tea and coffee farms, these farms exhibit minimal agricultural activities in terms of cultivation and hence present almost ideal conditions of undisturbed environment. This sub-basin experiences a mean annual rainfall of 1136 mm. Rainfall patterns and distribution in the sub-basins will be analyzed from the data obtained from rainfall stations in the area. Rainfall data for the area exhibited a bimodal pattern of distribution as indicated in figures 5, 6 and 7.

1.6.3.1.1. Sub-drainage area code 3B

This makes the Nairobi river drainage basin. It is drained by the streams of Thiririka, Ruiru, Kamiti, Gatharaini, Ruaraka, Mathare, Nairobi and Mutoine/Ngong. This is the most intensively and extensively affected sub-basin by human activities such as population settlement, agricultural activities mainly small scale vegetable growing and industrial activities. Other land use activities include flower gardening, tree nurseries and small scale cropping plots all along most of the river banks in this sub-drainage basin. These activities are increasing in intensity due to the ready market opportunities of their produce in the city of Nairobi and the associated manufacturing entities.

For purposes of this study, the sub-basin area is further sub-divided into four (4) sub-drainage basins, sub-coded 3B1, 3B2, 3B3 and 3B4. Sub-basin 3B1 represents the Ngong (Mutoine) river, Nairobi and Mathare rivers. It houses the main urban centre (Nairobi city) and the major industrial concentration in the country in addition to being the most developed. It is this sub-basin and sub-streams which are of great interest in the foregoing study. These rivers drain areas of great contrasts. Ngong river drains the Industrial area and some informal (slum) settlements while Nairobi river drains residential areas and partly the urban centre and Mathare river drains residential areas (the Mathare slums), most of which have poor sanitary facilities and non-sewered areas.

In order to appreciate the different land use activities taking place within the sub-basin, sampling-cum-gauging stations were used. Industrial activities were related to the presence or detection of metallic elements in water as opposed to agricultural activities/population settlement which related more to suspended sediment loads.

In this sub-basin, sampling of sediment loads was done in the open drains, especially the main Nairobi drain at Lusaka/Bunyala road junction during the rains and in some residential estates as indicated in table 3. The flow of water in these drains was also estimated in assessing the effects of industrial and urban activities on the water quality degradation.

Table 3: Some water quality characteristics of runoff in open channels and unconfined sources (mg l^{-1})

Source/ Parameter	Q $m^3 s^{-1}$ Estimated	TSS	TDS	COND (μcm^{-1})	BOD_5	COD	TURB.
Surface Runoff /Nbi main drain channel	0.122	1,028	89	136	6.0	106	264
Storm water/Jericho estate	0.057	348	148	225	4.5	106	256
Uhuru highway/ Nyayo stadium	0.02	878	43	66	4.5	32	342

Source: Field data (1998-2000)

Table 3 results indicate that samples from unconfined sources after rains display high levels of total suspended sediments, conductivity and turbidity. This implies that water from these sources collected randomly is physically highly turbid and of low quality. The low measured levels of BOD_5 and high levels of COD indicate that the water is not highly polluted with organic pollutants. This explains the high yields of sediments from the road pavements and open spaces in the estates which have been tumbled by human activities resulting to severe erosion from these open spaces.

The compounded effects on each of the sub-basin were monitored at sampling points downstream, each stream confluence with samples taken from each stream just before the confluence point at an interval of two weeks or a month. These areas experience high amounts of rainfall with a mean annual of between 988 mm in Nairobi to 1126 mm in

Kikuyu escarpment. Analysis and comparison of rainfall data were collected from meteorological stations 9136022 Uplands Lari station with a record of 14 years, 9136121 Dagoretti corner with a record from 1961 to 1999 and 9136028 JKIA with a record from 1960 to 1998. These were graphically represented in figures 5, 6 and 7 showing the bimodal pattern of rainfall distribution.

1.6.4. Population Characteristics and Implications

The area is densely populated with a population density of 3,079 Persons km^{-2}, a record six times higher than the National average of 37 according to the 1999 population census. There is a high population settlement on the top of the inter-locking spurs that dominate the entire drainage basin leaving the slopes and the river beds to either large-scale or small-scale farming. The slopes are gentle in some parts (with a slope gradient of 2%) while in others they exhibit steep slopes with a slope gradient ranging between 0-3% within Kikuyu and Lari divisions (headwater areas). In the study area, population distribution is partly determined by the fertility of the soils, rainfall distribution and, to some extent agricultural activities undertaken. The study area's population characteristics are generalised by the population growth in Nairobi, Kiambu, and to a lesser extent, in Machakos districts. These displays an annual growth rate of 3.3-5.0% $year^{-1}$ and inter-censal growth rate of between 2.91 in Kiambu to 5.81 in Kajiado as indicated in Tables 4 and 5.

Table 4: Population characteristics of Nairobi, Kiambu, Machakos and Kajiado (1999 census data).

Area	Total Pop^n	Density km^{-2}	Land area (km^2)	% annual growth rate	Inter-censal growth rate % as of 1999
Nairobi	214,3254	3079	719	5.0	4.98
Kiambu	744,010	562	2,549	3.2	2.91
Machakos	906,644	144	14,209	3.3	3.14
Kajiado	406,054	19	21,960	5.6	5.81

Source: Republic of Kenya, 1999 population and Housing census, pp i-xxxiii, CBS

Table 5: Nairobi population (1906 -1999).

Year	Area (Ha)	Population	% increase of Pop^n
1906	1,813	11,512	-
1928	2,537	29,864	159.4
1931	2,537	47,919	60.5
1936	2,537	49,600	3.5
1944	2,537	108,900	119.6
1948	8,315	118,976	9.3
1962	68,945	266,795	124.2
1969	68,945	509,286	90.8
1979	68,945	827,775	62.5
1989	68,945	1,324,570	60.5
1999	68,945	2,143,254	61.8

Source: Republic of Kenya, 1999 Population and Housing census, pp i-xxxiii CBS and R.A. Obudho and G.O. Aduwo, (1992) Table 1:58

Table 5 clearly indicates the population increase and changes in the city since the 1900's and 1960's. In 1969 it had 509,286 people rising to 827,775 in 1979 and 1.6 million in 1989. The current population according to the 1999 population census stands at over 2 million people. The population growth is about 5.5% $year^{-1}$ which is attributable to a number of factors, activities and the fact that it is the administrative and commercial center of the country and the Eastern Africa region. The growth in population increases the pressure on the municipal amenities such as provision for water and sanitation in addition to infrastructure. The growth in size of the city started with expansions in boundaries in 1900, 1920, 1927 (30 square miles) and by 1963 the boundary was extended to cover an area approximately 266 square miles (approx. 689 km^2) and this has remained ever since with only expansions focused on the functions and activities within the urban center (Kithiia, 1998). This has contributed significantly to the increased housing units, industrial establishments and activities with subsequent changes and demands on water and drainage systems as well as adequate land for expansion. Thus, the rapid increase in the population and the size of the city of Nairobi has presented unusual problem to the planners as there is strain on existing infrastructures.

The collection of garbage and supply of treated water has been declining in the recent past, with most of the solid waste dumped into the Nairobi River directly at various points along the river course at river banks or left uncollected in various parts of the city. This results in water quality deterioration, especially downstream the city center (Kithiia, 1992). Pressure on the road network has resulted to severe degradation in the roads due to either benign neglect or poor maintenance. Most of the roads in the city and the suburbs are pot holed and therefore a major source of sediments in addition to causing a great constraint to the transport sector and the economy in general.

1.6.5. Land-use characteristics

Land use patterns within the study area are highly influenced by rainfall patterns, topography and human settlement-cum-activities. Agriculture dominates the economy of the upper catchment area (Kiambu District) providing a livelihood to about 70% of the population. This changes significantly moving away towards the city and the southern parts. Within the city industrial activities dominate, while in the southern parts livestock keeping and small-scale irrigation are more pronounced.

Soil types play yet a significant factor in determining the land use patterns and systems, more so in relation to the fertility and erodability. The soil types range from Humic nitosols, Cambisols and Acrisols in the highlands, Complex vertisols and vertic greysols, ironstone soils and litho sols in the city to the more fragile and easily eroded Pellic vertisols and Plano sols soils in the southern parts (upper Machakos and Kajiado districts). The main soil types are well illustrated in figure 9. A brief discussion of the most common soil types and their characteristics are well discussed in Table 6. This contributes more to the increased suspended sediment loads in the middle and lower reaches of the streams under investigation in this study. A more interesting factor is the contribution of the population settlement patterns and density to the sediment loads in the streams within the study area especially the upper sub-drainage basins. In the study area, land use has changed both in space and time. Information regarding these indicates that several factors have contributed to these changes. These factors include; the expansion in both activities and boundaries of the Nairobi city, agricultural to urban and human settlement lands (Krhoda, 1992 and Kithiia, 1997). The main land use systems in the study area are presented clearly in figure 10 showing distinct land use activities along each of the specific streams investigated.

Table 6: Main soil types and their characteristics (FAO-UNESCO system)

Soil code	Soil type	Soil characteristics	Remarks
R_2	Humic nitosols	Well drained, extremely deep, dusky red to dark reddish brown, friable clay with an acid humic topsoil.	Least eroded and produces less suspended sediments
R_3	Nitosols, Combisols and Acrisoils	Well drained, extremely deep, dusky red to dark reddish brown, friable clay; with inclusions of well drained, moderately deep, dark red to dark reddish brown, friable clay over rock	Not easily eroded especially when soaked with water. Has less TSS.
L_{17}	Complex vertisols and verticgreysols, ironstone soils and litho sols	Complex of moderately well drained; shallow, yellowish red to dark yellowish brown, friable, gravelly, clay over rock (ironstone soils and litho sols) and poorly drained, deep to very deep, dark brown to very dark greyish brown, firm cracking clays in places with vertisols and greysols	To some extent erodable depending on the soil conditions, produces high SS at the onset of rains
L_{11}	Pellic vertisols	Imperfectly drained, very deep, dark grey to black, firm to very firm, bouldery and stony, cracking clays in places with a calcareous, slightly saline deeper subsoil	Erodable and to some extent may produce increased SS concentrations

Source: Nairobi-Kiambu-Kajiado-Machakos Soil area Map (1980)-Survey of Kenya.

Generally, the soils of the study area are developed on undifferentiated Tertiary volcanic and basic igneous rocks. They are well drained, shallow, dark reddish brown though in some places and imperfectly drained, very deep, dark grey to black in some areas. Most of the soil types produce naturally low sediments except in cases when interfered with by human activities. In the hilly areas of river basins, sediment yields are relatively high due to the increased agricultural activities in these areas coupled with the steep nature of the slopes.

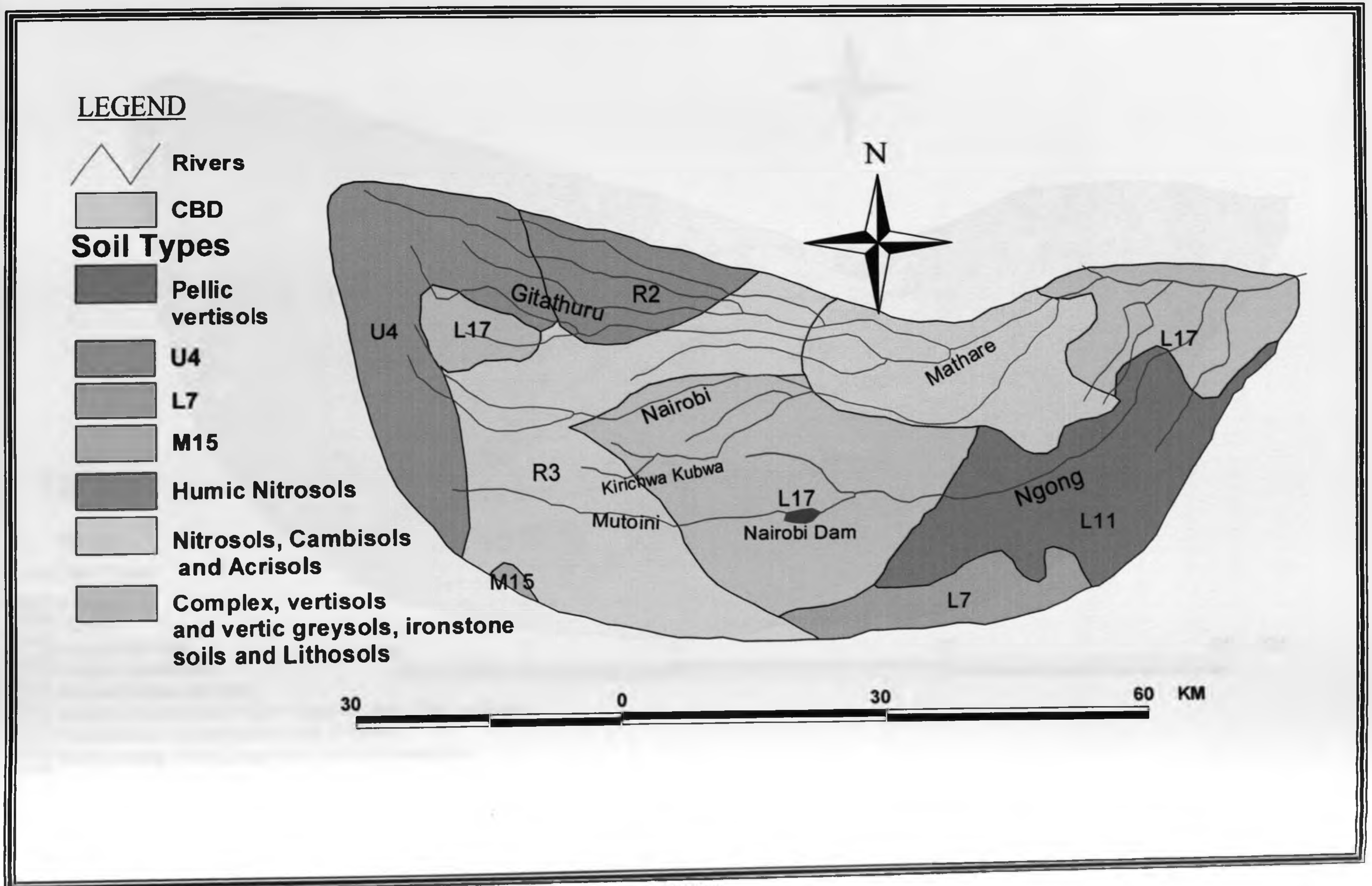


Figure 9: Soil Types in the Nairobi District (Survey of Kenya (1980))

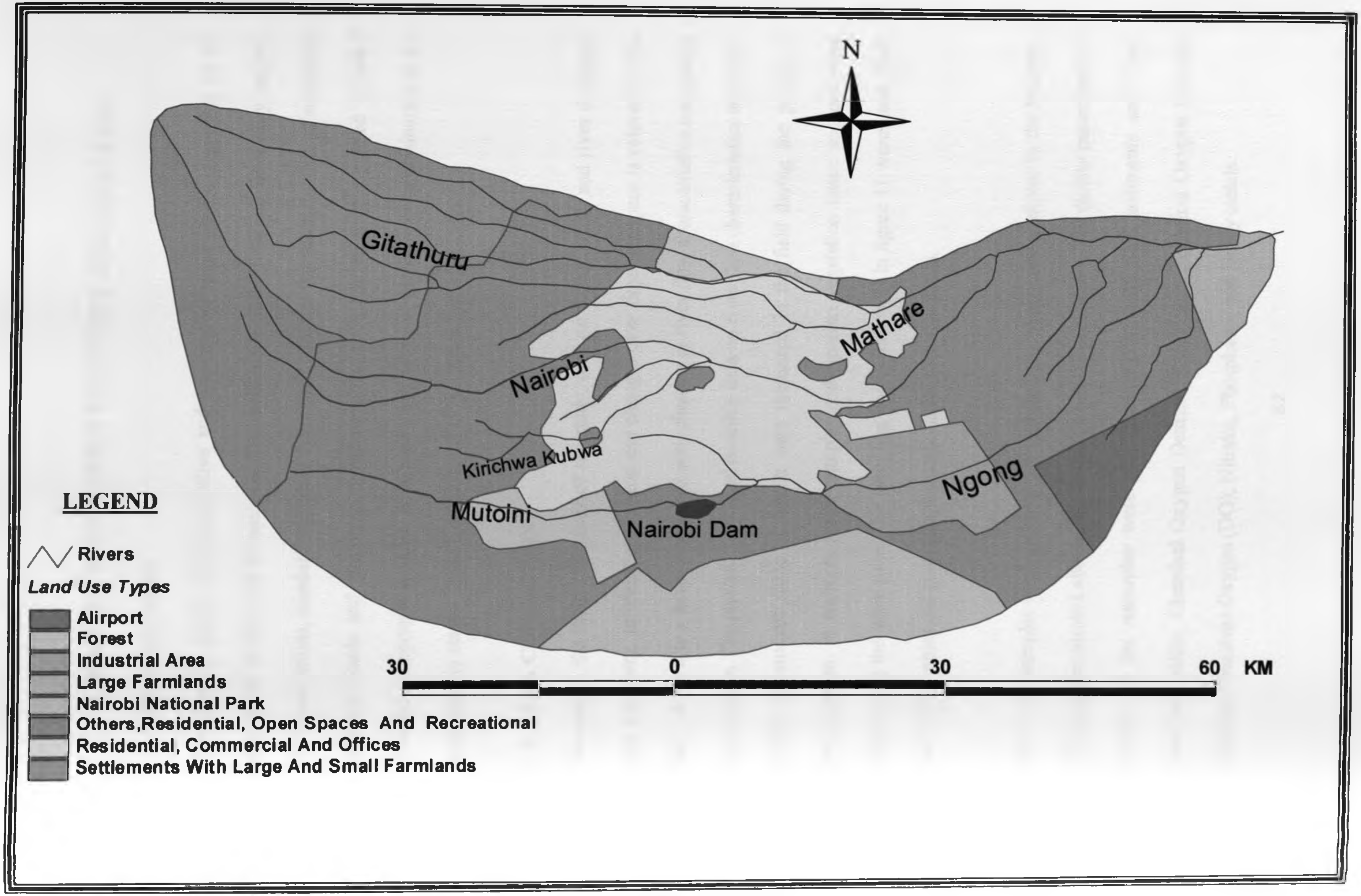


Figure 10: Land Use Systems in the Nairobi District (Survey of Kenya (1980))

CHAPTER 2- METHODS OF STUDY AND ANALYSIS

2.0. INTRODUCTION

This chapter details both qualitative and quantitative study methods applied in the acquisition of data and its analysis. The methods include, field and laboratory analysis and observations, standard empirical formulae in use for the determination of suspended sediment loads and discharge measurements. Quantitative methods used included principal component analysis, time series and chemical methods in determination of the water quality status. These are discussed in the following sub-sections.

2.1. DATA COLLECTION

To achieve the main objectives of the study, data on water quality and river discharge was necessary. Information on land use changes over time and space is relevant to the study since it is a factor associated with changes in river flow characteristics and quality degradation. The present study used monthly data on river flow characteristics and water quality parameters some of which were measured in the field during the period of investigation. In addition, water samples and riparian vegetation tissue sections were collected at the same time. The sampling points indicated in figure 11 were used both for field samples and river gauging stations for secondary data.

The water samples were collected fortnightly (two weeks) and analyzed in the Ministry of Water Resources Laboratories for water quality parameters. The quality parameters of concern to the researcher were pH, Conductivity, Suspended sediments and Total dissolved solids, Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5), Dissolved Oxygen (DO), Nitrates, Phosphates, and Heavy metals.

Other water quality parameters such as Sodium, Potassium, Chloride, Magnesium, Alkalinity and Fluoride were also analyzed. The river discharge measurements enabled the researcher to quantify the amount of water quality parameters conveyed in the river channels at each specific point and ascertain their harmful effects downstream the sampling points. The discharge volumes were indicators for water pollution dilution while the vegetation tissues were used to monitor the uptake of heavy metal pollutants along the various river courses as well as indicators of pollution sources.

2.2. DATA TYPES

In this study, two types of data were used in making the conclusions and in meeting the objectives of the study. These are field data (primary data) and secondary data (published materials).

2.2.1. Primary Data

This type of data was collected from the site or field in a designed systematic method of data collection. This included stream flow measurements (river discharge), collection of water samples related to sediment loads, and other water quality parameters and rainfall data. Others include TDS and DO determined in the field to gauge the pollution levels and type of pollutants through automatic field measurements. Riverine vegetation was also sampled for heavy metal detection in the various plant tissue sections, Viz; Leaf, Stem and Root. This formed the backbone of the on-going study objectives and the results arrived at.

2.2.1.1. Discharge Measurement

River discharges were determined by applying the velocity-cross-sectional area method (Linsley and Franzini, 1979; Linsley et al. 1988; Wilson, 1990). At the River Gauging Station (RGS), cross-section of the river was subdivided into several sub-sections through which water depths and velocities were measured using a plastino Echo-sounder and current meter, respectively. For each section, the water depths were multiplied by the respective width to determine the cross-sectional area, which were then multiplied by the flow velocities to yield river discharges for the particular section. The river discharges in different sections were summed to yield the total river discharge for each river investigated and sampling points. This was calculated using the following equation:-

$$Q_r = \sum_{i=1}^{n} Ac_i K_i \quad \text{.......... (1)}$$

Where:

Q_r is the river Discharge ($m^3 s^{-1}$), Ac_i is the sectional river cross-sectional area (m^2) and K_i is the sectional flow velocity ($m\ s^{-1}$). This was done at each sampling point and on every sampling time and date. The river discharge measurements were conducted once in a month during periods of low flows, however, the measurement frequency was increased to twice a week during periods of high river discharges during rainy seasons. This is a standard method of discharge measurement as illustrated by Linsely *et al.* (1982; 1985 and 1988).

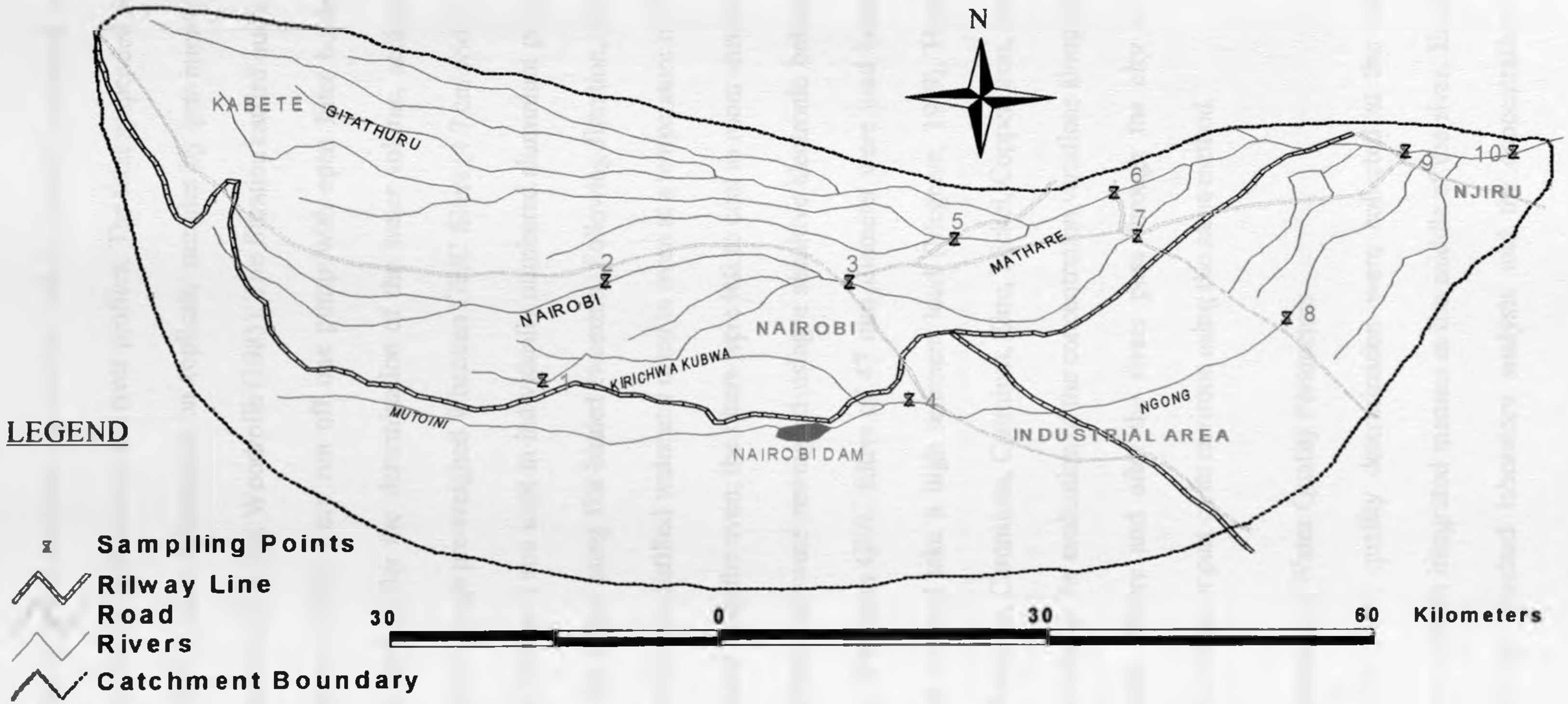
2.2.1.2. Sampling strategy

This section focuses on the methods and means used to collect water samples and riparian vegetation tissues along the streams investigated. Measurement of river discharge techniques are included to give an overview of its impact on water quality degradation and restoration within the streams investigated and in relation to riparian land use activities.

2.2.1.2.1. Sampling Points

It is important to note on the onset that the assigned sampling points are not for one river profile, but constitutes the three rivers investigated. Sampling points 1, 2, 3 represents Nairobi River in the upstream areas before entering the city and after, while points 4 and 5 are in the downstream areas. Sampling points 6 and 7 represents Mathare River, while points 8 and 9 represent Ngong River before and after passing through the industrial area. In total ten (10) sampling points were used as indicated in figure 11.

The sampling points were distributed in accordance with the level of importance in terms of land use activities within the streams investigated. The major land use activity was used as the major determining factor in locating the sampling point(s). Nairobi River which is the main stream had six (6) sampling points, followed by Ngong and Mathare Rivers with two (2) each, respectively. This was based on the land use activities along the stream and the expected sources of pollutants along the stream or river. Nairobi River drains the urban and commercial areas on the Nairobi city in addition to draining areas with informal settlements and high intensity of Jua Kali motor garages and food Kiosks, hence the high number of sampling points. Both Ngong and Mathare Rivers had each a distinct land use activity. Ngong River drains part of Kibera slum areas which are lacking in sanitary facilities although has a high population density in addition to draining the industrial hub of the city while Mathare River drains the Mathare slums. In total, 200 samples were collected within the period of study and in each sampling point, 15 water quality parameters were analysed translating to a total of 3000 parameters. Water samples were obtained using standard methods according to American Public Health Association (APHA, 1995). Depth integrated (equal transit rate) water-sediment mixture samples were taken at the middle zone of the river channel using USDH48 sampler. Occasionally, grab sediment samples were collected from the most turbulent section of the river (Sharma, 1993). Water samples for metal analyses were filtered through a standard Whatman type 0.45mm pore diameter membrane filter. The sample was then preserved by acidifying with concentrated Nitric acid (HNO_3) to pH=2. Heavy metals analysis was done by Atomic Absorption Spectrophotometer (AAS) technique at the Ministry of Water and the Department of Mines and Geology laboratories. This technique has a wide application in the metal analysis because of its speed, low cost per analysis, simplicity and frequent ability to analyse complex mixtures without separation and accuracy (Mancy, 1971).



SAMPLING POINTS

1. Kirichwa Kubwa D/S Kawangware
2. Nairobi at Muthangari
3. Nairobi at Museum (RGS 3AA22)
4. Ngong at Langata Road Bridge
5. Mathare at Thika Road Bridge (3BB 10)
6. Mathare at Outer Ring Road
7. Nairobi at Outer Ring Road
8. Ngong at Embakasi D/S Industrial Area
9. Nairobi at Njiru 1
10. Nairobi at Njiru 2 - Ruai

2.2.1.2.2. Laboratory Analysis

Laboratory analysis of water samples was carried out to quantify sediment loads and water quality deterioration status along the river profiles. The total suspended sediments concentrations (TSSC) were determined on replicate samples by gravimetric method according to Mcgrave (1979) and Woodroffe (1985). The filtration carried out by suction in which two vacuum flasks were run off one pump with open filter holders being mounted on each flask. After the determination of the water volume, sediment-water mixture was filtered through pre-weighed Whatman GF/C filters (4.7 cm wide, pore size 0.4 μm, thickness 260 μm) and kept in individually numbered aluminium packs. These were handled at the edges using flat-bladed tweezers. Following filtration, the filtrates were washed with filtered distilled water and dried in oven at a temperature of 105^0C for 24 hrs. After removal from the oven, the filters were left to cool to room temperature for about 2 hours before they were reweighed using a sensitive electronic balance to the nearest 0.0001 g. Whatman GF/C filters of 47 mm diameter were used because they have a high flow rate and take a high sediment load (Mcgrave, 1979). Heavy metal analysis notably Mercury, Chromium, Cadmium, Zinc, Nickel, Copper, Iron, Manganese and Fluoride was done in the evaluation of the concentration variations along the stream course distance-wise before and after the rivers pass through the city of Nairobi (urban/commercial areas) or part of its environs using the same method.

2.2.1.2.3. Measurement of Water Quality Parameters

Water samples for water quality determination were collected at the designated sampling points in a depth integrated manner at the middle of the river. Each sample was subjected to the standard laboratory analysis and the concentration of each parameter determined. The basic method applied in the determination of each metallic cations was the AAS. Measurement of other water quality parameters was by use standard laboratory methods and included BOD_5, COD, TSS, pH, Total Alkalinity, Total dissolved solids, Conductivity, Calcium, Magnesium, Sodium, Potassium, Chloride, Fluoride, Total hardness and Turbidity. Vegetal tissues were also analysed in the same manner.

BOD_5 was determined over 5 days for biochemical oxidation of organic substances at 20^0C. The detection limit was set at about 5mg l^{-1} and the same was done for the chemical oxygen demand (COD). The total dissolved solids (TDS) concentration was done through evaporating the water sample on a previously weighed dish and the residue dried at 180^0C and then weighed again to allow for the concentration to be determined while suspended solids (SS) were determined by filtration of a well mixed sample on a standard glass-fibre filter disk (0.45 mm filter; detection limit SS $\leq$ 5mg l^{-1}). Fluoride was determined by titration of the water sample with a standard Thorium nitrate in a solution buffered at about 2.9-3.3, using sodium alizarin sulphonate as indicator. Volumetric analysis or otherwise filtration method was used in the analysis of most of the other water quality parameters since it is usually more rapid than the gravimetric analysis if the filtrate reagent is specific for the water quality constituent. The sensitivity and/or precision may also exceed that of a gravimetric analysis for some determinants. It was widely used in the present study for the analysis of water quality parameters as pH, total hardness, and alkalinity according to Mancy (1971). Their results were used to group the parameters into three main categories; chemical, biological and physical related water pollution parameters. In addition, their magnitude values (concentrations) were used to infer on whether there was water quality deterioration or not. The water quality parameters were discussed as follows:-

2.2.1.2.4. Suspended Sediment Measurement

Water samples for suspended sediment analysis were collected at the middle and both sides of the river banks using USDH48 sampler. At each point, a depth integrated (equal transit rate) water-sediment mixture samples were taken. The samples were stored in 3 litre sample bottle and taken to the laboratory for suspended sediment concentration determination according to American Public Health Association (APHA, 1992) techniques and methods. Sediment discharge (mg l^{-1}) at the cross-section was computed by multiplying suspended sediment concentration (mg l^{-1}) with the river discharge $m^3\ s^{-1}$) and the correction factor of 0.0864 (Sharma, 1993).

The total sediment yield in tonnes for the days (n) sampled was computed according to Jorgensen and Vollenweider, (1988) and Sharma (1993) as:-

$$S=0.0864 \sum_{i=1}^{n} C_i\ Q_r \quad \text{.....(2)}$$

Where:

S is the sediment yield in t day^{-1}, C_i is the measured suspended sediment concentration in mg l^{-1} and Q_r is the cross sectional river flow in $m^3\ s^{-1}$. This procedure in combination with procedure 9 was used to calculate the sediment yields and mass loadings in the sub-basins investigated.

2.2.1.2.5. Heavy Metal Analysis in water

Metal analysis was done by use of Atomic Absorption Spectrophotometer (AAS) technique. The technique has a wide application in the metal analysis because of its speed, low cost per analysis, simplicity and frequent ability to analyse complex mixtures without prior separation (Mancy, 1971 and APHA, 1992, 1995). The atomic absorption spectrophotometry technique uses the principles of atomic absorption and electron emission, thus making it more precise, accurate and cheap. It's often useful for heavy metal determination in water analysis. The heavy metal analysed were copper (Cu), Zinc (Zn), Lead (Pb), Aluminium (Al), Manganese (Mn), Cadmium (Cd), Nickel (Ni) and Chromium (Cr). Consequently, the results of the analysis represent filtrate (dissolved) metals. Quantification of the metals was based upon calibration curves of standard solution of metals. The set detection limit was 0.001mg l^{-1}.

In spite of the inherent instrument and technique problems associated with AAS, spectrophotometers are well suited for water analysis because often the determinants of small quantities of substances can often be detected readily and accurately and the difference in techniques of individual analysis are also minimized. This method was found ideal for water quality parameter investigations, plant tissue analysis and was widely applied in the study.

2.2.1.2.6. Determination of Heavy Metals in Plant Tissues

The vegetal samples were first selected along the river profile depending on the species dominance and the Presence/Absence method of the most dominant species used at each sampling point. Dominant species were each sampled systematically by using a quadrant and proportionate sampling method applied in extracting the various tissue sections required. After each vegetation species was identified, then three tissue sections were extracted and then taken for identification, and tissue analysis for detection of heavy metal traces in three main parts of the plant Viz:- leaf, stem and root. This was to determine the vegetation tissue part and the plant species with high heavy metal uptake and hence of high concentration.

Sample preparation and digestion was performed as described in HACH PROCEDURES MANUAL systems for food, feed and beverage analysis. Hach procedure for food and foliage applies to ensiled material (haylage, silage), hay green chop, feeds, plant tissue and other moist samples that require drying or preliminary chopping before they can be ground to a fine consistency.

A plant tissue sample of about 100 g was cut into fine pieces and air-dried in an oven at about 60°C. This was then transferred into a mortar and ground until it was free flowing (<1 mm) and mixed uniformly by repeated inversion.

The ground sample was then digested using deionised water, Hydrogen peroxide and concentrated Sulphuric acid (AR). The method of extraction consisted of chelation with ammonia pyrrolidine dithiocarbamate (APDC) and extraction into methyl isobutyl ketone (MIBK), followed by aspiration into air-acetylene flame at a temperature of 440°C. The pH levels of the samples and their corresponding standards were adjusted to 3. The samples were carried through the same preparation as for the standards to obtain organic extracts and then aspirated directly to obtain the concentrations. The instrument gives concentration values directly on the screen and printer with a detection limit equivalent to <0.001mg l^{-1}. This method was used for the analysis of heavy metals Chromium (Cr), Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn) and Nickel (Ni) concentrations in plant species tissues.

2.2.2. Secondary Data

This is data normally stored in archival records, publications, books, journals and articles. It includes mostly the recorded discharge measurements, rating curves, agricultural practices, population density and industrial characteristics of the study area. Previous records of river flow discharges, water pollution parameters, and land use changes was used in order to assess the validity and accuracy of the collected primary data. Rainfall data covering the area was used as control measure against which discharge rates were judged. This correlation determines changes in land-use and water quality degradation within the study area sub-basins.

2.2.2.1. Rainfall Data

The data used included monthly rainfall totals for rainfall stations 9136022 Uplands Lari, 9136121 Dagoretti corner and 9136168 JKIA. These data were obtained from Dagoretti Meteorological Station in Nairobi and the monthly totals computed for each station. The rainfall data used for Uplands Lari station were for the years (1960-1998), Dagoretti corner station (1961-1999) and Nairobi Jomo Kenyatta International Airport station (JKIA) 1960-1999. The data represented many years and exhibited rainfall distribution pattern in the study area and river sub-basins investigated.

2.3. METHODS OF STUDY

Data acquisition and analysis in the field and laboratory, respectively, form the basis of data interpretation. Water samples and field measurements formed the data acquisition part, while quantitative techniques such as Time series analysis, especially for prediction purposes, Principal Component Analysis (PCA) and Multiple Regression Analysis (MRA) were used in understanding the behaviour of the data collected and status of the study objectives. Analysis of water quality was sometimes done in the field as well as in the laboratory. An examination of water in the field to determine its approximate chemical character is often useful. The utility of the field analysis was for the determination of water quality constituents which change rapidly after the sample is obtained and which therefore require undue and perhaps impossible speed in transport to the main laboratory. These statistical methods of data analysis are described later in section 2.3.1 in this study report.

The procedures range from the determination of specific conductance of the water, pH and temperature to extensive chemical analysis of dissolved oxygen (DO) and Chemical Oxygen Demand (COD) made with semi-portable laboratory equipment. Instruments used were portable Jenways meters model 4075 and 9070 for measuring in situ specific conductance, total dissolved solids and DO, respectively. These measurements were undertaken in accordance to Brower and Zar (1977) and Goldman and Horne (1983).

The methods used in the field involved use of a submersible metallic probe dipped into the flowing river water and the measured parameter values read off from the meter gauge. The method was applied in determining some water quality parameters in the field; however; water samples collected occasionally from the field were taken to the laboratory for further analysis. The methods most ideal for the sample collection are those which involve the use of air-tight samplers rinsed with acids and alkalines to neutralise and kill any micro-organisms in the sampler prior to the sampling. This is made to ensure that the sample is free from oxygen dependent organisms that may utilise the oxygen in the sample and thus affecting the BOD_5 and COD levels in the sample. The samples were then transported to the central laboratory in a cool box. BOD_5 was determined over 5 days for biochemical oxidation of organic substances at 20°C in the laboratory. The detection limit was set at about 5 mg l^{-1} and the same was done for the chemical oxygen demand (COD).

The laboratory results were further subjected to statistical analysis to yield data useful in the assessment of the water quality status and the implication of water pollution within the studied river sub-basins.

2.3.1. Methods of Statistical data Analysis

Analysis of water resources data and its proper interpretation is a pre-requisite to better development and management of this vital resource. This is more so, especially in the determination of the quantities and quality in any given sub-basin or catchment area. The methods must be sufficient and adequate ranging from the field to the laboratory.

The methods applied were both qualitative and quantitative in nature. The methods considered are statistical techniques of data analysis once data has been obtained from the field through field observation, measurement and laboratory analysis for pollution or water quality assessment. The principal statistical methods used include; Time series, Principal Component Analysis (PCA) and Regression Analysis methods.

2.3.1.1. Time Series

Most of the statistical methods used in hydrologic studies are based on the assumption that the observations are independently distributed in time and that the occurrence of an event is assumed to be independent of all previous events. This assumption is not always valid for hydrologic time series (Chow, 1964, 1988). Generally, high values tend to follow high values and low values tend to follow low values, thus leading to clustering of the data.

A time series may be considered time-homogeneous if the identical events in the series are equally likely to occur at all times. More, specifically, a time series is homogeneous if the occurrence of an event is independent of the previous events. Usually, types of departure from time homogeneity in hydrology data may be grouped as trend, periodicity and persistence. Trend is the tendency of the observations to increase or decrease gradually in magnitude with time. Periodicity is the tendency to form successive maxima and minima like the crests and troughs of water waves. Persistence means that the successive observations in a time series are linked among themselves in some persistent manner, resulting in non-pure-randomness. Many hydrological sequences exhibit a departure from randomness in that large values tend to be followed by large values, and small values of similar magnitudes tend to be persistent throughout the sequence. One measure of this tendency is the lag-one serial correlation coefficient denoted by r_1, describing the strength of the relation between a value in the sequence and that preceding it by one time interval (hence 'lag-one').

The trend of a time series is often determined from an examination of plotted time series and by the method of moving averages of a convenient number of successive terms. The periodicity and persistence are usually detected by Auto-regression analysis.

Auto-regression analysis is used to analyse the linear dependence among the successive values of a series with a given lag apart. The Auto-correlation coefficient (r), sometimes known as serial correlation coefficient, is a standardized measure of linear relationships between 2 variates with a lag apart. The concept of "lag-one serial correlation" (r_1) can be generalized to give the "lag-K serial correlation coefficient", denoted by r_k (FAO, 1973). The Lag-k or r_k is computed as follows:

$$r_k = \frac{\frac{1}{(N-1)}\sum_{(t=1)}^{(n-k)}(Y_t - y)(Y_t + K - y)}{\frac{1}{N}\sum_{(t=1)}^{N}(Y_t - y)^2} \qquad \text{.......................} (3)$$

Where:

r_k is lag one serial correlation coefficient, y_t and y are the sequence of hydrological events or variables while N is the total number of observed events in the sequence.

In strictly random sequences, the values of r_1 necessarily differs from zero only by sampling variation; for sequences showing strong persistence, its value is close to 1. That is, when r=1.0 or -1.0, the variates are perfectly correlated, when r=0, variates are said to be un-correlated. A negative value of the lag-one serial correlation implies that the large values in the sequence tend to be followed by small ones and the vice-versa. Usually the calculated coefficients are plotted against the corresponding lags to form a correlogram. An exact test for the lag-one serial correlation coefficient states that, if r_k lies outside the range:-

$$[-\frac{1}{(N-1)}+1.96\frac{(N-2)}{(N-1)^{3}/^{2}}, -\frac{1}{(N-1)}-1.96\frac{(N-2)}{(N-1)^{3}/^{2}}] \quad ...(4)$$

then, there is evidence that r_1 is significantly different from zero, unless an unusual event has occurred. This also suggests the presence of persistence in the data sequence.

Time series analysis is ideal for use in the data analysis because most of the data (variables) relating to river flow characteristics and water quality tends to show some clusters. The range was used to indicate the variations in the different water quality parameters. Thus, variables were classified as time significant if trends show persistence. This method was quite ideal for the present study.

2.3.1.2. Principal Component Analysis (PCA)

The relationships between a number of inter-connected variables can generally be summarised in terms of a fewer number of principal component's analysis technique. This technique is an introduction to factor analysis and both are used for investigating the interdependence of variables. Both aim at finding a small number of hypothetical attributes (components or factors) which contain the essential information expressed in a large number of observed attributes (Howard, 1991). The methods are based on mathematical models which present simplified, but not exact, representations of the data on certain assumptions.

In the PCA model, the assumption is that a small set of attributes (variables) sampled at a particular time accounts for all the variables of each attribute in common factors (components) peculiar to the restricted set of attributes. It is therefore a method for partitioning variances, and it assumes linearity in the data.

In PCA, the final form of each model is a number of factors (components) obtained by rotating the principal component solution according to the varimax criterion. Howard (1991) pointed that the varimax criterion produces a matrix of vectors in each of which a few attributes (variables) tend to have high loadings while the rest have small or zero loadings. Each component is expressed in terms of several factor (component) loadings (i.e. one for each characteristic). These are then used to indicate a characteristic or group of characteristics which may be identified with each factor (component). In PCA with P attributes $r<p$ non-zero eigen values are normally obtained. If $N<p$, a maximum of N-1 components are obtained. For many purposes, it is convenient to disregard components which have small variances treating them as constants.

The closer the factor loading for each factor (variables) are to be $= \pm 1.0$, the closer the relationship between factors and characteristics. The component loadings may be interpreted as the correlation coefficients between factors and characteristics; and the choice of ± 0.500 (significance level) is a reasonable division between important and unimportant characteristics (parameters). Where a component contains only one important characteristic, this characteristic is said to be independent. If more than one important characteristic occurs for each component, then theoretically, each of the characteristics (parameters or variables) have a common attribute found in that data associated with the components.

The main advantage of principal component analysis is in the robustness of the least square approach to approximating the data matrix or co-variance matrix. Other advantages lie in the relative simplicity of the techniques; e.g., it is easy to see the contributions made by the attributes (variables) to each component. The others are (1) the orthogonality of the components and (2) the reduction of dimensionality.

The main disadvantage lies in the assumption that any relation among the original attributes are essentially linear, or at least that any non-linear contribution is small. The orthogonality of the components implies functional independence only if the objects are normally distributed.

PCA is a very useful method for analysis of interdependent data. It was used in the study as a tool to grouping the various water quality parameters into groups with respect to their sources and their mass loadings along the river courses. This explained extent of water pollution and quality degradation in the study area.

2.3.1.3. Regression Analysis

Mather (1976) stated that regression analysis involves specification and identification of the type and nature of the dependence or a single variance upon a set of controlling, predictor or explanatory variables. In simplicity, it is a statistical technique which aims at establishing a relationship between a dependent (response, Y) or criterion variable and a set of independent variables (explanatory or predictory variables, X's). Depending on a number of variables involved, two types are known, simple and multiple regression analysis. When only two variables are related (regressed), the analysis is one of a simple regression, when three or more variables are involved, the analysis is one of multiple regression. The general aim is to fit a line of best fit (regression line).

The general model of regression analysis is given as:-

$$Y = a + b_1x_1 + b_2x_2 + ... + b_kx_k + E_i \quad (5)$$

Where:

Y= dependent variable

$x_1, x_2 ... x_k$ = independent variables

a= intercept value, which determines the value of Y when $x=0$

b= correlation coefficient (is the gradient or slope of the regression line).

E_i= is the residual or error term (it represents the un-explained factors in the regression equation).

The derivation and working principles of the regression equation are not dealt with in this study but are well documented by Chow (1964), Mather (1976) and Howard (1991). The test statistics for the regression analysis (line of best fit) is R^2 which is the multiple coefficient of determination. It explains the proportion of the vital variation in the dependent (Y) variable accounted for by the independent variables (X's). It is usually given in percentage (%).

R^2 is computed by the formula:-

$$R^2 = \frac{TSS - SSR}{TSS} \quad \text{.......................................} (6)$$

where: TSS is the total sums of squares and SSR is the sums of squares due to residues.

or $R^2 = \frac{\text{Total SS - Unexplained SS}}{\text{Total SS}}$

where;

$$TSS = \sum_{(i=1)}^{n} (Y_p - \bar{y})^2 \quad \text{.......................................} (7)$$

The amount of explanation if we do not take account of the variation of the other factors (deviance) and

$$SSR = \sum_{(i=1)}^{n} (Y - Y_p)^2 \quad \text{.......................................} (8)$$

Equation (6) represents the sum of the squares of the deviations of the actual Y values from the least-squares line. It indicates the amount of error in prediction. It is the unexplained sum of squares or sum of squares due to residues.

The computed value of R^2 normally lies between +1 and -1. If it is 0 there is no relationship. The closer R^2 is to ±1 the better the use of the regression equation and the stronger the explanation. It may be used in interpolating or predicting values of the dependent variable or may form part of the process of scientific explanation, in which the variation in the dependent variable is accounted for in terms of the explanatory variables (Mather, 1976 and Nachimias ,1996).

The present study used regression analysis in the verification of water quality status in terms of deterioration within the sub-basins studied by relating river flow (discharges) with the concentration (measured values) of water quality parameters under different land use systems. The values were expected to show distinct quality characteristics in the three sub-regions of the study area under totally different land use systems. River flow discharges were plotted against water quality values in each sub-basin and the variations were attributed to changes in land-use activities. These are clearly depicted in the results indicated in tables 13 through 16 and figures 17 to 27. Kithiia (1992 and 1997) found a negative relationship between river discharges and water quality deterioration suggesting that an increase in river discharge results to water quality deterioration in physical terms whereas a decrease results to quality deterioration in ionic concentration. This varied from one river sub-basin to another and had seasonal trends.

CHAPTER 3 - RESULTS AND DISCUSSIONS

3.0. INTRODUCTION

This chapter explains the results of the data analyses as well as providing a detailed discussion of the same. It deals in some depth with analyses of the data obtained in the field and in the laboratories. The results presented, include the discharge characteristics of the rivers in the three sub-basins investigated, namely Ngong, Nairobi and Mathare Rivers, rainfall characteristics, spatial land use changes and water quality degradation status and parameters. Rainfall pattern and characteristics were matched with river flow characteristics to evaluate the seasonal changes of water quality degradation during the wet and the dry season. Parameters of water quality degradation measured both in the field and analysed in the laboratories were presented to indicate water quality degradation status in each sub-basin and rivers investigated. The results are presented both qualitatively and quantitatively in the various sub-sections.

3.1. RAINFALL DISTRIBUTION AND PATTERN

The upper-Athi River drainage basin is generally humid. In the upper-catchments areas, rainfall distribution normally ranges between 1000-1200 mm. These are the headwater areas of the three tributaries investigated in the study. In the middle areas, rainfall reaches an average of 1000 mm within the city of Nairobi while downstream the city rainfall amounts decrease dramatically to between 700-800 mm year^{-1} (Griffins (1972) & Kenya Meteorological Department (1984). Therefore, it is in essence the rainfall amounts in the headwater areas that influence the river flow characteristics. Consequently, this is also important in cleaning up the rivers after heavy storms. The rainfall pattern is that of bimodal type with the area generally experiencing peaks in the months of April-May and October-December as indicated in figures 5, 6 and 7, respectively, as presented earlier in this study work.

Rainfall distribution and pattern tends to be closely related to the nature of the river flow characteristics (volumes) in the various rivers investigated, with the peaks relatively similar in trend and shape as indicated in figure 12.

The peaks of both the rainfall and river flow characteristics signify the wet seasons whilst the lows represent the dry seasons. This consequently has some bearing on the water quality degradation in a seasonal manner. The implication of this is that during the wet seasons, water quality in the rivers is good chemically but poor physically because the water is highly loaded with sediments but chemically diluted. During the dry season water is chemically polluted with high concentration loads of metal ions. This assertion was found to be true by Kithiia (1992, 1997) and Newson (1994).

3.2. HYDROLOGICAL VARIABILITY

The hydrology of the study area is defined by three main tributaries of the Athi River, namely Nairobi, Ngong and Mathare rivers. These drain the upper catchment area of the study area, flowing in a lateral direction in a south-east direction through the city of Nairobi. These streams form a dense parallel drainage network deeply incised at higher levels. Downstream the city of Nairobi, they emerge on a rolling plateau at an elevation of between 1200-1600 m. The plateau is predominantly underlain by deeply weathered gneiss and schists. The drainage density is generally low.

The flow characteristics are clearly described by low flows during the dry season and high flows in the wet seasons. Figure 12 indicates the mean flows in the sub-basins under investigation. Generally, the mean river flows were recorded as 2.5, 0.6 and 1.1 cubic metres per second for Nairobi, Ngong and Mathare rivers, respectively. The mean flows measured varied in an increasing trend downstream each of the streams investigated. The measured mean values recorded were 0.9, 1.5, 2.0, 3.9 and 4.0 $m^3 s^{-1}$ for Nairobi River at Muthangari, Museum, Outering Road Bridge, Njiru 1 and Njiru 2, respectively. Ngong River was recorded as 0.3 and 0.9 at Langata Road Bridge and Embakasi. Mean flow values of 0.9 and 1.3 $m^3 s^{-1}$ were recorded along Mathare River. This is well illustrated in Table 7.

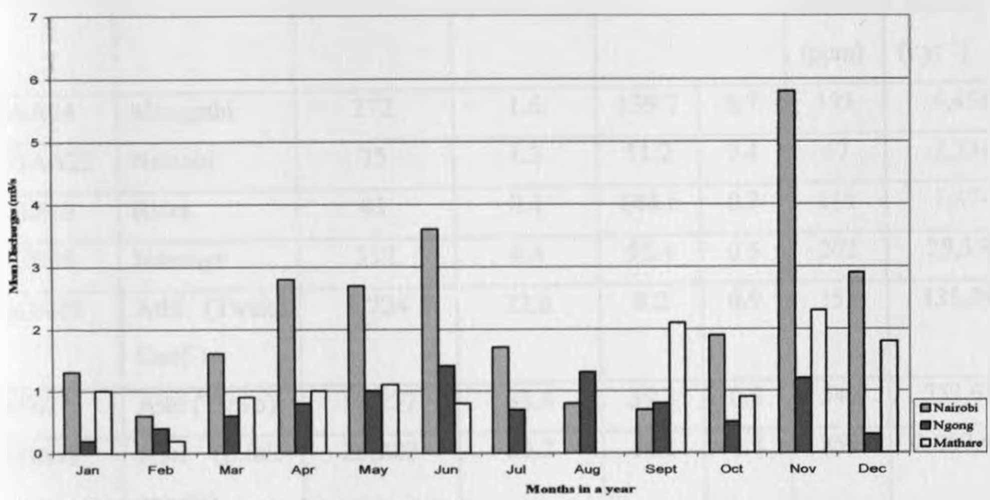


Figure 12: Mean monthly river flows per sub-basin (m3/s)

Table 7: Measured Mean Monthly River Flows Sub-Basin^{-1}

Sub-basin	Mean monthly river flows per sub-basin in $m^3 s^{-1}$											
River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nairobi	1.3	0.6	1.6	2.8	2.7	3.6	1.7	0.8	0.7	1.9	5.8	2.9
Ngong	0.2	0.4	0.6	0.8	1.0	1.4	0.7	1.3	0.8	0.5	1.2	0.3
Mathare	1.0	0.2	0.9	1.0	1.1	0.8	-	-	2.1	0.9	2.3	1.8

Source: Field data (1998-2002)

Table 8 indicates sediment ratings for selected streams within the upper-Athi River drainage basin as reported in the National Water Master Plan (NWMP, 1992) report. The table demonstrates a close correlation with the study findings as shown in table 9 that increasing river discharge leads to an increase in sediment load fluxes in the streams investigated.

Table 8: Rating Equation of Suspended load and its volume of some selected streams in the Athi river drainage basin.

Code	River	Catchment area (Km^2)	Annual mean discharge (cms)	Rating Equation		Suspended Load	
				a	b	Mean (ppm)	Annual ($t\ yr^{-1}$)
3AA04	Mbagathi	272	1.6	139.7	0.7	193	4,456
3BAA22	Nairobi	75	1.3	51.2	0.4	57	2,231
3BB10	Riara	41	0.4	144.6	0.2	118	1,474
3CB05	Ndarugu	312	4.4	95.4	0.5	202	29,356
BDA02	Athi (Twake Conf.)	5,724	23.6	8.2	0.9	153	131,089
3F02	Athi (Tsavo)	10,272	33.6	39.3	0.8	549	753,627
3HA12	Athi (L.fall-mouth)	25,203	33.2	48.1	0.8	859	2,057,487

Source: Adapted from NWMP, 1992 report Vol. 1, Table 2.31

From table 9, it can be observed that downstream the river profiles, the amount of total sediment load increases. The exception only occurs at Njiru 2 sampling point which is the outlet of all the three streams investigated where the value of TSS was calculated to the tune of 5166.23 t $year^{-1}$. This can be attributed to widening of the river channel, sedimentation and dilution effects which may have resulted to the deposition of the sediment loads and combined stream discharge increase from the three streams at this point. There is also a significant reduction in land use activities.

Table 9: Concentration of Total Suspended Sediments (TSS) In the Nairobi river Sub-basins in tonnes per year

Sampling Stations	Station Number	Main river	TSS Values t $year^{-1}$
Langata rd Bridge	4	Ngong	188.02
Embakasi rd Bridge	8		1733.15
Thika rd Bridge	5	Mathare	1194.54
Outering rd Bridge	6		2986.63
Muthangari	2	Nairobi	1001.02
Museum	3		1611.15
Outering road	7		6317.20
Njiru 1 after Mathare Confluence	9		12520.17
Njiru 2 All streams joined	10		5166.23

Source: Field data (1998-2002)

A cross-sectional view of the streams as demonstrated by figures 13, 14, 15 and 16 indicates stable conditions in the stream discharges. Figure 16 which shows the main Nairobi River after its confluence with the other two streams displays stable river bank conditions although it appears wide in width. The stream depth on average was 0.85m below the water surface and a mean width of 6.6 metres. This indicates very little bank erosion if any, with little suspended sediment contribution in the flow. This implies that most of the suspended load emanate from the various land use activities along the river banks courses.

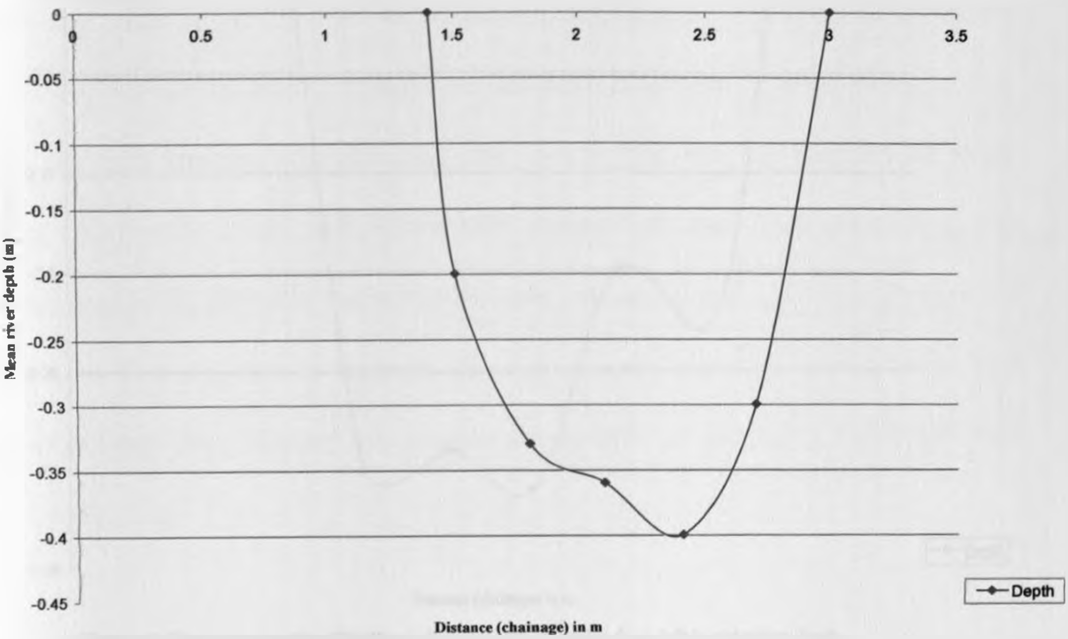


Figure 13: Mean cross-section of Nairobi river at Museum from right to left river bank

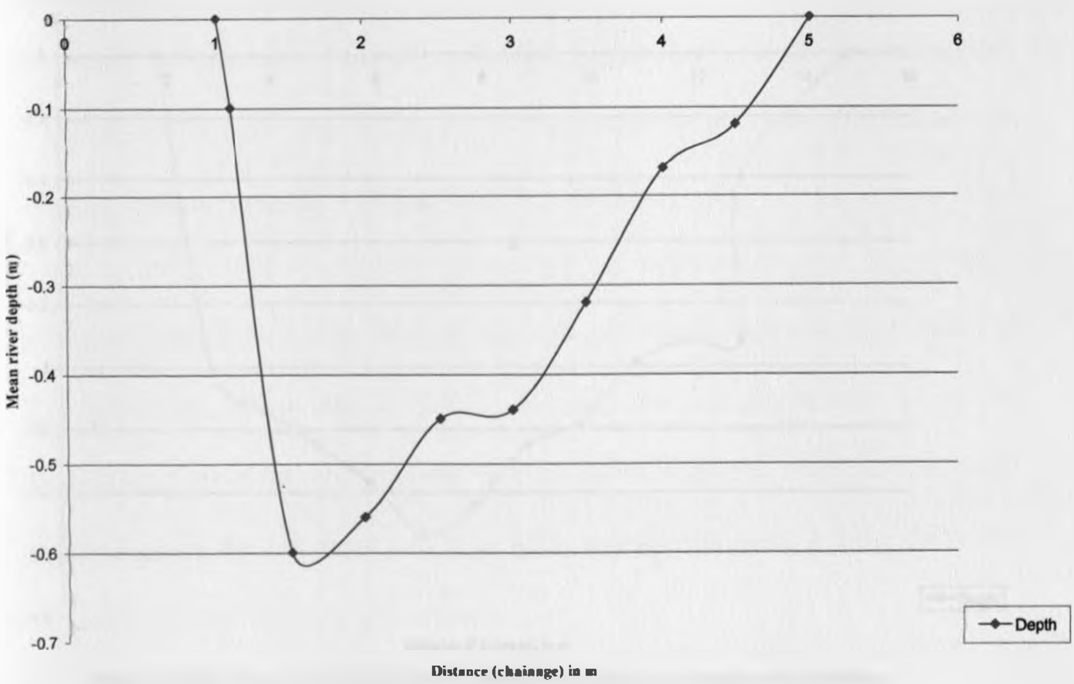


Figure 14: Mean cross-section of Ngong river at Langata rd bridge from right to left river bank

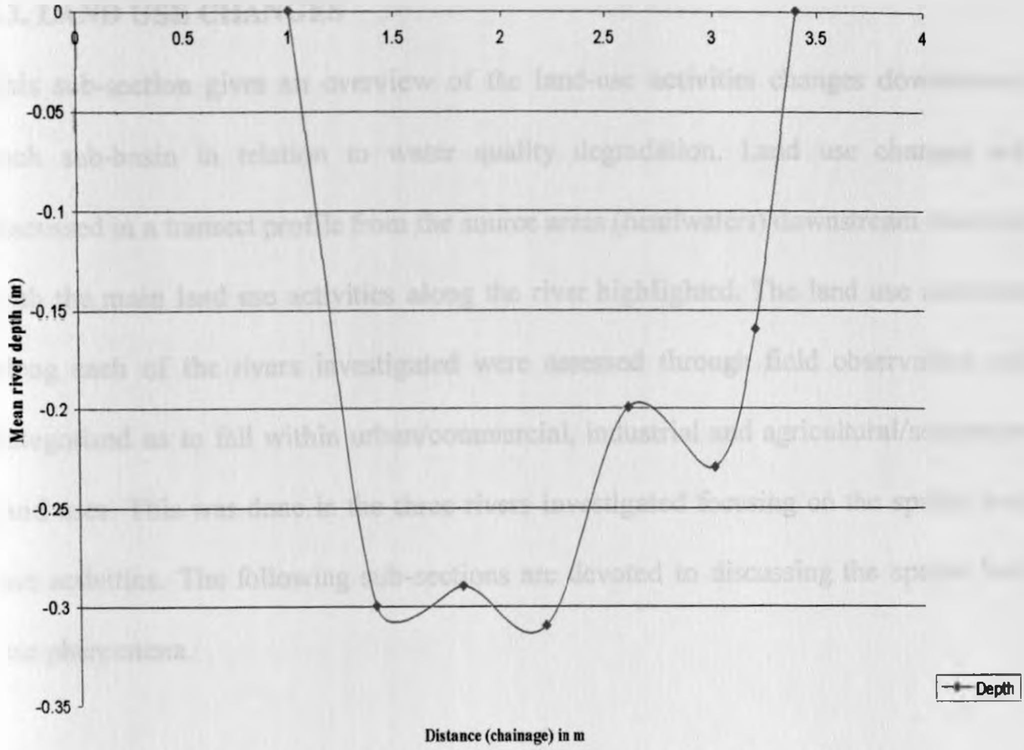


Figure 15: Mean cross-section of Mathare river at Thika rd bridge from left to right river bank

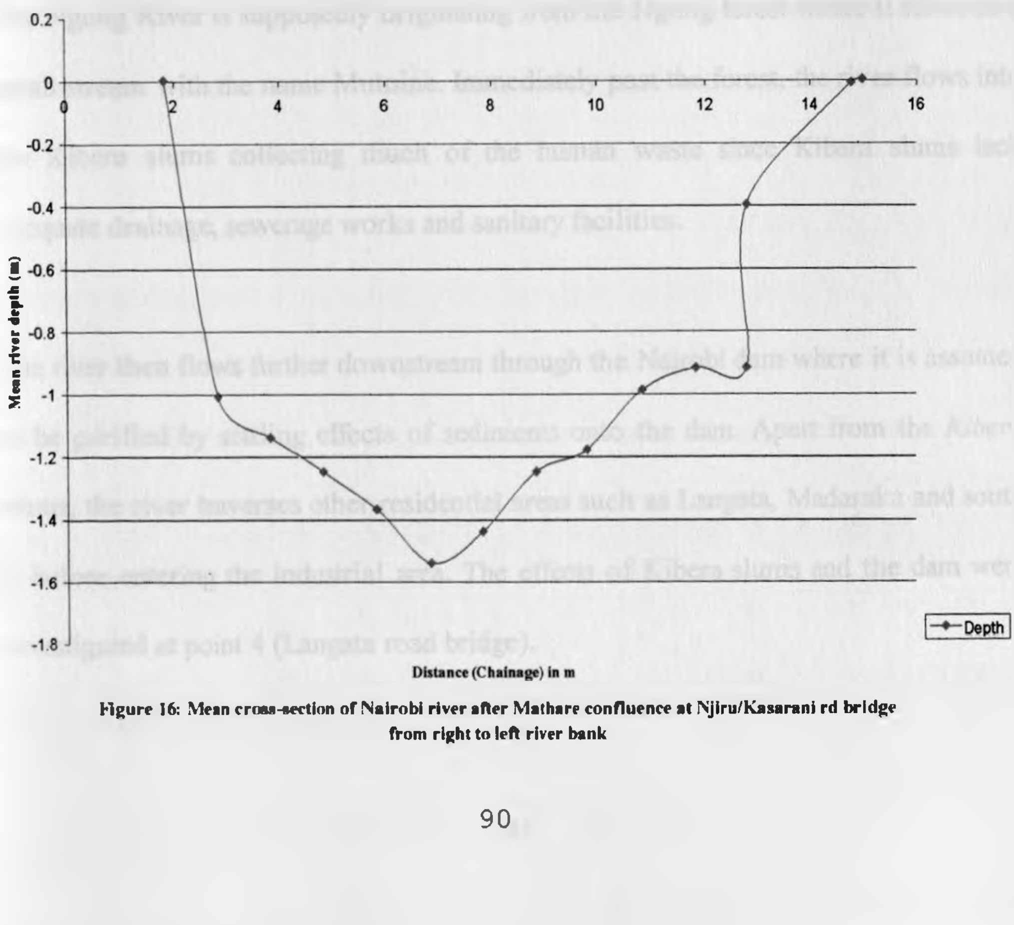


Figure 16: Mean cross-section of Nairobi river after Mathare confluence at Njiru/Kasarani rd bridge from right to left river bank

3.3. LAND USE CHANGES

This sub-section gives an overview of the land-use activities changes downstream each sub-basin in relation to water quality degradation. Land use changes are discussed in a transect profile from the source areas (headwaters) downstream the river with the main land use activities along the river highlighted. The land use activities along each of the rivers investigated were assessed through field observation and categorized as to fall within urban/commercial, industrial and agricultural/settlement land uses. This was done in the three rivers investigated focusing on the spatial land use activities. The following sub-sections are devoted to discussing the spatial land use phenomena.

3.3.1. Land-use Change in Ngong/Mutoine River Sub-basin

The Ngong River is supposedly originating from the Ngong forest where it flows as a small stream with the name Mutoine. Immediately past the forest, the river flows into the Kibera slums collecting much of the human waste since Kibera slums lack adequate drainage, sewerage works and sanitary facilities.

The river then flows further downstream through the Nairobi dam where it is assumed to be purified by settling effects of sediments onto the dam. Apart from the *Kibera* slums, the river traverses other residential areas such as Langata, Madaraka and south C before entering the industrial area. The effects of Kibera slums and the dam were investigated at point 4 (Langata road bridge).

Once the river enters the industrial area, it assumes high water quality degradation levels, sometimes attaining dark-brown colour with an irritating smell. Passing through the industrial areas, it collects waste materials from pulp and paper industries such as Tetra Park, Paint industries such as Glaxo and Crown and other related industries. The effect of industries on the water quality was measured at point 8 (Embakasi road bridge) downstream the industrial areas. In addition to the industrial activities, the river also drains Mukuru, Kaiyaba, Kwa-Jenga and kwa-Reuben slums which lack the necessary drainage and sewerage works. The river then flows relatively over less populated areas until it joints Nairobi River slightly downstream Njiru 1 sampling point as indicated in figure 11.

The effects of these land use activities along the river on the water quality are clearly depicted in table 10 and figure 17 for some water quality parameters. The conclusion is that water in the up-stream areas tends to be polluted with organic pollutants hence the high values of BOD_5 and COD, while in the industrial areas, there is increase in the chemical pollutants, i.e. increased conductivity values and total dissolved solids. There is also an increase in values of the dominant cations such as Na^+, Ca^{++} and K^+ and anions as $Cl^-$and F^- at this point as shown in table 10 and figure 17.

Table 10 : Mean values of water quality parameters along Ngong river profile in mg l^{-1}

Sampling point	Measured water quality parameters														
	Q $m^3 s^{-1}$	BOD_5	COD	TSS	pH	T.AL	COND $\mu\ cm^{-1}$	Ca	Mg	Na	K	Cl	F	TDS	T.H	Tur N.T.U
Ngong F.	0.11	0.4	21	33	6.7	36	134	8	5.3	15	7.1	28	0.6	88	42	23
Langata Rd	0.305	20	83	59	7.7	17	599	28	8.6	59	25	52	0.8	365	104	42
Embakasi	0.949	67	279	160	7.4	214	611	24	7.8	70	16	46	1.1	404	95	71

Source: Field data 1998-2000

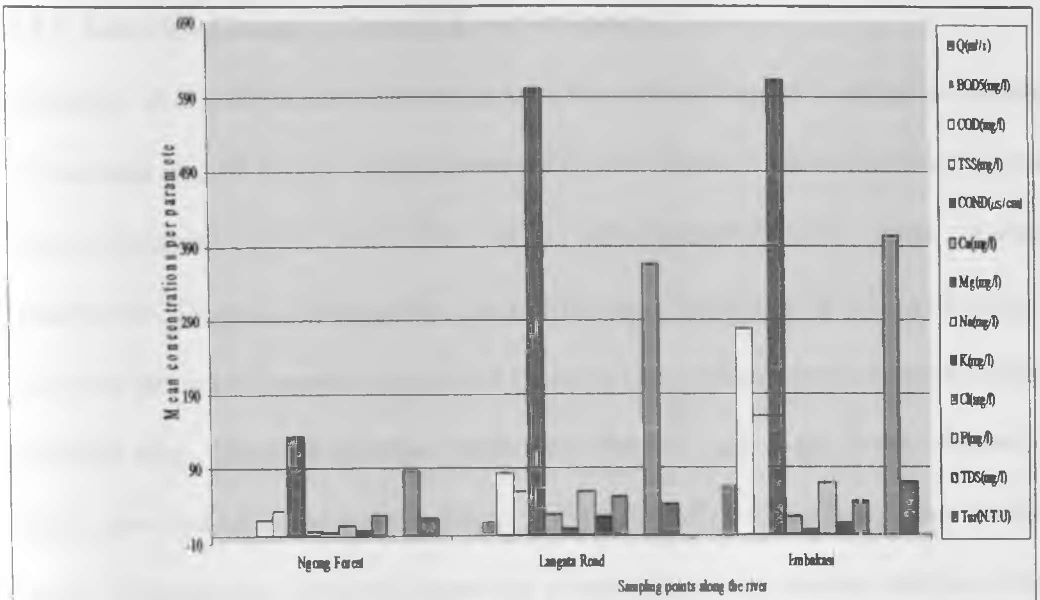


Figure 17: Longitudinal profiles of water quality parameters along the Ngong River transect

<u>**NB**</u>: BOD_5=Biological Oxygen Demand. COD= Chemical Oxygen Demand. TSS=Total Suspended Sediments. COND=Ionic Conductivity, Ca=Calcium. Mg=Magnesium. Na=Sodium. K=Potassium. Cl=Chloride. F=Fluoride. TDS=Total Dissolved Solids. Tur=Turbidity. These water quality parameters apply to Figs. 17, 18 and 19.

The river is less polluted at the source point (Ngong forest) but river water quality degrades downstream through the *Kibera* slums. Nairobi dam and the industrial area. Generally, the water is less polluted in the upstream areas and degrades progressively past the main land use activities which are basically settlements and industrial uses. Nairobi dam acts as sink for most of the pollutants and hence the reason for the low concentration values recorded at Langata Road Bridge downstream the dam. The trend is increasing concentration of the water quality parameters through the industrial areas and further down.

3.3.2. Land use Change in Nairobi River Sub-basin

Generally, this is the largest sub-basin among the three sub-basins investigated holding a total land area of 75 km^2. It drains areas of diverse land use activities, notably in the upper-catchment areas; the river drains agricultural/residential areas (Kikuyu escarpment, Thogoto, Kawangware, Lavington areas). In the middle sub-basin areas, it traverses the urban/commercial areas of the city of Nairobi and some residential slums (Nairobi city, Gikomba/Majengo Slums and Market) and in the lower reaches, it drains low class residential/cum slums viz; Eastleigh, *Kya Maiko* slums and Dandora areas. To monitor the effects of these land use activities in the upstream reaches, water samples were collected at designated points, E.g., in the upper areas, sampling point 2 at Muthangari and sampling point 3 at Museum while the effect of urban/commercial activities and Gikomba-Majengo slums were monitored at sampling point 7 at Outering Road bridge. These sampling points were indicated in figure 11 of the present study.

The results of some water quality parameters along the river course were presented in Table 11 and Figure 18. The overall effect is water quality degradation along the river profile, with the highest degradation effects magnified after Gikomba/Majengo and Eastleigh areas and measured at Outering Road-bridge as indicated in Table 11. Further downstream the Outering Road sampling point there is decrease in concentration of the measured values, a fact attributable to both settling effect and dilution after the river is joined by Mathare River just upstream sampling point 9 (Njiru 1) and Ngong River upstream Njiru 2. The effects of both Ngong and Mathare rivers is an increase in discharge (volume) resulting to the dilution effect and low concentration of pollutant loads. The decrease in concentration at Njiru 2 is also attributable to settling effect and aeration of the water due to widening of the river channel. The water appeared turbid due to increased total suspended sediment loads while conductivity increased in relation to increased total dissolved loads from the metallic ions in the water.

Table 11: Mean values of water quality parameters along Nairobi river profile in mg l^{-1}

Sampling point	Measured water quality parameters														
	Q $m^3 s^{-1}$	BOD_5	COD	TSS	pH	T.AL	COND μ cm^{-1}	Ca	Mg	Na	K	Cl	F	TDS	T.H	Tur N.T.U
Mutha.	0.77	8	62	129	7.5	72	392	18	6.4	43	9	54	0.5	240		
Museum	1.38	19	83	158	7.4	81	397	19	6.4	44	9	56	0.6	244		
Outering	2.14	124	313	255	7.3	175	565	18	8.4	59	16	47	0.8	291		
Njiru 1	5.08	65	262	199	7.2	170	510	17	7.2	47	14	40	0.6	311		
Njiru 2	5.34	41	133	96	7.4	158	475	16	4.4	43	11	29	0.6	297		

Source: Field data 1998-2000, S= Sampling, T.Al=Total Alkalinity, Tur=Turbidity T.H=Total hardness.

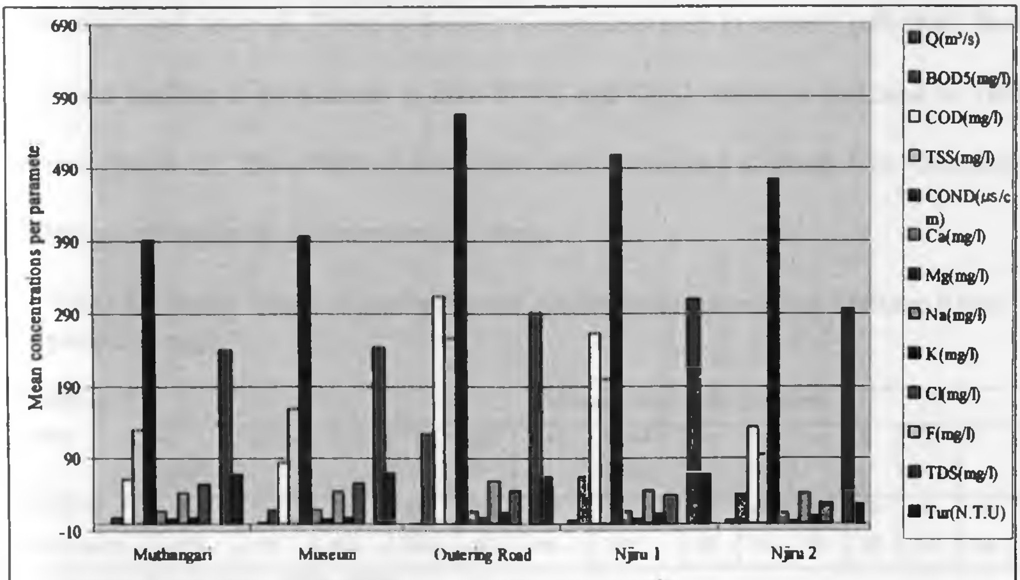


Figure 18: Longitudinal profiles of water quality parameters along Nairobi River transect

Most of the water quality parameters related to leaching of metal ions in water had high measured values as indicated in Figure 18.

3.3.3. Land use change in Mathare river sub-basin

This is the smallest in size of the three sub-basins investigated. The river also tends to traverse basically residential areas such as Westlands, Parklands and Muthaiga before entering into Mathare slums. Generally, the residential areas in the upper zone are well sewered except when bursts occur and therefore the water is relatively of good quality. Their effects were monitored at point 5 (Thika road bridge) before the river enters into Mathare slums. The river is also joined by river Gitathuru immediately behind the Kenya Utalii Training College at the heart of the slums.

Drastic water quality changes are noticeable immediately the river passes through the slums. The Mathare slums just like all other slums in the study area are inadequately drained and sewered. There is therefore, some increase in organic pollutants from the slums leading to an increase in both BOD_5 and COD values as indicated in Table 12 and figure 19. The effect of the slums was monitored at point 6 at Outering road bridge immediately downstream the slums.

Table 12: Mean values of selected water quality parameters along Mathare River profile in mg l^{-1}

Sampling point	Measured water quality parameters											
	Q $m^3 s^{-1}$	BOD_5	COD	TSS	pH	T.AL	COND μ cm^{-1}	Ca	Mg	Na	TDS	T.H
Thika Rd	0.738	37	184	70	7.1	123	352					
Outering Rd	1.371	196	413	251	6.7	184	327					

Source: Field data 1998-2000.

Studies by Newson, 1994, Amuzu, 1997, and Wurbs and James (2002) indicates that increased values of BOD_5 and COD are linked to human settlements and lack of adequate sanitary facilities which discharge human wastes into river courses. This is one major finding of the present study as outlined in the discussions of the research results.

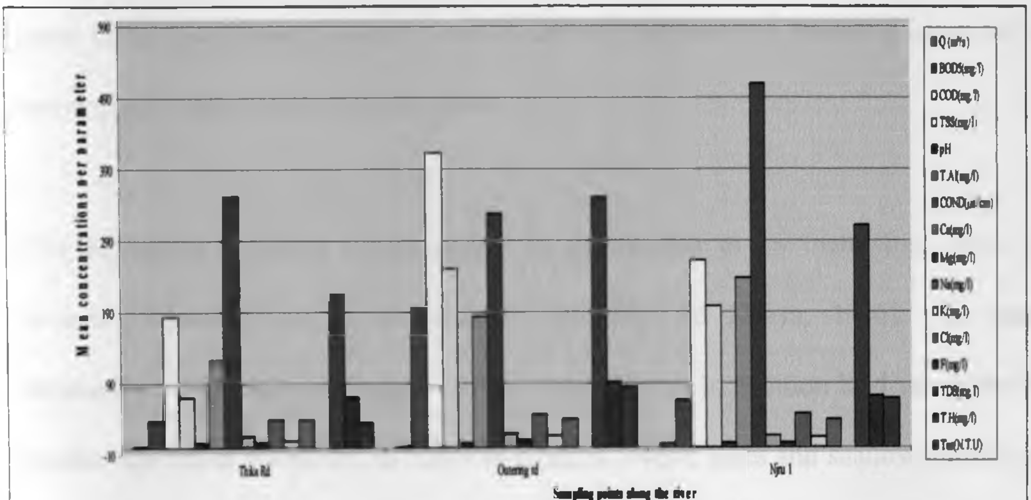


Figure 19: Longitudinal profiles of water quality parameters along Mathare River transect

Generally, it was observed that there was water quality degradation both physically and biologically downstream the river along the river profile due to changes in land use activities. The river flows further downstream to join Nairobi River at Dandora estate where more raw wastes are added into the river leading to further quality degradation as revealed at point 9 Njiru 1. Figure 19 graphically represent the scenario of water quality degradation along the Mathare river profile.

3.3.1.1. Compounded effects of land use change

The compounded effects of land use changes on the water quality along the river profiles investigated were monitored at two sampling points viz-, sampling points 9 and 10 at Njiru 1 and Njiru 2, respectively. Point 9 at Njiru 1 gives the compounded effect of changes in land use activities along rivers; Nairobi and Mathare past the main land use activities analyzed earlier. This is the point immediately after the confluence point of the two rivers. Table 11 and figure 18 illustrate the general picture of the water quality status after the confluence.

The increasing trend in water quality is attributable to an increasing quest for economic development in the country (Republic of Kenya, 1986). The same observation was made by Amuzu (1997) about Ghana. In addition land use activities profoundly affect the quality of water in streams, rivers, lakes and shallow aquifers as indicated by Linsley (1982). Most of the pollutants in the streams investigated are from non-point sources and are linked to land use activities. Kithiia (1992), Kithiia and Ongwenyi (1997), Aketch and Olago (2000), and Mavuti (2003) attributes water quality deterioration to changes in land use activities in the same catchment basin.

Sampling point 10 at Njiru 2 shows the overall effects of changes land use activities on water quality after all the streams have joined. Generally, the quality of water is not as bad compared to areas close to pollutant sources. This is attributed to settling effects of most pollutants (heavy metals and solid wastes), proper aeration effect due to increase in river channel width and dilution effect, in addition to self-purification of the river as the water flows downstream. There is also the effect of riverine vegetation which tends to take up most of the heavy metal leached into the soil in addition to settling effect along the river course/channel.

3.3.1.2. Land use Effect on River Hydrology

The observed change in land use from a more agriculturally based activities in the upper catchment areas to a residential and urban build up areas in the middle reaches results to increased urban storm water and hence floods and reduced infiltration rates (Kithiia 1997, 1998). The general effect of the changes in land use activities on the river hydrology results to increased surface run-off which leads to increased discharge of the rivers. In the three sub-basins investigated, physical water quality parameters increased with discharge downstream the river courses while metallic ions decreased or increased depending on river sub-basin as indicated in Table 13 and, figures 20 and 21.

Table 13: Mean measured values of physical water quality parameters at various sampling points

Sampling point	River	Mean Concentrations				
		Q $m^3 s^{-1}$	TSS mg l^{-1}	COND μcm^{-1}	TDS mg l^{-1}	TUR N.T.U
Muthangari	Nairobi	0.772	157.6	392.1	239.7	69.4
Museum	Nairobi	1.376	129.4	397.7	244.2	69.3
Outering Rd	Nairobi	2.140	255.7	564.5	290.9	65.5
Njiru 1	Nairobi	5.083	199.2	509.5	310.9	67.8
Njiru 2 (10)	Nairobi	5.341	95.5	474.8	298.8	28.5
Thika Rd	Mathare	0.738	161	352.2	215.5	35
Outering Rd	Mathare	1.371	251.2	527.1	349.9	85
Kibera slums	Ngong	0.110	164	233	88	98
Langata Rd	Ngong	0.305	59	598.8	59	42
Embakasi	Ngong	0.949	180	611.7	174.4	71

Source: Field data 1998-2000; COND=Electric conductivity, TDS=Total dissolved solids, TSS=Total suspended sediments, TUR=Turbidity.

The general trend is that there is increase in total suspended sediments with increase in river volume (Discharge) and consequently water turbidity. In cases of the reverse, it is due to river widening in channel size and therefore more settling or deposition of the sediments. Away from the main land use activities water in the streams was found to be less polluted both physically and chemically. A graphical representation of the relationship between river flow variations and water quality degradation illustrates this fact. This is well exhibited by Figures 20, 21 and 22 which indicate a close relationship between Total Dissolved Solids (TDS) with Conductivity on Ngong River at Embakasi sampling point. A computed correlation coefficient of determination (R^2) of 98% is a clear test to that fact as indicated by figure 22 in section 3.4.2.

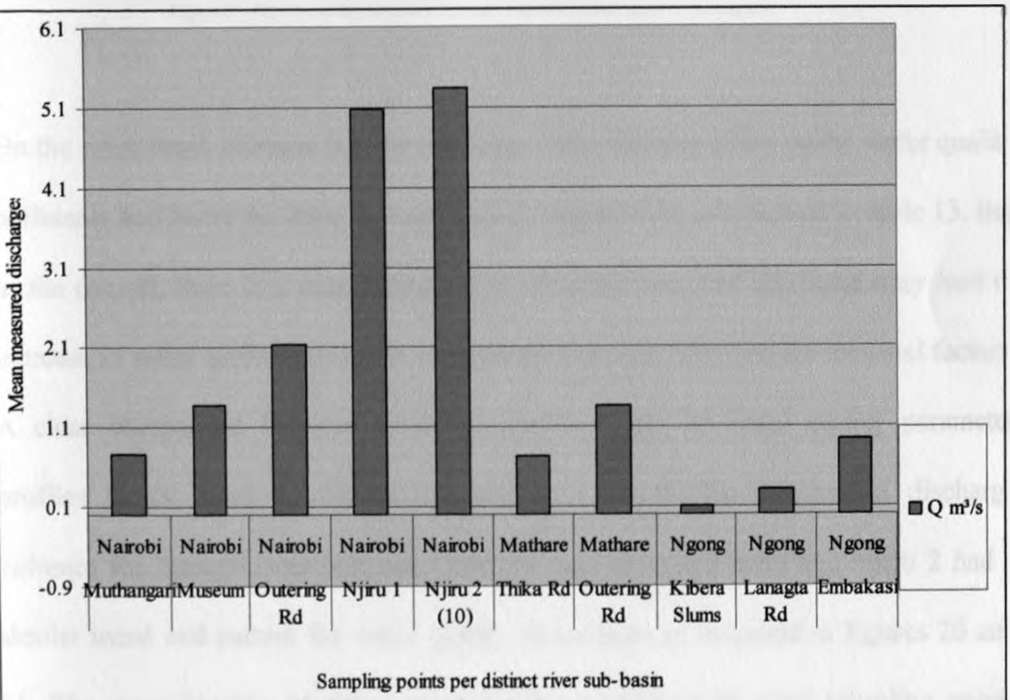


Figure 20: Variations in River discharge (Q) along each of the river sub-basins

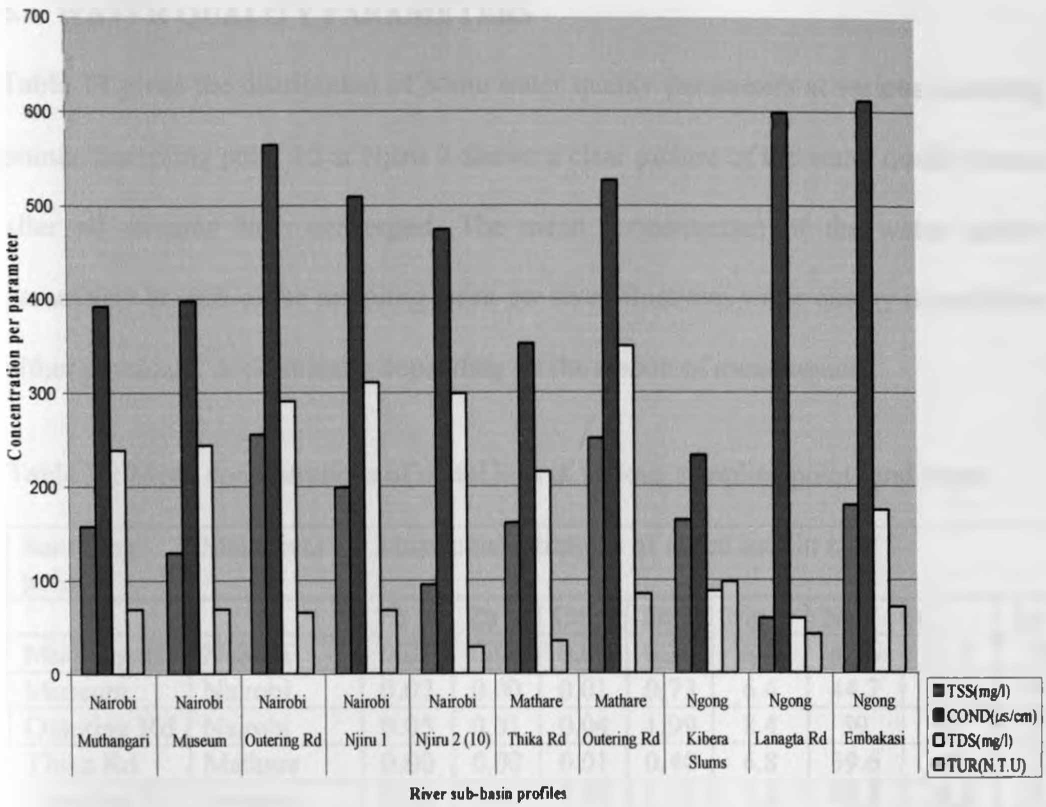


Figure 21: Downstream variation of some physical water quality parameters

On the other hand, increase in river discharge had a diluting effect on the water quality pollutants and hence decrease in water quality degradation as indicated in table 13. But in the overall, there is a magnifying effect whereby increased discharge may lead to increase in water quality pollutants in concentration depending on the seasonal factors. A close comparison between discharge profiles with the water quality parameter profiles in the three sub-basins investigated revealed that increase in discharge volumes for Nairobi river between Outering road sampling point and Njiru 2 had a similar trend and pattern for water quality parameters as indicated in figures 20 and 21. The mass loading of some water quality parameters in some sampling points testify to this fact as indicated in Tables 17, 18 and 19 in section 3.4.1.

3.4. WATER QUALITY PARAMETERS

Table 14 gives the distribution of some water quality parameters at various sampling points. Sampling point 10 at Njiru 2 shows a clear picture of the water quality status after all streams have converged. The mean concentration of the water quality parameters at each of the sampling point per river illustrates water quality degradation either physically or chemically depending on the season of measurement.

Table 14: Mean concentrations of metal ions at various sampling points and rivers

Sampling point	Main river	Mean concentrations of metal ions in mg l^{-1}							
		Pb	Zn	Cu	Fe	Mg	Na	Cl	Ca
Muthangari	Nairobi	0.01	0.00	0.00	0.30	6.4	42.6	53.7	18
Museum	Nairobi	0.02	0.00	0.01	0.73	6.4	44.7	55.5	19.3
Outering Rd	Nairobi	0.05	0.01	0.04	1.99	8.4	59	47	17.9
Thika Rd	Mathare	0.00	0.00	0.01	0.40	6.8	39.6	40	17.1
Outering Rd	Mathare	0.01	0.01	0.02	1.59	9.6	45.8	38.8	19.6
Langata Rd	Ngong	0.05	0.00	0.01	1.10	8.6	58.5	52	27.6
Embakasi	Ngong	0.07	0.02	0.15	1.30	7.8	69.5	46	24.3
Njiru 1	Nairobi	0.04	0.02	0.18	1.44	7.2	46.6	39.5	17.1
Njiru 2 (10)	Nairobi	0.03	0.03	0.20	1.17	4.4	42.5	29	16.4
Donyo Sabuk	Athi (middle)	0.00	0.00	0.00	0.30	4.4	28.8	8.0	10.1
Malindi	Athi/Sabaki (Coast)	ND	ND	ND	ND	29.1	118.8	19.1	21.4

Source: Field data (1998-2000), ND- not detected

Table 14 demonstrates the fact that there is an increasing trend in the major metallic ions, possibly due to the effect of leaching from the rocks or as a result of effluent discharges into the river courses. Major changes were more significant at the downstream sampling point of the individual stream before its confluence. However, drastic reductions in metallic ions concentrations were noticed at the last sampling point (Njiru 2) which is attributable to the increase in river discharge (volume) contributing to a significant dilution and sedimentation effect. This is true further downstream at Ol Donyo Sabuk where other streams such as Gitathuru, Ruaka, Kamiti and Ruiru have joined the river to form the main Athi River. At the mouth of the river (Malindi) the same trend emerges with lowest recorded mean concentrations of metal ions. This is partly attributed to increased discharge and hence increased leachage from the rocks/ geology and the fact that water is physically polluted with increased TDS and TSS with values of 566.5 mg l^{-1} and 456.5 mg l^{-1}, respectively. The main river (Athi) is, in addition, joined by the Tsavo and Mzima springs all originating from dominant volcanic geological environments. The fact that the river flows through a more arid environment leads to increased precipitation of major ions in the water due to high rates of evaporation. The soils are more susceptible to erosion and hence more sediment load yields.

Table 15: Variability of toxic substances (Parameters) at different stations and river basins (mgl^{-1})

Parameter	Mean Concentrations per river station before confluence after major land use activities				
	Nairobi at Outering Rd	Mathare at Outering Rd	Ngong at Embakasi	Nairobi at Njiru 1	Nairobi at Njiru 2
Iron	1.99	1.59	1.3	1.44	0.60
Magnesium	8.4	9.6	7.8	7.2	4.4
Sodium	59	45.8	69.5	46.6	42.5
Chloride	47	38.8	46.3	39.5	29
Fluoride	0.8	0.6	1.1	0.6	1.17

Source: Field data (1998-2000)

Generally, Ngong River exhibits high concentrations of toxic substances at Embakasi sampling point which is downstream the industrial activities in the country.

This is followed by Nairobi River at Outering road which is the point immediately after the effects of urban activities of the city centre and the Gikomba open air market. The recorded values are far more than the limits for toxic substances in drinking water according to the Kenya Standards for drinking water quality as indicated in Table 16.

Table 16: Limits for toxic substances in drinking water (Kenya standards for drinking water quality) compared to measured values at various sampling points per river

Substance	Upper limit of concentration in mg/l	Ngong at Embakasi	Nairobi at Outering Rd	Mathare at Outering Rd	Nairobi at Njiru 1	Nairobi at Njiru 2
Lead as Pb	0.05	0.07	0.05	0.01	0.04	0.03
Mercury (total as Hg)	0.001	0.01	0.01	ND	ND	ND
Copper as Cu	1.0	0.15	0.04	0.02	0.18	0.02
Zinc as Zn	5.0	0.02	0.01	0.01	0.02	0.03
Iron as Fe	0.3	1.3	1.99	1.59	1.44	0.60
Magnesium as Mg	0.1	7.8	8.4	9.6	7.2	4.4
Fluoride as F	1.5	1.1	0.8	0.6	0.6	0.6

Source: Kenya Bureau of Standards (KBS), Standard no. KS 05-451, 1985, Field data

3.4.1. Mass Loadings

The results of water quality presented in mass loadings gave an in-depth status of water quality in the streams investigated and its variation over time. The implication of the results is that, the streams are heavily polluted and the water can pose a danger to human health when used for domestic purposes or even to irrigate crops over a long period of time. There is a possibility of bio-magnification of the pollutants in the riparian vegetation analysed. It is, however, important to note that, in most events, continuous analytical measurement is not practicable. Exceptions may be temperature, conductivity, and pH and dissolved oxygen, if appropriate instrumentation is available. These were simultaneously measured with river discharges in the field. Instrumentation exists also which permits flow-proportional sample integration over limit time periods (Jorgensen and Vollenweider, 1988). Often, however, such equipment is not available as was the case with the present study. Therefore, load estimates had to be calculated from the relationship between intermittent concentration and concomitant water flow measurements (Q) and continuous water discharge measurements. Calculations had to be made separately for each sub-basin of the catchment basin investigated namely; Ngong, Nairobi and Mathare rivers and at each sampling station.

There are many procedures applied in the calculation of mass loads according to Jorgensen and Vollenweider (1988) and Sharma (1993). However, in the present study, total load calculation over time was computed using mean values of concentration (mg l^{-1}) and flow (m^3 s^{-1}).

This procedure provided first approximation and reasonably correct, for sites of relatively constant flow and concentration. This was the assumption in all the river basins and sampling points. The procedure was used to compute mass loadings in the three river systems investigated in the present study. The results and discussions were therefore presented in Tables 17, 18 and 19.

Table 17: Mean mass loadings of selected water quality parameters for Ngong River at Langata and Embakasi sampling points

Water quality variables	Unit	Mass Loadings in tonnes/day and tonnes per year					
		Langata Q=0.315m^3 s^{-1}			Embakasi Q=0.953m^3 s^{-1}		
		Mean	Mass Loads		Mean	Mass Loads	
			t day^{-1}	t yr^{-1}		t day^{-1}	t yr^{-1}
BOD_5	Mg l^{-1}	17.89	0.16	56.79	59.46	1.60	571.06
COD	Mg l^{-1}	88.43	0.78	280.72	266.15	7.10	2556.12
TSS	Mg l^{-1}	59.23	0.52	188.02	180.46	4.81	1733.15
T.Alk	Mg l^{-1}	162.27	1.43	515.12	198.69	5.30	1908.23
COND	μ cm^{-1}	610.27	5.38	1937.29	605.92	16.16	5819.28
Ca	Mg l^{-1}	27.57	0.24	87.52	24.34	0.65	233.76
Mg	Mg l^{-1}	8.59	0.08	27.27	7.83	0.21	75.20
Na	Mg l^{-1}	58.50	0.52	185.71	69.46	1.85	667.10
K	Mg l^{-1}	25.34	0.22	80.44	15.56	0.42	149.44
Cl	Mg l^{-1}	52.33	0.46	166.12	46.31	1.24	444.76
F	Mg l^{-1}	0.83	0.01	2.63	1.13	0.03	10.85
TDS	Mg l^{-1}	370.73	3.27	1176.87	375.38	10.01	3605.17
Turb	N.T.U	41.80	0.37	132.69	71.38	1.90	685.54

Source: Field data (1998-2002)

In general, for the same mass of pollutant, a small volume of water means high pollutant concentration and for a high volume of water this means less pollutant concentration. Then, if the pollution is from a point-source, then, as the pollutant goes downstream, then, the concentration is bound to reduce due to increased volume of water and sedimentation effect. Table 17 revealed a mean increase of some water quality parameters concentration and decrease for others with increase in river water flow (Q). The increase is from Langata to Embakasi along the river course profile. In the same table, mass loads of the total load concentration of physical water quality parameters and metallic ions showed the same trend. e.g., TSS had a daily mass load of 0.52 t day^{-1} at Langata Road Bridge and 4.81t day^{-1} at Embakasi sampling point while for Calcium, Magnesium and Fluoride ions decreased with increasing river flow volumes due to dilution and sedimentation effects.

Table 18: Mean mass loadings of selected water quality parameters for Nairobi River at Museum, Outering road and Njiru 1 sampling points

Water quality variable	Unit	Mass Loadings in t day^{-1} and t $year^{-1}$								
		Museum Q=1.38 m^3 s^{-1}			Outering Q=2.10 m^3 s^{-1}			Njiru 1 Q=5.08 m^3 s^{-1}		
		Mean	Mass loads		Mean	Mass loads		Mean	Mass loads	
			t day^{-1}	t yr^{-1}		t day^{-1}	t yr^{-1}		t day^{-1}	t yr^{-1}
BOD_5	Mg l^{-1}	6.92	0.27	96.24	143.25	8.42	3031.62	82.78	11.77	4237.90
COD	Mg l^{-1}	55.37	2.14	770.04	301.30	17.71	6376.46	253.11	35.99	12957.9
TSS	Mg l^{-1}	115.85	4.48	1611.15	298.50	17.54	6317.20	244.56	34.78	12520.2
T.Alk	Mg l^{-1}	70.00	2.70	973.51	179.60	10.56	3800.90	163.78	23.29	8384.67
COND	μ cm^{-1}	388.46	15.0	5402.40	558.20	32.81	11813.3	459.00	65.27	23498.4
Ca	Mg l^{-1}	19.26	0.74	267.85	17.90	1.05	378.82	17.07	2.43	873.89
Mg	Mg l^{-1}	6.42	0.25	89.28	8.37	0.49	177.14	7.18	1.02	367.58
Na	Mg l^{-1}	44.69	1.73	621.51	59.00	3.47	1248.63	46.56	6.62	2383.63
K	Mg l^{-1}	9.18	0.35	127.67	16.70	0.98	353.42	14.24	2.03	729.01
Cl	Mg l^{-1}	55.46	2.14	771.29	47.00	2.76	994.67	39.56	5.63	2025.26
F	Mg l^{-1}	1.03	0.04	14.32	0.80	0.05	16.93	0.57	0.08	29.18
TDS	Mg l^{-1}	237.69	9.18	3305.61	337.50	19.84	7142.57	282.33	40.15	14453.8
Turb	N.T.U	69.31	2.68	963.91	65.50	3.85	1386.19	67.78	9.64	3469.98

Source: Field data (1998-2002)

Generally, Table 18 illustrates a downstream increase in the concentration of the various water quality parameters along the river profile. This appears to correspond well with the increase in the river discharge downstream the river from Museum through outering rd to Njiru 1 sampling points. The mean recorded discharges were 1.38 m^3 s^{-1}, 2.10m^3 s^{-1} and 5.08 m^3 s^{-1} for Museum, Outering and Njiru 1, respectively. The total mass loadings of the water quality parameters followed the same trend in the three sampling stations.

The implication of this is that measuring the concentrations in tonnes per day and tonnes per year, a clear picture emerge showing that water quality deteriorates with increased discharge and over time. Thus, water that appears clean or less polluted may be highly polluted if evaluated in terms of tonnes per year. If the same water is therefore used over a long period of time it may cause serious health problems due to the effects of biological magnification in food chain. This was found to be quite significant in plant tissues sampled along the river courses.

Table 19: Mean mass loadings of selected water quality parameters for Mathare River at Thika road and Outering road sampling points

Water quality variables	Unit	Mass Loadings in tonnes/day and tonnes per year					
		Thika road Q=0.735 $m^3 s^{-1}$			Outering Q=1.24 $m^3 s^{-1}$		
		Mean	Mass Loadings		Mean	Mass Loadings	
			t day^{-1}	t yr^{-1}		t day^{-1}	t yr^{-1}
BOD_5	Mg l^{-1}	34.85	0.72	258.14	195.75	6.79	2446.16
COD	Mg l^{-1}	181.55	3.74	1344.76	662.33	22.99	8276.70
TSS	Mg l^{-1}	161.27	3.32	1194.54	239.00	8.30	2986.63
T.Alk	Mg l^{-1}	113.82	2.34	843.08	171.50	5.95	2143.12
COND	µ cm^{-1}	352.55	7.25	2611.38	500.83	17.38	6258.54
Ca	Mg l^{-1}	17.15	0.35	127.03	19.60	0.68	428.62
Mg	Mg l^{-1}	6.80	0.14	50.37	9.63	0.33	118.80
Na	Mg l^{-1}	39.63	0.82	293.62	45.75	1.59	571.71
K	Mg l^{-1}	9.51	0.20	70.44	15.52	0.54	193.94
Cl	Mg l^{-1}	40.18	0.83	297.62	38.83	1.35	485.23
F	Mg l^{-1}	0.58	0.01	4.30	0.59	0.02	7.37
TDS	Mg l^{-1}	215.18	4.43	1593.86	307.67	10.68	3844.75
Turb	N.T.U	35.00	0.72	259.25	85.17	2.96	1064.31

Source: Field data (1998-2002).

Table 19 demonstrates increasing trend in the concentration of the various measured water quality parameters in the two stations. The total mass loadings calculated in the sampling points appeared to indicate an increase in the mass load concentrations. e.g., TSS and TDS concentration significantly increased with discharge. Their values too were quite high when measured in a yearly concentration as tonnes per year.

Linsley (1982) contends that the over-all effect of non-point source pollution on water quality is best expressed as 'total pollutant mass loading', the product of concentration (mg l^{-1}) and flow (m^3 s^{-1}). This was found useful in revealing the levels and trends of water quality deterioration in the three streams investigated.

In conclusion, Tables 17, 18 and 19 demonstrated an enormous increase in the concentration of the various water quality parameters in terms of mass loadings. The general implication of this is an increasing trend in water quality degradation downstream the river system profiles. Thus, the water resource becomes less useful downstream the main land use activities for any purposeful human use. This means that any intended use of the waters in these sub-systems must consider carefully the quality of the water to avoid transfer of any harmful effects to humans hence affecting the human health with dire consequences.

Figures 20 and 21 indicated that increase in discharge results to decreased water quality degradation chemically and biologically as shown by low values both of TDS, Conductivity and BOD_5 and COD, respectively. Physically, the water is highly polluted as shown by the high values of TSS and Turbidity. In other relevant studies, Amuzu (1997) observed that, rivers passing through heavily populated sections of a city receive discharges of domestic effluent which cause gross pollution and thus depleting the available oxygen (DO) and increasing values of BOD_5 and COD. This confirms the scenario found in the streams investigated, especially in areas of informal settlements (Slums).

3.4.2. Effects of Storm water on Water Quality

Generally, the effect of storm water to reduce the water quality degradation status depending on the land use activities and the river flow energies generated after heavy storm events diluted the water chemically if the river flow volumes are high and get polluted with the excessive hard dump wastes which is in abundance in the riverine system during the dry periods. Plates 2, 4, 6, 7 and 8 demonstrate that water in the Nairobi River can be cleaned through storm water incidents, especially after heavy storms and if further dumping of solid wastes along the river banks is stopped or discontinued through proper environment education programmes or by legal means. A cross-sectional investigation of Nairobi River indicates some areas that are heavily polluted with solid wastes before the rains and after the rains. Plates 1, 3 and 5 of the same river at Globe Cinema round about, Gikomba bridge at Machakos country Bus and Gikomba bridge downstream Gikomba open air Market or Shauri Moyo bridge. The same points are clearly cleaned by storm water run-off after heavy storms in the upper-catchment areas as indicated in plates 2, 4, 6 and 7 of the same points, respectively. Plate 1 shows a section of the river highly polluted with solid wastes and other materials and Plate 2 shows the same section after a heavy storm wash off. The water only appears coloured and conforms to the WHO standards (1993 and 1995) showing high turbidity and TSS values. In over-all, the Nairobi river appears clearly cleaned off solid wastes at Njiru 2 (10) after a heavy storm (wet season). Thus increase in discharge volumes results to increased sediment loads as indicated in figure 21. The importance of river discharge in the clean up of the waters in the three streams investigated was well demonstrated by figure 22, 23 and 24 of regression results.

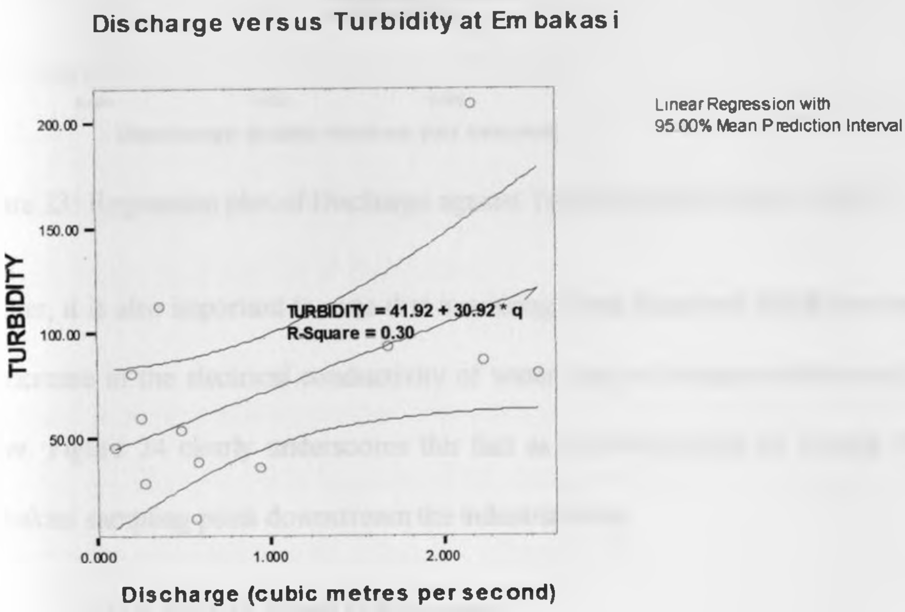


Figure 22: Relationship between River flow (Q) and Turbidity along Ngong River

Figure 22 illustrates that increase in discharge leads to an increase in turbidity which is a product of suspended sediments in water and hence increased sediment loads. However, increase in discharge has a dilution effect on the water quality parameters such as Total Dissolved Solids (TDS) and Conductivity which is the concentration of dissolved ions in water. Figure 23 explores the fact that an increase in discharge results to a decrease in Total Dissolved Solids which is attributable to the diluting effect of water during the wet season or the peak flow periods.

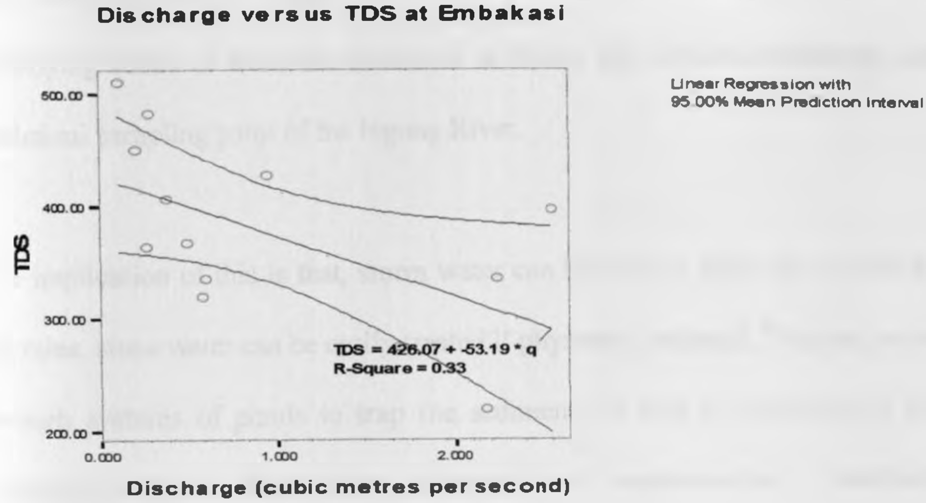


Figure 23: Regression plot of Discharge against Total Dissolved Solids (TDS)

Further, it is also important to note that increasing Total Dissolved Solids may result to an increase in the electrical conductivity of water due to increase in dissolved ions in water. Figure 24 clearly underscores this fact as observed along the Ngong River at Embakasi sampling point downstream the industrial area.

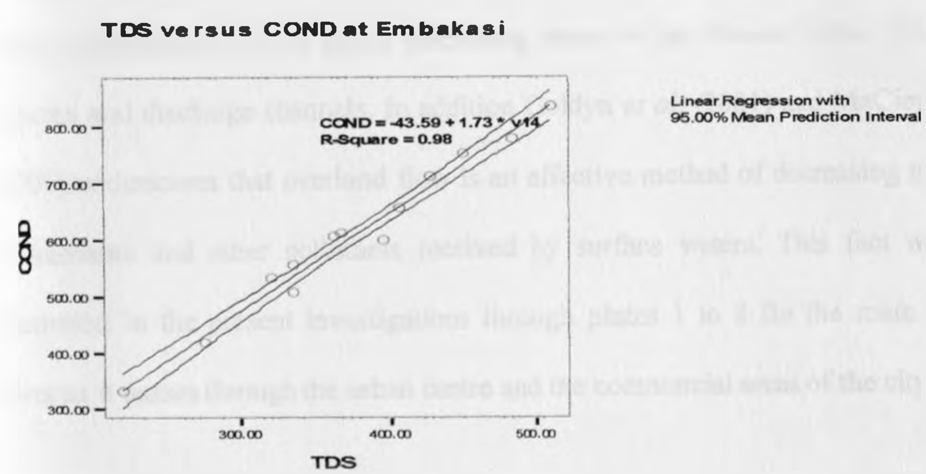


Figure 24: Relationship of Total Dissolved Solids against Conductivity in Ngong River at Embakasi Sampling point

The scenario shown by Figure 24 can be attributed to mineral leachates from the underlying rocks or from the industrial activities and effluent discharges upstream Embakasi sampling point of the Ngong River.

The implication of this is that, storm water can be used to clean up the rivers during the rains, since water can be easily treated if physically polluted. This can be achieved through systems of ponds to trap the sediments or use of convectional treatment methods such as flocculation, filtration and sedimentation. Construction of engineering water falls along the river courses may prove useful in improving the oxygen content and aeration of the waters.

The use of storm water to reduce concentrations of heavy metals and other pollutants were recommended in EPA Manuals (EPA, 1986, 1992), while Kithiia and Ongwenyi (1997) recommended use of Integrated Management Plan (IMP) to mitigate water quality degradation in the upper catchment areas of the Nairobi River by use of lagoons and discharge channels. In addition Goldyn *et al.* (2001) and MaCiey *et a.l* , (2001) underscores that overland flow is an effective method of decreasing the loads of nutrients and other pollutants received by surface waters. This fact was well illustrated in the present investigations through plates 1 to 8 for the main Nairobi River as it passes through the urban centre and the commercial areas of the city.

Plate 1: Globe Cinema round about before heavy storm (dry season)- notice heaps of garbage and solid wastes on the river channel and banks.

Plate 2: Globe Cinema round about near the bridge after heavy storm (Wet season)- heaps of garbage/solid wastes washed by storm water but water is turbid

Plate 3: Mchakos country bus bridge at Wonderful inn Kiosk (dry season)-notice heaps of garbage and solid wastes near a Kiosk with a street hutchin

Plate 4: Machakos country Bus Bridge at the Wonderful inn kiosk (Wet season) notice-a food kiosk flooded and part of the garbage washed away after a heavy storm but appears turbid due to increased total suspended solids (TSS).

Plate 5: Gikomba-Shauri Moyo Bridge D/S Gikomba open air market-showing decomposing heap of raw garbage on the river bank.

Plate 6: Gikomba-Shauri Moyo Bridge D/S Gikomba open air market-solid wastes, car shell and Jua-kali garages in the foreground.

Plate 7: Gikomba-Shauri Moyo Bridge D/S Gikomba open air market –showing "clean" river bank with all garbage and solid wastes washed away after a heavy rain storm.

Plate 8: Nairobi River downstream Njiru 1 and Njiru 2 after heavy rainfall storm-notice "clean" river banks and no traces of solid wastes/garbage except turbid water.

3.4.3. Effects of River Sediments on Water Quality

River sediments were sampled for heavy metal analysis to enable the researcher be able to determine concentration points of heavy metals. The heavy metal concentrations in water samples and river sediments were compared. The results indicated river sediments had more (higher levels) of heavy metal concentrations compared to water as indicated in table 20. This can be attributed to heavy metal settling and deposition on the sediments as well as leachage of metal ions into the soils. Water has some dilution effects and hence the low heavy metal concentration in water samples. The implication is that sediments can be used to clean up water off heavy metals through metal adsorption. Thus, sedimentation can be a useful tool in cleaning up the rivers under investigation. Pomogyi *et al.* (1984) indicated that, macrophytes in aquatic ecosystems form a link between the sediments and the overlying water. However, river sediments may act as media for heavy metal contamination (Jolankai, 1992) and thus metal leachates may cause water pollution depending on their concentration in water. Mwamburi (2003) found increasing trends of heavy metals in sediments of rivers in the Lake Victoria basin although not alarming and recommends their use in restoring water quality in the rivers and the Lake itself.

Table 20: Mean heavy metal concentrations in water and river sediment samples

Water quality constituents (mg l^{-1})	River sediments (mg kg^{-1})	Water samples (mg l^{-1})	WHO Values (mg l^{-1}) (Threshold values)
Zinc (Zn)	700	0.04	5.0
Lead (Pb)	51	0.10	0.05
Nickel (Ni)	0.34	0.01	0.2
Copper (Cu)	11.4	0.11	1.0
Mercury (Hg)	0.1	0.01	0.001
Cadmium (Cd)	2.7	0.01	0.005
Iron (Fe)	%16	4.11	0.3
Chromium (Cr)	0.27	0.010	0.05

Source: Field data, (1998-2000) and WHO (1993, 1995).

3.4.4. Effects of Riverine Vegetation on Water Quality

Samples of riverine vegetation were collected at the various sampling points in the study area. The plant species sampled were those growing at a close proximity from the river water on either side of the river banks. The affinity of the plant species to grow towards the river water or on the swampy or river pond areas was also considered in picking the plant species. The concentration values in the plant species and rivers are illustrated in Tables 21, 22 and 23 for Ngong, Nairobi and Mathare rivers, respectively.

Table 21: Mean Concentration Values in Selected Plant Species along Ngong River Profile.

Sampling point	Plant Spp.	Mean Measured Heavy Metal Concentrations (mg l^{-1})-ppm or $\mu g\ g^{-1}$					
		Pb	Cu	Zn	Cd	Cr	Ni
Langata Rd	1	0.19	0.18	0.31	0.12	0.14	0.25
	2	0.09	0.14	0.32	0.14	0.12	0.17
	3	0.12	0.21	0.32	0.13	0.18	0.22
	4	0.14	0.26	0.45	0.15	0.16	0.17
Embakasi D/S Industrial area	1	0.21	0.24	0.32	0.17	0.15	0.25
	2	0.13	0.26	0.38	0.16	0.13	0.20
	3	0.15	0.17	0.21	0.12	0.16	0.14
	4	0.17	0.37	0.48	0.18	0.20	0.21

Source: Field data 1998-2001, Spp.=Species, 1=*Sphaeranthus napirae*, 2=*Commelina benghalensis*, 3=*Pennisetum purpureum*(Napier grass), and 4=*Xanthium pungens*

Table 21 indicates high values of Zinc metal concentration in all the selected plant species. However, some of the species had specific uptake of certain metals and therefore their concentration varied with the specific plant species. Species 1 (*Sphaeranthus napirae*) had a high uptake of both Lead and Nickel at the Embakasi sampling point downstream the industrial area, while high values of Zinc and Copper were detected in two sampling points across the Ngong river profile. There was an increase in heavy concentration for plant species 1, 2 and 4 but a decrease in species 3 for Zinc, Cadmium, Chromium and Nickel probably due to settling effects and dilution at both Langata and Embakasi sampling points.

Figure 25 strongly emphases the fact that concentrations of Zinc as detected in tissue sections of plant species along Ngong River were high in all the plant species and sampling points. This was followed by Copper, Nickel and Chromium in that order. Low concentration values of Lead and Cadmium were detected similarly in all the plant species conforming to the results presented in Table 21.

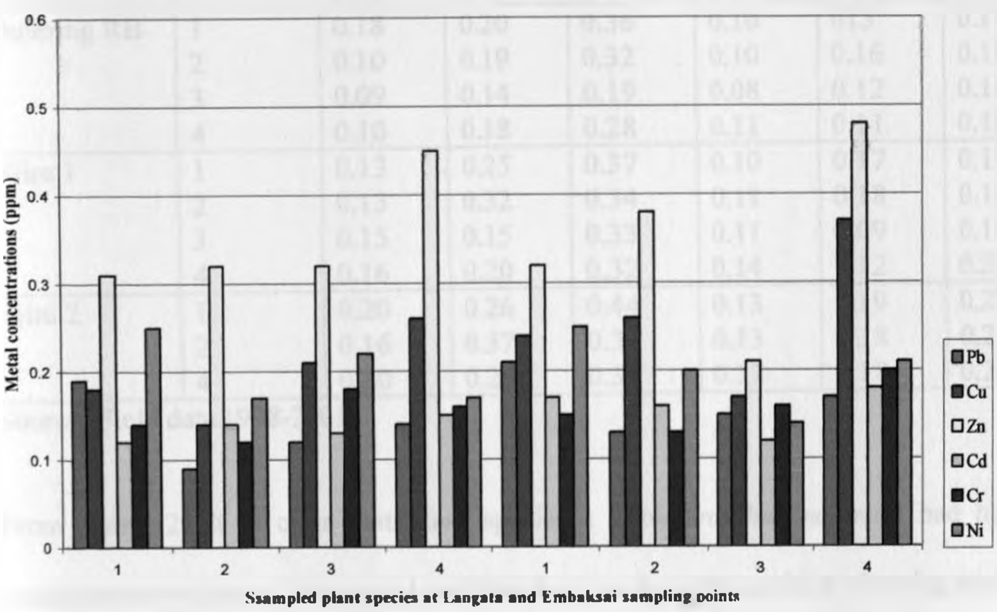


Figure 25: Mean concentrations of heavy metals in plant species along Ngong River

Table 22 show the distribution of heavy metal concentration per species at the various sampling points along the Nairobi River. This gives possible heavy metal pollutant sources. At sampling points Njiru 1 and Njiru 2 high levels of Copper, Cadmium, Chromium and Nickel metals were detected as opposed to sampling points Muthangari (1) and Museum (3) in the upstream reaches indicating increasing trends in the heavy metal pollution. The river passes through an area of heavy medium scale industries dealing with light industrial production like metal plating, battery charging and paint production (*Kariobangi* area).

Table 22: Mean concentration values in selected plant species along Nairobi River.

Sampling point	Plant Spp.	Measured heavy metal concentrations (($mg\ l^{-1}$) –ppm or $\mu g\ g^{-1}$					
		Pb	Cu	Zn	Cd	Cr	Ni
Muthangari	1	0.13	0.13	0.34	0.08	0.10	0.10
	2	0.10	0.14	0.31	0.08	0.10	0.11
	3	0.19	0.14	0.22	0.10	ND	0.12
	4	0.10	0.17	0.21	0.10	0.10	0.12
Museum	1	0.16	0.16	0.35	0.09	0.13	0.14
Outering RB	1	0.18	0.20	0.36	0.10	015	0.15
	2	0.10	0.19	0.32	0.10	0.16	0.13
	3	0.09	0.14	0.19	0.08	0.12	0.13
	4	0.10	0.18	0.28	0.11	0.11	0.18
Njiru 1	1	0.13	0.25	0.37	0.10	0.17	0.17
	2	0.13	0.32	0.34	0.11	0.18	0.14
	3	0.15	0.15	0.33	0.11	0.09	0.15
	4	0.16	0.20	0.32	0.14	0.12	0.23
Njiru 2	1	0.20	0.26	0.44	0.13	0.19	0.22
	2	0.16	0.37	0.34	0.13	0.18	0.21
	4	0.20	0.25	0.34	0.17	0.18	0.25

Source: Field data 1998-2001

From Table 22 it is clear that plant species 1 (*Sphaeranthus napirae*) had high concentration values of Zinc metal and therefore can be quite useful in cleaning up the rivers. Species 2 (*Commelina benghalensis*) and 3 (*Pennisetum purpureum*) are sometimes used as fodder for livestock and therefore could have some significant human health implications if the livestock meat is consumed by human beings. This is because of the heavy metal biological magnification effect along the food chain.

In addition, Figure 26 indicates high measured concentration values in the four plant species in all the sampling points along Nairobi River transect. Species 1 (*Sphaeranthus napirae*) had high heavy metal values detected in the tissue sections analysed from Njiru 2 sampling point, the confluence point of all the tributaries of the Nairobi River. The magnitude values of Copper, Chromium and Nickel followed a similar pattern as in Ngong River. Lead and Cadmium had the least measured values measured along the Nairobi River transect.

The detected values are attributed to the small scale industrial activities that are found along the river course and the small satellite areas where there are intense battery charging activities, metal plating and light paint manufacturing industries.

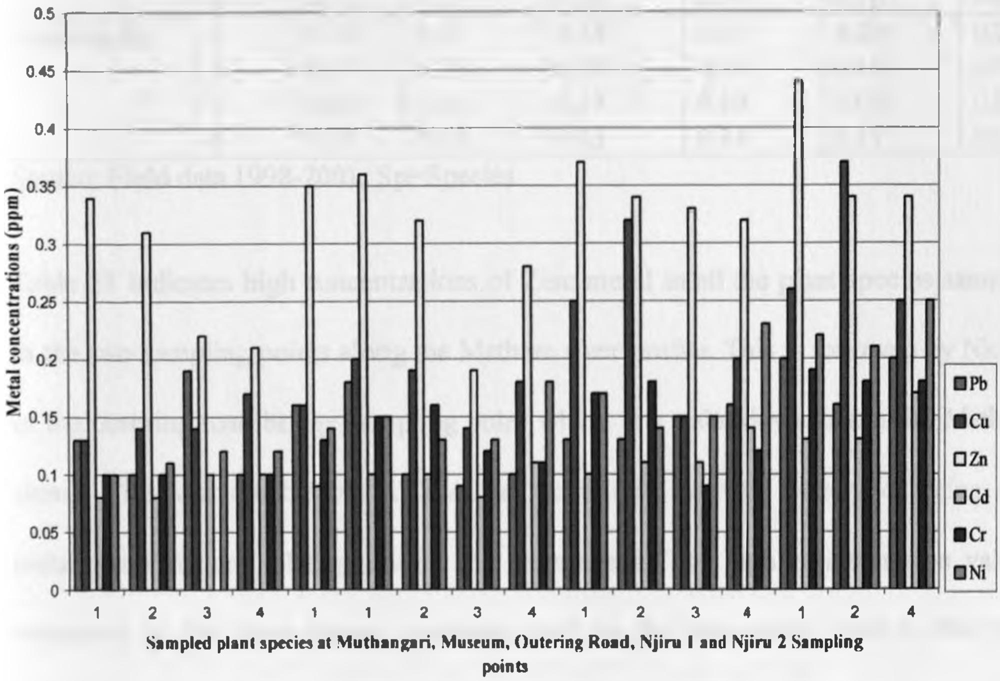


Figure 26: Mean concentrations of heavy metals in plant spcecies along Nairobi River

Siva and Masuda (2001) notes that water purification using artificial wetlands and aquatic macrophytes is attracting attention as a river water purification technology that can create rich ecosystems while imposing minimal load on the environment hence the study of the effects of riverine vegetation on the water quality in the study area. Goldyn *et al*. (2001) recommends the use of filtration uptake by plants as a means of decreasing pollutant loads in surface waters. The uptake of some heavy metal ions by some macrophytes in the three streams investigated is a major finding and was recommended for use within the study area as a means to control water pollution.

Table 23: Mean concentration values in selected plant species along Mathare River.

Sampling point	Plant Sp.	Mean Measured Heavy Metal Concentrations (mg l^{-1}) =ppm or $\mu g\ g^{-1}$					
		Pb	Cu	Zn	Cd	Cr	Ni
Thika Rd	1	0.13	0.20	0.37	0.13	0.12	0.19
	2	0.11	0.17	0.33	0.12	0.12	0.18
	4	0.11	0.13	0.34	0.14	0.16	0.09
Outering Rd	1	0.19	0.23	0.54	0.13	0.20	0.23
	2	0.17	0.19	0.50	0.14	0.18	0.25
	3	0.07	0.16	0.27	0.10	0.08	0.20
	4	0.21	0.18	0.43	0.14	0.17	0.21

Source: Field data 1998-2001, Sp=Species

Table 23 indicates high concentrations of Zinc metal in all the plant species sampled in the two sampling points along the Mathare river profile. This is followed by Nickel in the outering road bridge sampling point which is a point downstream the Mathare slums. This was attributable to *Jua-Kali* activities involving battery charging and metal smithing and plating within the slum areas. The high concentration values measured in the plant tissues correlates well to the high metal ions in the river sediments leached from the water into the soils. The heavy metals are also assumed to settle down at river points where the flow is either very slow or stagnant or the river cross-section is wide.

Figure 27 demonstrates the same trend in heavy metal concentrations in plant species. Zinc exhibited high concentration levels in all the plant species and sampling points along Mathare River. The other metals were detected in a decreasing order of Nickel, Chromium, Copper, Lead and Cadmium. This can be attributed to active Jua Kali activities involving metal plating and iron smithing along the Mathare River transect as illustrated in Table 23.

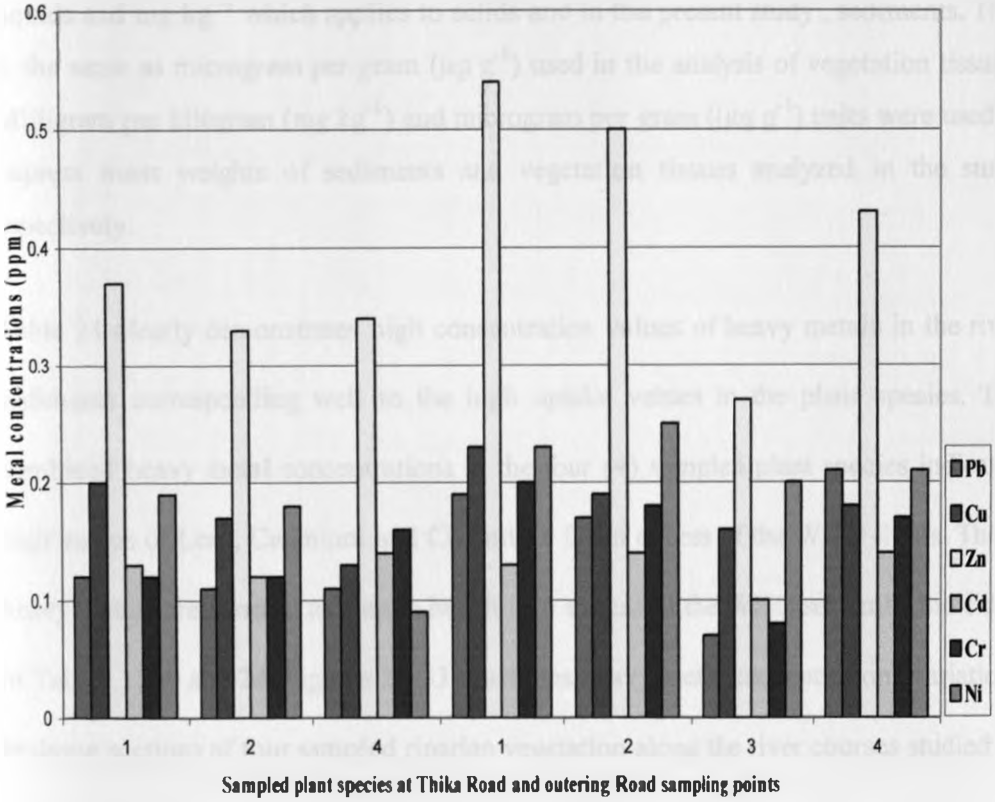


Figure 27: Mean concentrations of heavy metals in plant species along Mathare River

Table 24: Mean Heavy Metal Concentrations in Water, River Sediments and Plant tissue Samples

Water quality constituent	River Sediments (mg kg^{-1})	Water Samples (mg l^{-1})	Mean heavy metal load in four(4) sampled plant species ($\mu g\ g^{-1}$)	WHO Values (mg l^{-1})
Zinc (Zn)	700	0.04	0.32	5.0
Lead (Pb)	51	0.10	0.14	0.05
Nickel (Ni)	0.34	0.01	0.17	0.2
Copper (Cu)	10	0.11	0.19	1.0
Mercury (Hg)	0.1	0.01	NM	0.001
Cadmium (Cd)	2.7	0.01	0.12	0.005
Chromium (Cr)	0.27	0.01	0.13	0.05

Source: Field data (1998-2000), WHO (1993, 1995), NM=Not measured

N.B.

ppm (parts per million or 10^{-6}) are the same units as mg l^{-1} which is more applicable in liquids and mg kg^{-1} which applies to solids and in the present study , sediments. This is the same as microgram per gram ($\mu g\ g^{-1}$) used in the analysis of vegetation tissues. Milligram per kilogram (mg kg^{-1}) and microgram per gram (($\mu g\ g^{-1}$) units were used to express mass weights of sediments and vegetation tissues analyzed in the study repectively.

Table 24 clearly demonstrates high concentration values of heavy metals in the river sediments corresponding well to the high uptake values in the plant species. The combined heavy metal concentrations in the four (4) sampled plant species indicated high values of Lead, Cadmium and Chromium far in excess of the WHO limits. These heavy metals are harmful to human health if in excess of the WHO set limits indicated in Tables 1, 20 and 24. Figures 28-33 illustrates heavy metal concentrations variations in tissue sections of four sampled riparian vegetation along the river courses studied.

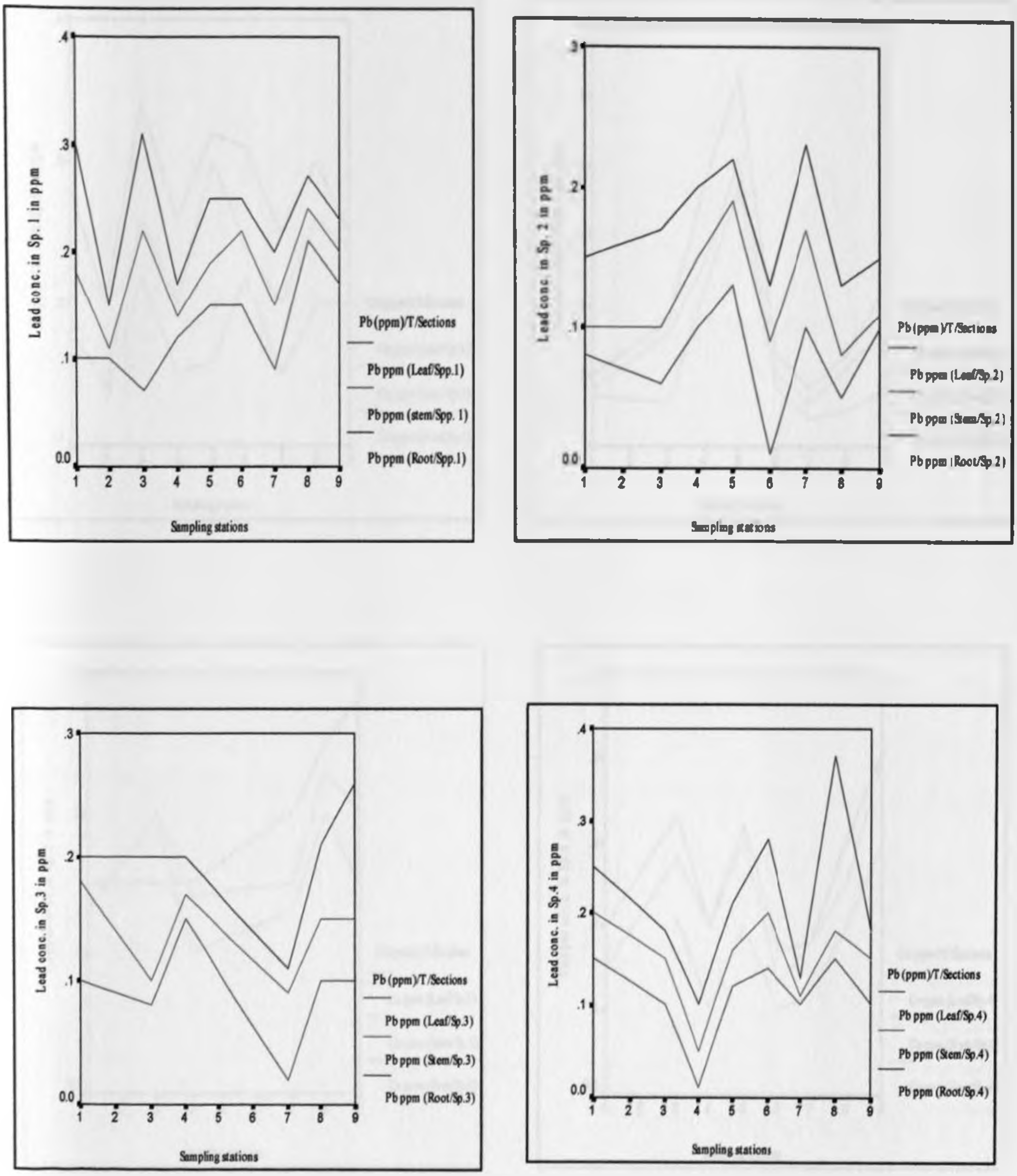


Figure 28: Concentration of Lead in the Leaf, Stem and Root of Four plant Species

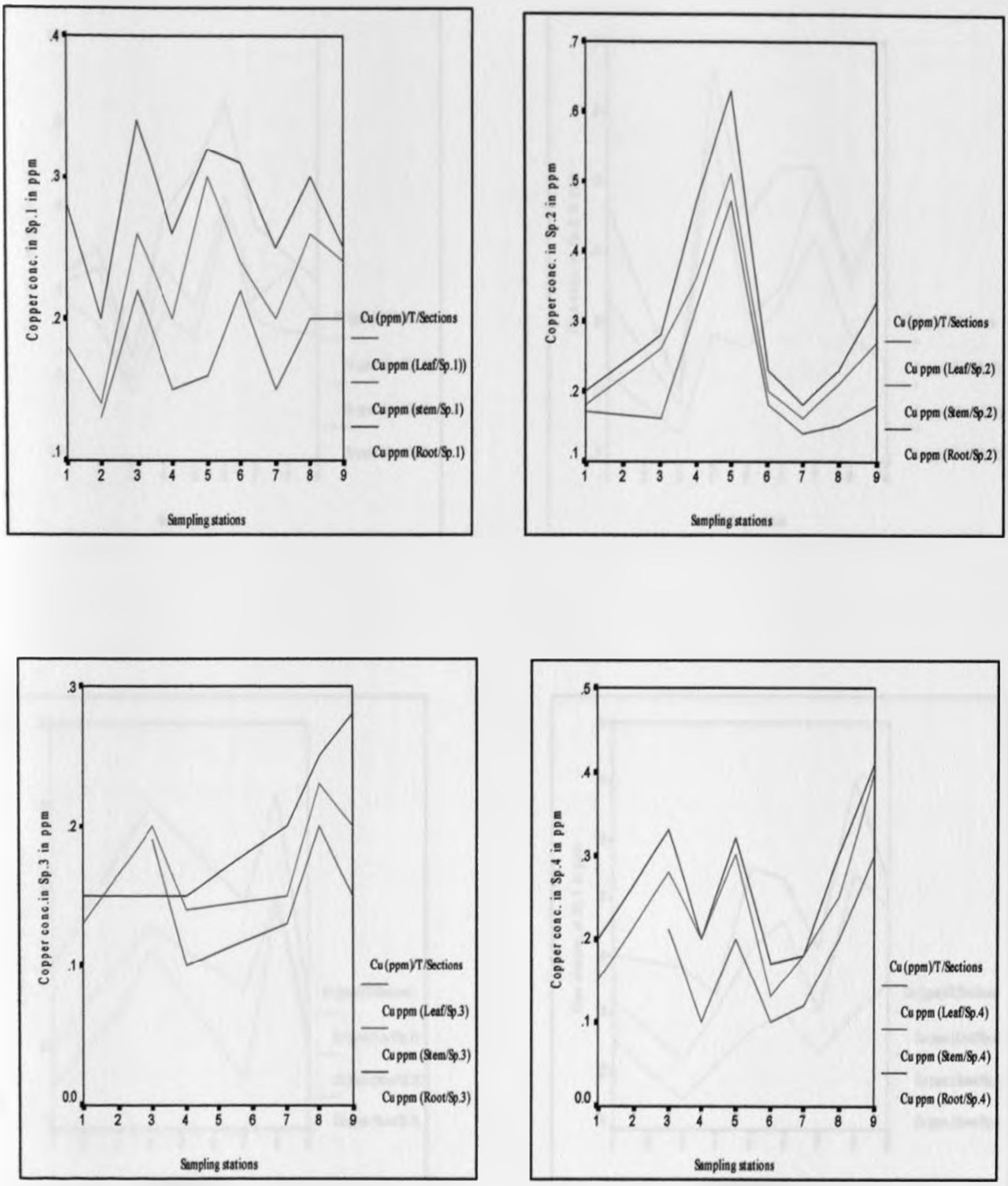


Figure 29: Concentration of Copper in the Leaf, Stem and Root of the four plant Species

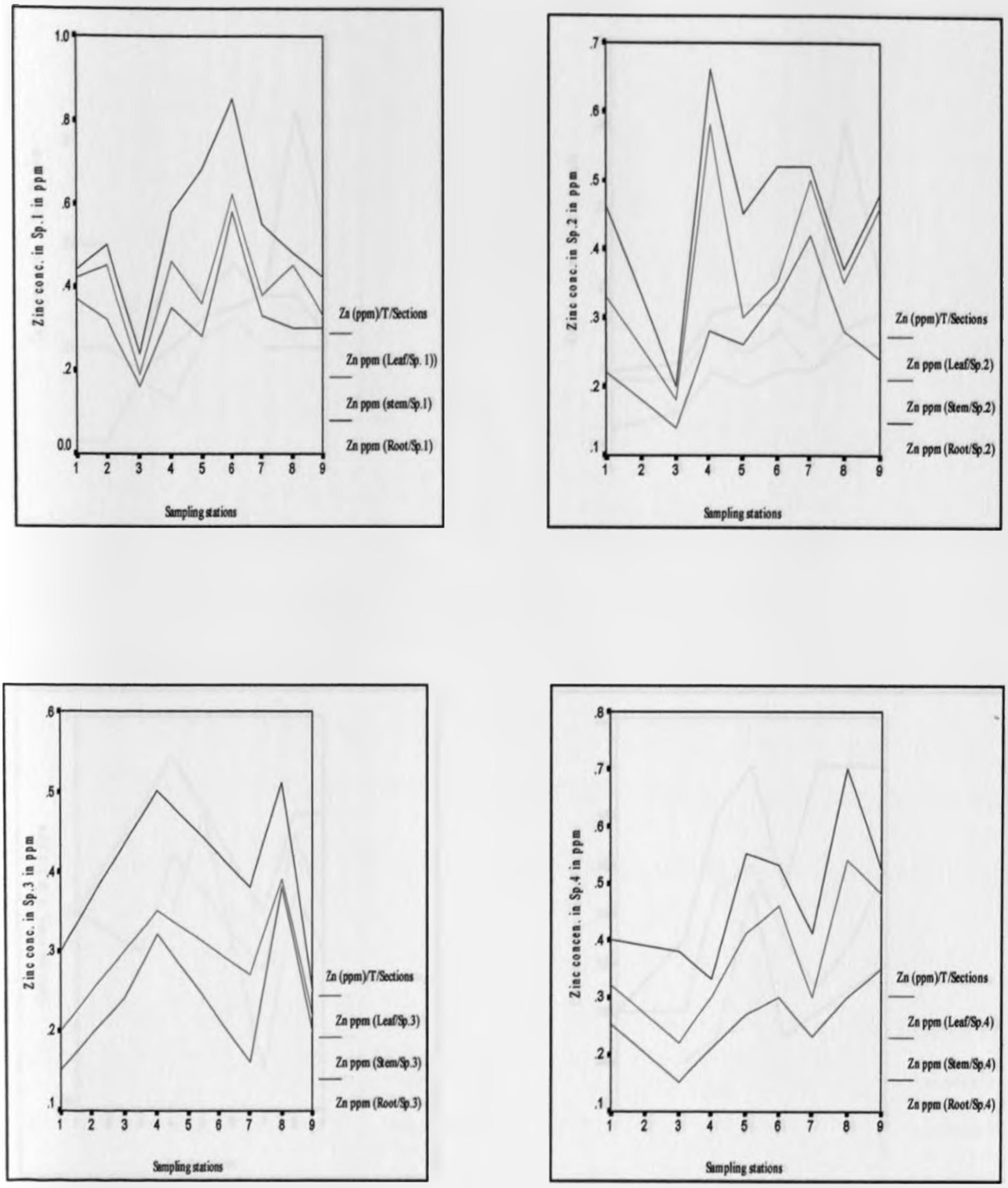


Figure 30: Concentration of Zinc in the Leaf, Stem and Root of the four plant Species

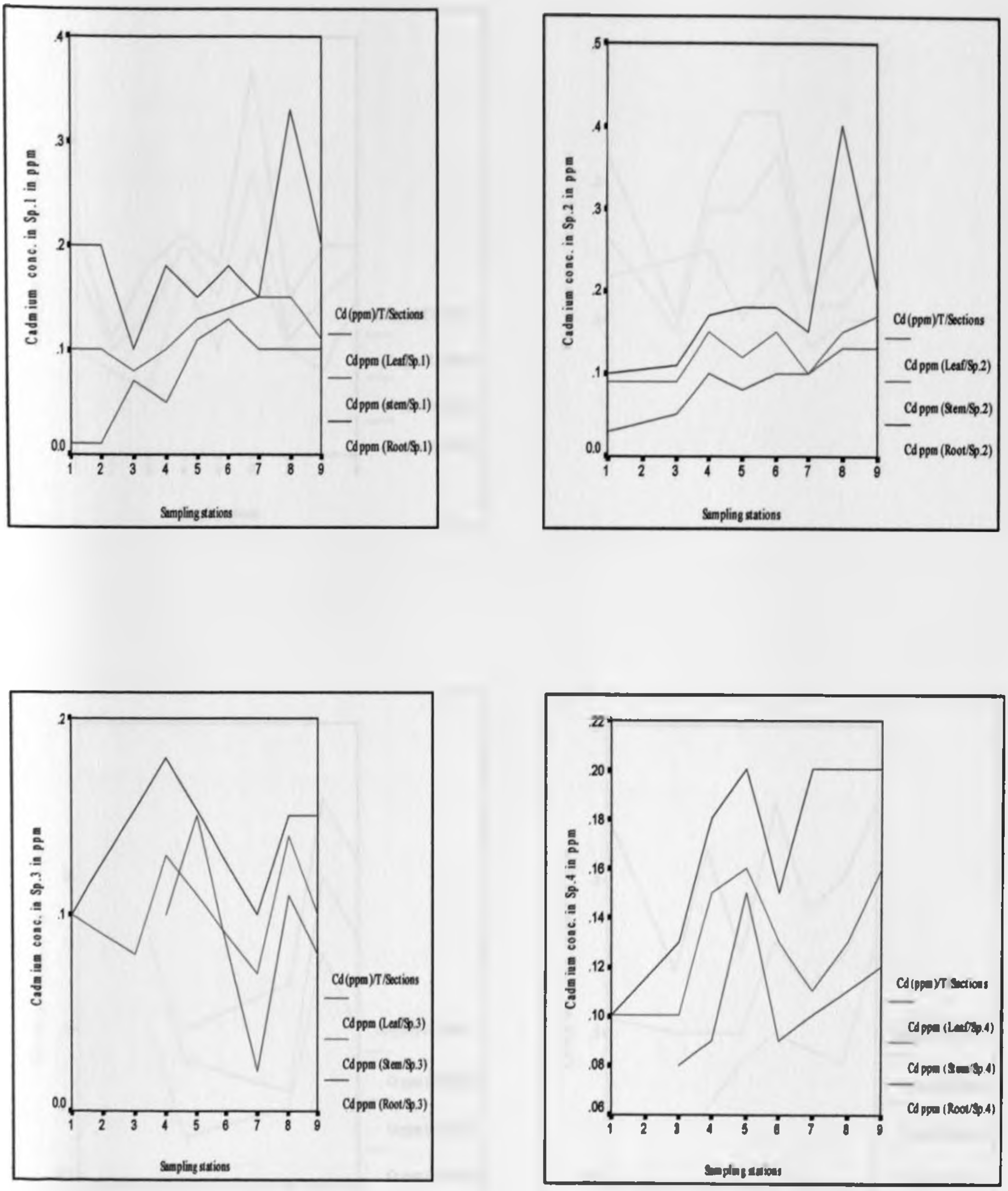


Figure 31: Concentration of Cadmium in the Leaf, Stem and Root of the four plant Species

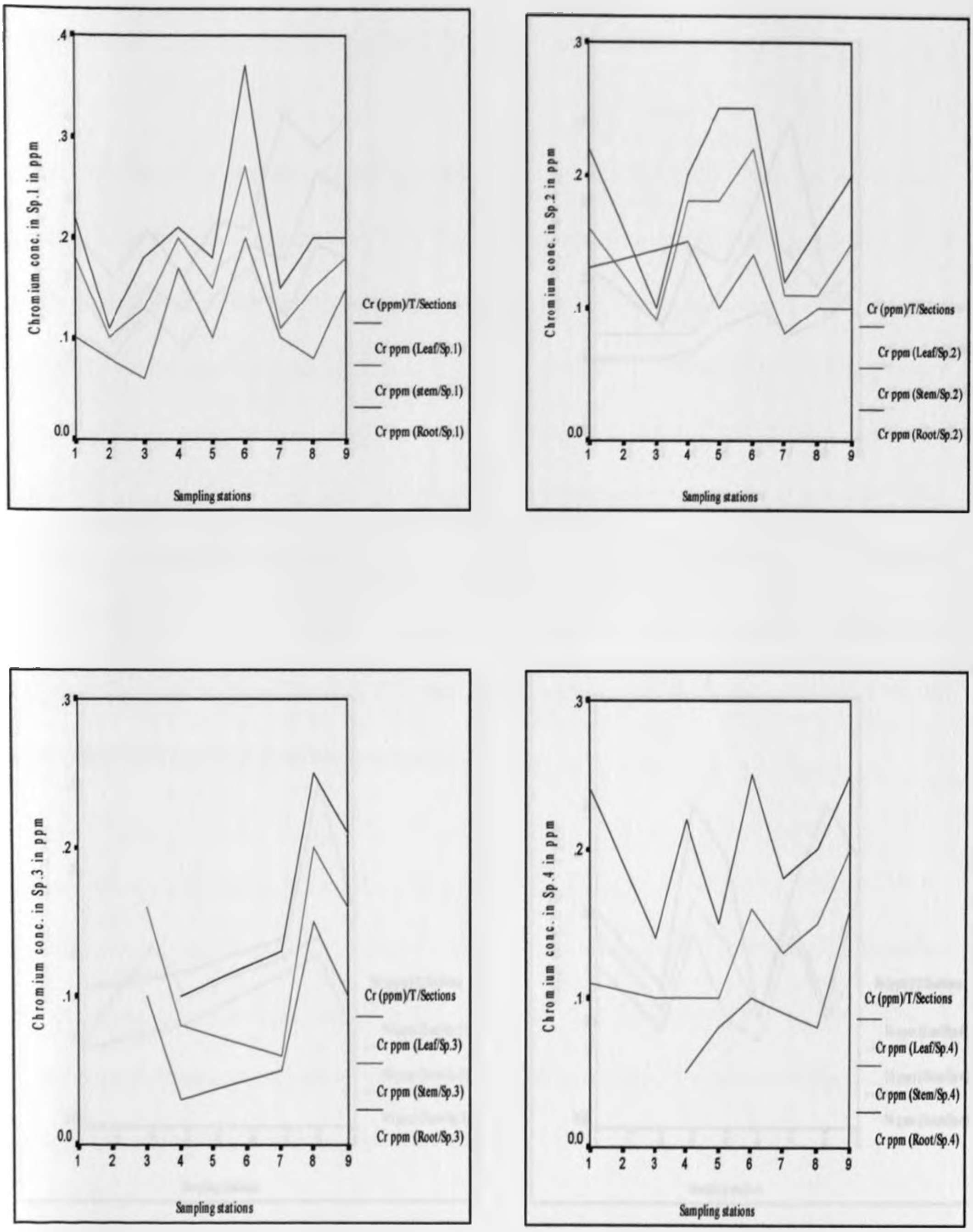


Figure 32: Concentration of Chromium in the Leaf, Stem and Root of the Four Plant Species

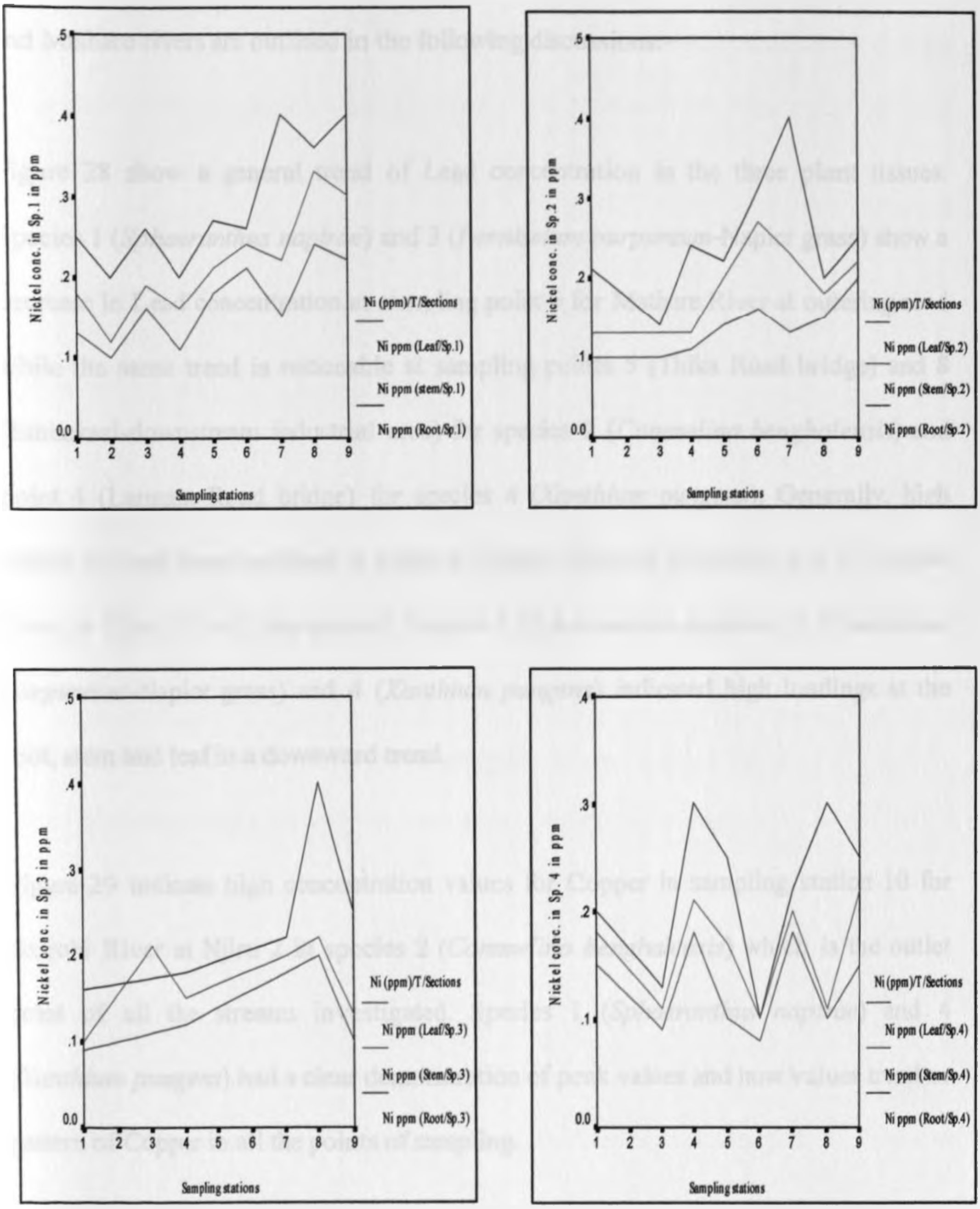


Figure 33: Concentration of Nickel in the Leaf, Stem and Root of the Four Plant Species

The implication of figures 28 to 33 to the cleaning of the pollutants in Nairobi, Ngong and Mathare rivers are outlined in the following discussions:-

Figure 28 show a general trend of Lead concentration in the three plant tissues. Species 1 (*Sphaeranthus napirae*) and 3 (*Pennisetum purpureum*-Napier grass) show a decrease in Lead concentration at sampling point 6 for Mathare River at outering road while the same trend is noticeable at sampling points 5 (Thika Road bridge) and 8 (Embakasi-downstream industrial area) for species 2 (*Commelina benghalensis*) and point 4 (Langata Road bridge) for species 4 (*Xanthium pungens*). Generally, high values of Lead were recorded in points 8 (Ngong River at Embakasi) and 9 (Nairobi River at Njiru 1) in all the species. Species 1 (*Sphaeranthus napirae*), 3 (*Pennisetum purpureum*-Napier grass) and 4 (*Xanthium pungens*) indicated high loadings at the root, stem and leaf in a downward trend.

Figure 29 indicate high concentration values for Copper in sampling station 10 for Nairobi River at Njiru 2 in species 2 (*Commelina benghalensis*) which is the outlet point of all the streams investigated. Species 1 (*Sphaeranthus napirae*) and 4 (*Xanthium pungens*) had a clear demonstration of peak values and how values trend or pattern of Copper in all the points of sampling.

Figure 30 demonstrates peak values of Zinc in all the three tissue sections at sampling points 4 (Langata Road Bridge), 7 (outering Road Bridge) in species 1 (*Sphaeranthus napirae*) and 3 (*Pennisetum purpureum*-Napier grass) while species 3 (*Pennisetum* *purpureum*-Napier grass) and 4 (*Xanthium pungens*) indicated peak values at sampling points 8 (Embakasi) and 9 (Njiru 1). This implies that Zinc ion concentration is more pronounced in Ngong River waters possibly due to increased pollution levels from the industries along the river profile.

Figure 31 gives a general picture of increasing trend in Cadmium concentration in the tissue analysed across all the sampling points in species 1 (*Sphaeranthus napirae*), 2 (*Commelina benghalensis*) and 4 (*Xanthium pungens*). Low concentration values of Cd were, however, recorded in species 3 (*Pennisetum purpureum*-Napier grass) at sampling point 6 for Mathare River at Outering Road Bridge.

Figure 32 is a demonstration of increasing Chromium concentration in species 1 (*Sphaeranthus napirae*) and 4 (*Xanthium pungens*) in all the sampling points, while very high values were recorded in species 1 (*Sphaeranthus napirae*), 3 (*Pennisetum purpureum*-Napier grass) and 4 (*Xanthium pungens*) at sampling points 5-Mathare River at Thika road and point 4- Ngong River at Langata road.

Figure 33 indicates an increasing trend of Nickel in the plant tissue sections analysed in all the plant species, sampling points and river sub-basins investigated.

Figures 28 through 33 indicate the concentration of the various heavy metals in the leaf, stem and root tissues of the plant species selected and analysed. Species 1 (*Sphaeranthus napirae*) indicated a close relationship of heavy metal concentrations in all the plant species' tissues and the parameters analysed. In general, high concentrations of the heavy metals were noticeable in the roots, followed by the stems and leaves of the various plant species.

Further, Figures 28, 29, 30, 31 and 33 demonstrated that species 2 (*Commelina benghalensis*) followed by 1 (*Sphaeranthus napirae*) and 4 (*Xanthium pungens*) had the highest uptake of Cadmium, Zinc, Copper and Lead parameters implying that they can be used for cleaning purposes of the streams investigated. Whitton, Burrows, and Kelly (1989) found that the ability of aquatic plants to accumulate metals can be used in several ways to monitor aqueous pollution and suggested use of *Cladophora glomerata* in monitoring heavy metals in rivers in the U.K. These results correlates quite well with other studies by Goldyn *et al.* (2001) and Siva and Masuda (2001) that plants and especially bryophytes are useful in filtration and uptake of pollutants from water courses. It is important to extend this type of investigation to cover the interactions between the river sediments and macrophytes in relation to metal leachages and uptake by plants. This was not investigated in the present study.

The human health implications of these metal ions are discussed as follows:-

Sodium (Na^+)

Sodium is a main cation in natural water. In fresh water, such as river or lake water, Sodium is collected from natural minerals dissolved in water. In low concentration, Sodium in drinking water is a mineral necessary for electrolysing blood balance in human bodies; however, high concentration of Sodium will disturb human health and may cause high blood pressure. If less than 200 mg l^{-1} is harmless. This is the case in all the streams investigated, water, river sediments and riverine vegetation in the study area.

Calcium and Magnesium (Ca^{++}, Mg^{++})

Calcium and Magnesium as main cations are factors causing water hardness. In natural water, Ca^{++} and Mg^{++} originate from natural process, which is dissolvent of mineral containing Ca and Mg. Other sources can be industrial waste and sometimes agricultural waste. Ca and Mg are non-toxic, and Ca is highly needed for bone structure and teeth growth. Concentration of Ca and Mg for drinking water is classified as unlimited, however, maximum Ca and Mg content are limited by hardness usually a value less than or equal to 500 mg l^{-1} are acceptable. In the present study, mean of 19 mg l^{-1} and 8 mg l^{-1} for Ca and Mg were recorded on average in all the streams studied. The water is therefore useful if only can be treated off the colour and turbidity.

Chloride (Cl^{-})

Chloride may not disturb health. On the other hand Cl is an ion needed for human bodies to balance electrolyte. In drinking water, Cl is composed with other ions. E.g. Na^{+}, which may cause salt concentration. Usually the limit is set at less than or equal to 250 mg l^{-1}.

Turbidity

Turbidity is an important parameter for drinking water evaluation. Turbid water containing suspended material from soil particles may cause growth of micro-organisms. The limit is usually set at less than or equal to 5 NTU. The study, however, revealed higher values of turbidity in the three rivers measured at Museum, Outering road and Embakasi in Nairobi, Mathare and Ngong rivers, respectively. This suggests that the water is unfit for drinking purposes. Usually, turbidity can be reduced through flocculation, sedimentation and filtration.

Heavy metals

Heavy metals selected for examination are those dangerous for health like Cadmium (Cd), Chromium (Cr) and Plubium (Pb)-Lead. These heavy metals were measured, in water, river sediments and riverine vegetation. Cd can accumulate in human bodies and cause kidney ailment, stomach ache, osteoporosis and imbalance of haemoglobin. The set limit is less than or equal to 0.01 mg l^{-1}. This value is quite lower than the measured values of Cd in riverine vegetation which were 0.17 ppm, 0.15 ppm and 0.13 ppm in species 4, 1and 3, respectively. This suggests high risks of using water in the three streams investigated in the study as indicated in Tables 21, 22 and 23.

Cr is another toxic substance especially Chromium hexavalent. This element is expected to cause skin cancer, respiration disturbances, kidney ailment or metabolism disorder. The set limit is usually less than or equal to 0.05 mg l^{-1}. The measured values in the aquatic plants are, however, quite high and indicative of harmful effects to human beings in the streams investigated.

Pb may accumulate in the nerve system and may cause anaemia and paralysis in children. The set limit is less than or equal to 0.005 mg l^{-1}. The measured values in the riverine vegetation are high. The measured values of both these metals were indicated in Table 24.

Faecal Coli and total coli

Faecal coli content is another important parameter to examine water quality. The identification of faecal coli in drinking water sources is indicating water pollution by faeces and can cause many diseases. The set limit is less than or equal to 50 mg l^{-1}. It can be treated by sterilization using ultra violet or ozonization and other methods.

3.5. POLLUTANT SOURCES

Water quality characteristics, and the parameters used to measure them, are commonly categorized as physical, chemical, and biological. Tchobanoglous and Schroeder (1985), Tebbutt (1985), McCutcheon, Martin, and Barnwell (1993), Malina (1996), and Wurbs and James (2002) explore water quality characteristics and parameters in detail. The Nairobi sub-streams are receptors of untreated wastewater from the Nairobi city, industrial, residential and agricultural discharges in and around the city. Newson (1994) explained the main sources of pollution as industrial, urbanization, and agricultural human activities and mentioned the concerted efforts being made to control and manage water quality status of rivers in the European Union and by extension in the developing countries. Recent studies Kithiia (1992 &1997) have shown that the water in the Nairobi River sub-basins is increasingly deteriorating in quality. This is mainly due to anthropogenic activities going on around the city environs and along the river banks. This water quality degradation is seen from three fronts: The chemical, the biological and the physical perspective as discussed in the following sub-sections.

3.5.1. Chemical Quality

The chemical quality of the Nairobi river sub-streams is degraded through various pollution sources, which can be classified as either point source or non-point sources.

Point sources: These originate from different industries and human settlements (urban and residential areas). Industrial pollution is most severe along the Ngong River sub-catchment while residential pollution is more pronounced along the Mathare River. Urban wastewater and auto-mobile garage wash off contribute significantly to pollution and water quality degradation.

Non-point sources: These pollution sources originate mainly from agricultural and flower gardening activities going within the basin. There are two sources of agricultural pollution of the rivers:-

i) Agrochemical pollution which involves the application of pesticides, herbicides and fungicides for crop protection.

ii) Pollution from organic and artificial fertilizers which are used on land.

Linsley (1982) indicates that the sources of non-point pollution are described in terms of land uses that produce the pollutants. These were found to contribute significantly to water quality deterioration in the upper-catchment areas according to recent studies by Kithiia, 1992 and 1997, and Kithiia and Ongwenyi (1997). This was a major finding in the present study in the three river sub-basins investigated.

3.5.2. Biological Quality

Amuzu (1997) found that rivers passing through heavily populated sections of Accra city receive discharges of domestic effluent which cause gross pollution, depleting the available oxygen (DO) and increasing values of BOD_5 and COD. This is basically organic wastes from untreated domestic sewage from residential settlements. The slum areas are the main source areas of the organic wastes to the rivers, especially Nairobi and Mathare Rivers. The high values of BOD_5 and COD recorded along these sub-streams reveals this fact since these areas lack sanitary facilities and only relies on pit latrines some of which are constructed on top of the river channels draining these areas. This is demonstrated in Table 25 on mean BOD_5 and COD measured values in the three sub-streams.

Table 25: Mean measured concentration values of organic parameters in the three river sub-basins

River/Parameters	Sampling point	Mean concentrations in $mg l^{-1}$		
		BOD_5	COD	pH
Nairobi	Muthangari	7.8	62	7.5
Nairobi	Museum	18.8	83	7.4
Nairobi	Outering Rd	123.6	313	7.2
Mathare	Thika Rd	37.4	184.1	7.1
Mathare	Outering Rd	196.4	413.7	6.7
Ngong	Langata Rd	19.6	83.28	7.7
Ngong	Embakasi	67.2	279	7.4
Nairobi	Njiru 1	82.8	510	7.1
Nairobi	Njiru 2	41.7	133.2	7.4

Source: Field data 1998-2000

There is a general increase in organic pollution in all the three streams as indicated in the increase in BOD_5 downstream the river profiles as shown by Table 25. At sampling point 10, Njiru 2, the three streams have joined and the river channel is wide about 5 metres leading to increased dilution and aeration of the water, hence decreased BOD_5 and COD values. The water is generally alkaline to neutral with a pH value of more than 7 on average. Amuzu (1997) indicates that the impact of urbanization and industrialization on the water quality of some surface waters in Ghana by the uncontrolled discharge of domestic effluents and industrial emissions has worsened since 1983 when the Government introduced the Economic Recovery Programme (ERP). This compares well with the situation in Kenya as reported by Kithiia and Ogwenyi (1997) that with industrial diversification (Republic of Kenya, 1986), there has been an increase in the number of industrial establishments and consequently of people employed.

This has resulted in increased effluent load discharged into the rivers passing through the city (Nairobi) hence causing serious deterioration in water quality. The source of pollution from untreated sewage is in the Coliform bacteria species *Escherichia coli* or E. *coli*. These bacteria are not pathogens. However, their presence in water samples indicates presence of faecal matter in a stream and thus the likelihood of other micro-organisms that are pathogenic (Wurbs and James, 2002).

The measured total coli forms per 100 ml were 100 per 100ml. This was far in excess of the WHO recommended values of between 0-10 per 100 ml indicating human faeces contamination of the river systems. This was pronounced in the informal settlement areas (Slums) with inadequate sewage and sanitation facilities. The implication of this is that the water in the streams investigated is polluted with human faeces and therefore unsafe for domestic use in areas of proximity to the slum settlements.

3.5.3. Physical Quality

This emanates from the wash-off or run-off from the exposed soil surfaces and flower gardens along the river banks. Linsley (1982) mentions that as water moves across the land surface during or after a storm, it transports dissolved and suspended materials which have been picked up along the path of flow and are major contributors to water pollution as found in the present study. They contribute significant amounts of suspended sediment load which affects the colour and turbidity of the river water. This was found to be appreciable after rain storms or during the periods of high discharge rates. Linsley (1982) explains that the over-all effect of non-point source pollution on water quality is best expressed as 'total pollutant mass loading', the product of concentration and flow. This was employed in the present study.

By using PCA, it was possible to categorize the various water quality parameters into the three main pollutant types and sources. This is well demonstrated in Tables 26, 27 and 28.

Principal Component Analysis (PCA) was used to group the various water quality parameters (variables) in respect to the pollution sources. The principles and procedures of this method were fully discussed in section 2.3.1.2 earlier in this study. It is paramount to note that the water quality parameters may not group together distinctively because water pollutant sources are often time variant, intertwined and auto-correlated. The main pollutant sources are human activities and their influence on the water resources are indicated in the studies by Linsley (1982), Kithiia (992), Newson (1994), Amuzu (1997), and Kithiia and Ongwenyi (1997).

In considering the site of the sampling station (point) and the activities taking place at its proximity, an attempt was made to characterize the pollutant sources (quality parameters) as industrial and physical; agricultural and natural and chemico-biological sources according to the PCA results and interpretation. These were chosen against their component loadings to verify their validity with a significance level of ±0.500 taken as standard for all the variables and stations. Computed mass loading values of less than ±0.500 were taken as insignificant and equal to zero.

Table 26: Rotated component loadings of some water quality parameters of Ngong River at Langata Road Bridge and Embakasi sampling stations

Water quality variables	Component loadings by variables and sampling stations								
	Langata road bridge				Embakasi station				
	1	2	3	4	1	2	3	4	5
Biological Oxygen Demand (BOD_5) $mg\ l^{-1}$			.96			.83			
Chemical Oxygen Demand (COD) $mg\ l^{-1}$			.93			.74			
Total Suspended Sediments(TSS) $mg\ l^{-1}$		-.92							.80
pH								.88	
Total Alkalinity (T.Alka.) $mg\ l^{-1}$	.85				.57	.55			
Conductivity $\mu s\ cm^{-1}$	.79				.84				
Calcium (Ca) $mg\ l^{-1}$	.89					-.91			
Magnesium (Mg) $mg\ l^{-1}$	.87						.95		
Sodium (Na) $mg\ l^{-1}$	.74	.53			.86				
Potassium (K) $mg\ l^{-1}$		.77			.80				
Chlorine (Cl) $mg\ l^{-1}$		.82			.92				
Fluoride (F) $mg\ l^{-1}$				-.91				-.83	
Total Dissolved Solids (TDS) $mg\ l^{-1}$	.79				.86				
Turbidity (Turb.) N.T.U		-.91			-.56				.60
% of total variance explained by component	32.7	27.6	15.0	9.7	30.0	24.5	13.6	11.0	9.6
% cumulative	32.7	60.1	75.0	84.7	30.0	54.5	68.1	79.0	88.6

Source: Field data (1998-2002)

Table 26 revealed that there is a maximum of five (5) distinct components in Ngong River together accounting for 85% and 89% at Langata rd bridge and Embakasi sampling points of the total variance. A close look at the table indicates that the first component is dominated by conductivity, total alkalinity, Calcium, Magnesium, Sodium and Total dissolved solids at Langata road while at Embakasi it is dominated by BOD_5, COD, Total Alkalinity, conductivity, Sodium, Potassium, Chloride, Fluoride and Total dissolved solids. Studies conducted (Ohayo-Mitoko, 1996) and Wandiga (1996) on the Ngong River found that the highest levels of heavy metals are in the sediments and high concentrations of organochlorides in the biota. This was found to be true in the findings of the present study.

The second component is dominated by TSS, Na, K, Cl and Turbidity at Langata rd and by TSS, Ca, Mg and Cl at Embakasi, pH appears to be significant in components 3 and 4 at Embakasi sampling point.

The over-all implication of these results is that physically related pollutants seem to group together in components 1 and 2. There is also a general increase in the component loadings downstream the river, indicating an increase in the sources of pollution/pollutants. Most of the variables tended to be grouped in component 1 which clearly indicates increase in human activities especially industrial activities before water reaches the Embakasi sampling point. The increase in TDS values at this point is a demonstration of the polluting effects of industries dealing with metallic components like electrical plating, battery manufacturing, steel works as well as chemical industries and paint manufacturing. These utilises Sodium and Chloride ingredients which when dissolved in water increases the ionic concentration in water. A component loading value of 0.95 for TDS was recorded at this point.

The high component values of BOD_5 and COD recorded at Langata downstream Kibera and Nairobi dam can be attributed to the effects of the Kibera slums where most of the human waste is discharged directly into the river due to either neglect, deliberate attempts or complete lack of sanitation facilities. This correlates well to a study in Accra city by Amuzu (1997), and Kithiia and Ongwenyi (1997) in a similar study in Nairobi city. A report by United Nations Environment Programme (UNEP) by Mavuti (2003) indicates the same trends in BOD_5 and COD changes along the Ngong River tributary.

Table 27 revealed maximum component loadings of five (5) accounting for a total cumulative variance of between 84% and 92% at Museum and Njiru 1, respectively, along the Nairobi river profile. The river at Museum depicted high component loadings of Total Alkalinity, Conductivity, and Total dissolved solids in the first component. The same trend was recorded at Outering Road and Njiru 1 in the first rotated component loadings.

Table 27: Rotated Component loadings of some water quality parameters of Nairobi River at Museum, Outering Road and Njiru 1 sampling points.

Water quality Variables	Component Loadings by Variables and Sampling points													
	At Museum					At Outering road					At Njiru 1			
	1	2	3	4	5	1	2	3	4	5	1	2	3	4
BOD_5 mg l^{-1}		-.81				.93					.77	.56		
COD mg l^{-1}					.71				.52				-.75	
TSS mg l^{-1}					.60			.68					.77	
Ph				-.94			-.86				.86			
T.Alk mg l^{-1}	.85					.90					.83			
COND μscm^{-1}	.83					.95					.97			
Ca mg l^{-1}	.84						.70					.84		
Mg mg l^{-1}				.79		.82					.71	.67		
Na mg l^{-1}					.83		-.59		.54		.94			
K mg l^{-1}		.90						.79			.81			
Cl mg l^{-1}			.82			.67		.51			.96			
F mg l^{-1}		-.62							.89			.91		
TDS mg l^{-1}	.90					.94					.98			
Turb N.T.U			-.77							.94				.95
% of total variance explained by components	24.7	19.8	14.2	13.7	12.4	35.5	17.7	13.0	10.9	10.7	50.9	18.2	12.1	10.6
% cumulative	24.7	44.5	58.7	72.4	84.8	35.5	53.3	66.3	77.2	87.9	50.9	69.1	81.2	91.5

Source: Field data (1998-2002)

Unlike in the other river sub-systems BOD_5 and COD were not clustered together which is an indication of a whole complexity in the variations of the water quality parameters. The sources of pollutants and hence pollution and water quality degradation depend on the prominent human-land use activity. For example, very high loadings values of BOD_5 were recorded at both Outering Road and Njiru 1 which are downstream Majengo/ Gikomba open air market and Eastleigh- Kyamaiko –Kariobagi areas with extensive informal settlements. Turbidity and Total suspended sediments were not grouped together either which is a clear indication of varied sources of pollutants within the catchment area.

The main sources of pollutants and/or pollution along the river profile are *Jua Kali* Auto-mobile garages, food Kiosks that tend to dump their wastes directly into the river system. Gikomba open air market is notorious in this with traders dumpling raw vegetables into the river as demonstrated in plates 1, 3 and 6. The urban run-off impacts negatively onto the river water quality by contributing enormous amounts of suspended sediments which is not necessarily season dependent.

Table 28: Rotated Component loadings of some water quality parameters of Mathare river at Thika Road bridge and Outering Road bridge sampling points

Water quality variables	Component loadings by variables and sampling points							
	At Thika road				At Outering road			
	1	2	3	4	1	2	3	4
BOD_5 mg l^{-1}	.89				.96			
COD mg l^{-1}			.50		.50			
TSS mg l^{-1}			.91			.91		
pH			.57			.56		
T.Alk mg l^{-1}	.93				.94			
COND μs cm^{-1}	.97				.97			
Ca mg l^{-1}		.92					.91	
Mg mg l^{-1}		.89					.91	
Na mg l^{-1}	.96				.95			
K mg l^{-1}	.93				.93			
Cl mg l^{-1}	.90							
F mg l^{-1}				.74				.79
TDS mg l^{-1}	.96				.97			
Turb N.T.U	.64			.59	.64			.56
% of total variance explained by components	42.8	18.1	14.8	10.6	45.8	16.0	13.0	11.0
%cumulative	42.8	60.9	75.7	83.3	45.8	61.8	74.7	85.6

Source: Field data (1998-2002)

From Table 28 it is clear that Mathare River water quality parameters were grouped into four main component loadings. These accounted for a cumulative total variance of 86% both at Thika Road and Outering Road sampling points.

The first component grouped together water quality variables; total alkalinity, conductivity, Sodium, Potassium, Chloride, Total dissolved solids and turbidity. These parameters can be attributed to the geology or natural causes as well as human activities along the river banks. These are water quality parameters related to the physical deterioration of water quality along the river profile.

Fluoride which is a very important quality parameter was not grouped with any other variable. Fluoride is usually associated with geological rock adsorption as well as human activities such as metal and electrical plating.

The high component loadings of both COD and BOD_5 along the river were associated with land use activities, mainly the informal settlements (slums) along the river course. These lack proper sanitation facilities and, occasionally, raw human wastes flows directly into the river water. Studies in other countries have found similar relationship between land use activities and water quality degradation (Linsley, 1982, Linslet *et al.*, 1988, Tebbutt, 1985, Newson, 1994, Amuzu, 1997, and Wurbs and James 2002) while in Kenya, studies by Ongwenyi (1979), Kithiia (1992), Ongwenyi *et al.* (1993), Kithiia and Ongwenyi (1997), Aketch and Olago (2000) and Mavuti (2003) have proved that changes in land use activities contribute significantly to water quality deterioration.

In conclusion, water quality pollutants and/or pollution within the three river sub-systems investigated can be grouped into land use sources, such as slum dwellings, cultivation along the river banks (notably, Napier grass-*Pennisetum purpureum*) and flower gardening; industrial and urban –cum- commercial sources.

Pollutant sources associated with land use activities related to physical contamination of water were more pronounced along Mathare River and the upstream reaches of Ngong and Nairobi rivers. These were more seasonal dependent as shown in table 3.

Industrial sources were prominent at Embakasi sampling point along the Ngong river downstream the industrial areas ; while urban influence and commercial activities affected Nairobi river downstream, the Nairobi city urban centre, Majengo and Gikomba open air market areas as indicated by high values of TSS, BOD_5 and COD Outering Road for all the streams. The same fact was well illustrated in the study by Kithiia and Ongwenyi (1997), Aketch and Olago (2000), and Mavuti (2003) within the same catchment basin but focusing only on the Ngong River.

CHAPTER 4- RESEARCH FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

4.0. INTRODUCTION

This chapter focuses on salient findings of the study based on the results of the investigations. Emerging from these results are the conclusions and overall recommendations to policy makers and future researchers in this field of Study.

4.1. RESEARCH FINDINGS

Based on the water quality investigations in the three sub-streams, the study revealed the following:-

a) There is an increasing trend in the chemical, biological and physical deterioration of water quality along the river cross-sections downstream the major land use activities. High deterioration rates were noticeable on the Ngong River downstream the industrial area. This was followed by Nairobi River downstream, the Gikomba market and Majengo slums. This was the general trend along each specific river investigated in the study.

b) The mean flows of the sub-streams exhibit a bimodal pattern of distribution similar to the rainfall distribution and pattern experienced in the study area. The peak flows conform to the wet season and the low flows corresponding to the dry season. Thus, on a seasonal basis, water quality tends to deteriorate physically and biologically during the wet season. However, during the dry season, the deterioration is chemical in nature.

c) Storm water run-off was found useful in cleaning up the river systems by washing away the solid wastes, diluting the chemical industrial wastes and waste-water from residential areas and burst sewers. In addition, the water was found to be only physically polluted and therefore, easily treatable using convectional methods of treating water such as filtration and sedimentation processes.

d) The main identified pollutant sources were industrial, residential and urban/commercial activities. This was however, found to be site-specific and river-specific. The implication of this is that each sub-stream should be treated separately in dealing with water pollutant sources.

e) River sediments and riverine vegetation were found to contain substantial amounts of heavy metal traces. This was due to the high affinity of sediments in leaking some heavy metal traces coupled with effects of heavy metal settling and deposition on the river sediments as the river flow (volume) decreases in speed and amount. Certain species of vegetation especially 1 (*Sphaeranthus napirae*), 2 (*Commelina benghalensis*) and 4 (*Xanthium pungens*) were found to absorb more zinc, Nickel, Lead, Cadmium and Copper meaning that they can also be used for river cleaning purposes and environmental quality restoration.

f) The effect of dilution (and hence, water quality improvement) increases downstream the river courses about 156 km away and 650 km from the city at both Ol Donyo Sabuk and Malindi (Sabaki outlet), respectively. This is largely due to the self purification of the river due to aeration conditions, settling, deposition of sediments and additional in-flows into the main rivers from other tributaries of less polluted or good quality water. Rivers Ndarugu and Thiririkwa drain their waters into the Athi-Nairobi river sub-systems in the upper reaches while the Mzima springs and Tsavo River from the Chyulu hills provide dry weather discharge into the middle and lower reaches of the Athi River (Athi-Galana-Sabaki river system).

g) The total suspended solids (TSS) and total dissolved solids (TDS) were found to vary widely from one river sub-basin to another and also within each specific individual sub-streams. These also varied from one season to another. This correlated well with river discharges and was in accordance with the seasons of measurement. Ngong River at Embakasi yielded suspended solids during the peak flows at the tune of 1640 t $year^{-1}$ and total dissolved solids at the tune of 3750 t $year^{-1}$, respectively and during the low flows at 1360 and 3600 t $year^{-1}$, respectively.

h) Water quality deterioration within the study area sub-streams was found to vary with increasing stream discharge. Thus, the study revealed that stream discharge and concentration of water pollutants exhibited a discordant relationship. This was found to be the case in all the streams studied. Their rates of water quality degradation varied widely over the whole study basin depending on the main land use activity (ies) dominant within the sub-stream. Ngong River at Embakasi sampling point (downstream industrial area) exhibited the highest rate of water quality deterioration chemically due to industrial waste effluents discharged directly into the river from the industries.

i) Other human activities were found to contribute significant amounts of water pollutant in addition to those discussed earlier. The motor garages, petrol filling stations and car washing sites are point sources for oil films found floating on the water surface in virtually all sub-streams, while Kiosks are notoriously known for dumping of solid wastes. Further, the open air Gikomba market affects the water quality significantly. Most of the floating solid waste finds its way into the river courses, sometimes settling on the river banks and on the water surfaces where it rots, thereby producing a foul irritating smell. All these factors reduce the aesthetic enjoyment of water sources in the sub-streams, in addition to causing water quality deterioration. The water within the study area was found to deteriorate in quality and sometimes the water pollutants investigated surpassed the critical WHO guidelines and the Kenya standards for drinking water quality.

4.2. CONCLUSIONS

From the results and findings of the investigations several conclusions can be made. The increasing trend in water quality deterioration requires a much more attention from the water quality control and conservation policy makers. More emphasis must be given to those water quality parameters (variables) found to have some time (seasonal) factor variation. These variables included suspended solids (SS), Total dissolved solids (TDS), chemical Oxygen demand (COD) and Biological oxygen demand (BOD_5). Others included heavy metals such as Mercury, Copper and Chromium in addition to other health related anions such as Fluoride (F^-). These were found to have pronounced pollution effects on water and hence causing water quality deterioration.

The measured concentrations of the various water pollutants investigated, mostly heavy metals and fluoride were in excess of the critical values recommended by the WHO and the Kenya standards for drinking water quality. Fluoride is closely associated with fluorosis, while mercury is highly toxic and harmful to human health. This potential risk varies from time to time depending on the duration of exposure to the measured concentrations.

Industrial activities were found to play a role in water pollution within the Ngong River sub-basin. High levels of most toxic in-organic substances such as Lead, Chromium and Mercury were measured. Their measured values surpassed the required WHO and the Kenya standards for drinking water quality. Within the Nairobi and Mathare River sub-streams, physical and biological related pollutants were measured. High values of BOD_5, COD, TSS and TDS were recorded. This related more to urban and commercial activities in addition to residential land use activities within the sub-basins. The mean measured values of BOD_5 at Nairobi and Mathare rivers were 50.1 mg l^{-1} and 116.9 mg l^{-1}, respectively. TSS was measured at between 95.5-255.7 mg l^{-1} for Nairobi River and between 161-251.2 mg l^{-1} for Mathare River while TDS measured at between 239.7-310.9 mg l^{-1} and 215.5-349.9 mg l^{-1} for Nairobi and Mathare rivers across the river profile, respectively.

The role of storm water and vegetal cover along the river banks was found to play a great role in cleaning these sub-streams. It was revealed that during the wet season, there were low measured concentrations of heavy metals, conductivity and total dissolved solids indicating that water was physically polluted. The root system of the riverine vegetation had the highest adsorbed values of heavy metals indicating their importance in cleaning up the river systems investigated.

In view of the conclusions made, it is worth noting that the study has provided significant data regarding water quality status within the three sub-streams. This information would be quite useful to policy makers and water pollution control and management bodies. It provides knowledge of water quality pollutants and their sources thereby allowing for quick remedial measures to be taken before detrimental consequences are reached. Increasing trends in water quality deterioration within the sub-streams calls for quick and appropriate measures to check the rate and to abate the eminent problems of disease out-breaks especially those related to water. The water in these sub-streams has also lost its aesthetic appeal enjoyed in the early 1900s when the city of Nairobi was established as the Headquarters of the then Kenya-Uganda railway (KUR) and therefore this requires multi-displinary efforts to reverse the trend.

Finally, the study is a useful planning tool in reference to water quality control measures and its results can be applied in other up-coming small urban centres and cities with rivers flowing through their boundaries and in the whole country in general.

4.3. RECOMMENDATIONS

Industrial activities were found to be major sources of heavy metals and therefore legal measures should be taken to those industries discharging harmful waste effluents to the rivers. Each industrial discharge drainage outlet should be installed with an automatic water quality (devise) recorder to ensure no illegal wastes are discharged into the river at night. Random water samples at these outlets should be taken at night when most of the industries discharge waste effluents into the rivers. In other words there is need for environmental law enforcement to reduce the rates of water pollution in the basins.

In the same manner, there is need for the provision of in-situ water quality measuring devices preferably portable for use by water quality specialists (Hydro-chemists) in monitoring pollutant levels in the water. In areas where there is increasing levels of physical and biological (organic) pollutants, sedimentation ponds can be useful in cleaning the river water as well as lowering levels of pollutants. Engineering works like the construction of artificial waterfalls may be useful to increase oxygen content in the waters and hence check the increase of BOD_5 and COD values resulting from organic wastes.

In the slum areas with inadequate drainage and sewerage systems, well constructed pit latrines should be provided far away from the river banks, in addition to a better drainage system. Good housing structures with toilets will also reduce direct discharge of raw human wastes into the rivers flowing through these slum areas. However, this is simply a stop gap measure usually for a short period. The long term solution would to have sanitation facilities connected to the entire city drainage and sewerage grid.

This will automatically solve the problem of direct raw sewage discharge onto the rivers and hence water quality deterioration.

There is an increase in the mushrooming of illegal structures such as "Kiosks" and auto-mobile garages along the river banks which were found to be either dumping and/or discharging harmful wastes into the rivers. Consequently, there is need to come up with a sound policy regarding these structures and their wastes. Waste oils from the garages can be collected and transported by specially designed trucks to dumping sites away from the rivers or recycled to another useable product or burned in furnaces to produce more power energy. The solid wastes from the "Kiosks" should be minimized through selective dumping and recycling. A buffer zone should be set aside between the river banks and the human land use activities to avoid any tendency of dumping wastes into the river. In addition, certain plant species such as *Sphaeranthus napirae* and *Commelina benghalensis* should be encouraged to grow into the river water and along the river banks as a cleaning measure and to restore the river system ecology.

As was evident in the study, land use changes and activities had profound effects on water quality. There is need to review the existing land use policy in this country to protect against encroachment of land use activities into the watershed areas. This will encourage land management control and conservation measures as well as riparian use of water resources in the headwater areas of the three sub-streams. Currently, the existing land policy has not been enforced to protect river catchments and headwater areas except what is provided for in the water Act of 1978. Therefore, the creation of the National Environment Management Authority (NEMA) is a move in the right direction towards the protection of our environment and water resources.

Community participation should be encouraged in garbage collection and disposal where sorting out of litter will be encouraged. Organizing public lectures and demonstration in the prevention and control of dumping along river banks is necessary. In addition, soil and water pollution control measures need be adopted. The knowledge acquired will be important in setting up an environmental impact assessment centre where all necessary information regarding environmental pollution will be passed onto the communities. In addition, sound legislation policies and a close monitoring of the environmental degradation is necessary.

Standards for industrial effluent discharge need be revisited to ensure that the actual natural river loads are taken into account. This is likely to restore the aesthetic and ecological quality of the water in the streams and in essence, will be significant in restoring the required water quality status for any use within the basin.

Water quality deterioration is not a new phenomenon in this country and indeed in the upper-Athi river drainage basin. However, the rate of deterioration is only becoming alarming, which means that there is need for a more intensified research into the courses and sources of pollution. This will help in a setting a regular inspection team of experts to monitor the ever changing water quality in the sub-streams investigated and in putting strategies to abate the problem.

There is need for public awareness regarding the pollution problems and the consequences arising thereof in the rivers and basins investigated. In overall, there is need for an integrated Environmental Education (EE) Program within the basins investigated. The program should focus on the need for people living within the city (Nairobi) and its environs to appreciate a cleaner environment. It should try to encourage people to properly manage their domestic raw wastes and avoid dumping these onto the rivers. Domestic wastes separation and sorting out would be a better option. People should also be encouraged to treat the Nairobi River as their friend and therefore protect its water quality for the present and future generations.

4.3.1. Suggestion for further Research

There is a need to initiate a research of the various water quality control measures in the sub-basin. The focus must be on the water quality parameters with high human health risks. These include fluoride, Lead, Chromium and Cadmium. Cadmium causes kidney ailment, osteoporosis and imbalance in haemoglobin if in excess of the recommended limits of 0.01mg/l. Excesses of Chromium concentration values are associated with skin cancer, respiration disturbances and kidney ailments in human beings.

The fact that some riverine vegetation had potential of heavy metal uptake and can provide good cleaning buffers for the already polluted stream waters implies a need for a further research on the usefulness of vegetation in the cleaning process. Specific attention should be given to species with the highest rates of heavy metal uptake and their environmental conditions of growth, especially *Sphaeranthus napierae*, *Commelina benghalensis* and *Xanthium pungens* which grow close to the river as their natural habitat. Some of the vegetation growing along the river profiles is used as fodder by livestock grazing in the open areas close to the river banks as well as the river waters. There is therefore a dire need for a detailed research on the propagation of the heavy metals and other water quality pollutants through the food chain system. The focus should be from the plant to animals and finally to humans in the case of the vegetation being used as fodder or from the vegetation to humans in the case of vegetation (Sukuma wiki-*Kales* and Spinach) being consumed directly by man. These plant species were not investigated due to the scope of the present study and financial constraints. A detailed study on *Pennisetum purpureum* which is cultivated along all the three streams as folder is necessary to establish heavy metal uptake and concentration.

There is need also to assess the importance of storm water as a measure of cleaning the streams by using graduation ponds along the streams to allow for water and sediment sedimentation and deposition. Dumping of solid wastes on the river banks should be put to an end by city council authority through enforcement of its city by laws.

An urgent investigation should be carried out to look at the implication of land use changes along the river profiles in order to assess the specific land use with high potential of polluting the environment. This will go a long way in putting strategies and measures of water deterioration control and conservation.

Finally, there is need to harmonize research in water quality degradation in rivers in the whole country and data in order to cope up with new water quality problems in the country. This can be achieved through use of GIS and computer data bases which can easily be accessed and retrieved for further use. This was not attempted due to the wide scope in the present study.

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ANNEXES

APPENDIX I-(WATER QUALITY DATA)

(i-a) Nairobi River at Muthangari upstream Museum

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
18.5.98	3.460	2.50	7.40	147.00	7.10	80.00	395.00	21.60	6.30	45.00	9.80	47.00	0.5.	260.00	80.00	193.00
22.6.98	.802	3.60	39.00	109.00	7.40	74.00	369.00	20.00	7.30	43.00	8.40	50.00	.35	243.00	80.00	110.00
24.8.98	.856	4.00	35.00	165.00	10.00	72.00	370.00	18.40	3.40	38.00	7.50	51.00	.80	248.00	60.00	100.00
28.8.98	.642	2.90	28.00	106.00	7.70	52.00	337.00	13.60	5.80	34.00	9.20	54.00	.90	202.00	58.00	61.00
21.10.98	.482	5.90	32.00	84.00	7.40	56.00	310.00	15.20	5.80	43.00	8.90	48.00	.45	186.00	62.00	20.00
13.11.98	.786	2.20	16.30	28.00	9.60	56.00	355.00	16.80	6.30	43.00	10.00	53.00	.40	213.00	68.00	53.00
8.12.98	1.523	1.00	13.00	117.00	7.20	60.00	369.00	18.40	6.30	31.00	15.00	59.00	.40	221.00	72.00	72.00
29.1.99	.240	4.00	45.00	43.00	7.70	32.00	362.00	16.80	58.00	43.00	6.30	44.00	.22	217.00	66.00	23.00
18.2.99	.222	9.00	63.00	103.00	7.40	64.00	374.00	16.80	6.30	46.00	6.40	46.00	.35	224.00	68.00	75.00
23.3.99	1.167	14.00	98.00	82.00	7.00	90.00	385.00	22.40	8.30	49.00	7.50	43.00	.74	231.00	90.00	85.00
13.4.99	2.596	2.00	13.00	104.50	7.10	80.00	405.00	20.00	6.30	38.00	6.80	58.00	.45	243.00	76.00	32.00
27.4.99	.337	6.00	105.00	123.00	7.10	70.00	438.00	18.40	5.30	48.00	10.00	74.00	.44	263.00	68.00	74.00
27.5.99	.253	6.00	28.00	148.00	6.80	70.00	403.00	17.60	12.60	45.00	11.30	59.00	.80	242.00	96.00	63.00
8.10.99	.235	5.00	22.00	33.00	7.70	66.00	412.00	17.60	4.40	50.00	9.40	66.00	.20	255.00	64.00	11.00
14.12.01	.462	160.00	240.00	79.00	7.80	70.00	354.00	999.00	999.00	999.00	999.00	999.00	999.00	219.00	999.00	999.00
05.01.02	.231	30.00	13.00	19.00	7.50	100.00	556.00	999.00	999.00	999.00	999.00	999.00	999.00	345.00	999.00	999.00
20.02.02	.423	70.00	620.00	1182.00	7.80	110.00	314.00	999.00	999.00	999.00	999.00	999.00	999.00	195.00	999.00	999.00
28.03.02	2.000	10.00	76.00	165.00	7.00	100.00	550.00	999.00	999.00	999.00	999.00	999.00	999.00	337.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(i-b) Nairobi River at Museum

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
29.05.98	4.640	3.00	63.00	148.00	7.70	80.00	339.00	22.40	4.40	38.00	12.00	34.00	.75	224.00	74.00	189.00
24.8.98	.923	6.10	25.00	71.00	7.20	70.00	372.00	19.20	6.80	38.00	7.50	47.00	.68	245.00	96.00	14.00
28.9.98	2.214	6.30	44.00	113.00	7.70	58.00	345.00	15.20	6.80	34.00	9.60	96.00	.45	207.00	66.00	32.00
13.11.98	2.667	1.60	4.80	76.00	7.60	42.00	343.00	16.80	6.30	41.00	10.00	50.00	.45	206.00	68.00	59.00
08.12.98	2.958	7.00	76.00	408.00	6.90	64.00	369.00	17.60	6.80	53.00	10.00	55.00	.50	221.00	72.00	84.00
29.01.99	.229	10.00	23.00	75.00	7.60	42.00	368.00	16.00	5.30	41.00	6.70	40.00	6.44	221.00	62.00	50.00
18.02.99	.268	11.00	37.00	89.00	7.30	68.00	410.00	20.00	5.80	49.00	7.00	51.00	.65	246.00	74.00	91.00
23.03.99	.213	9.00	28.00	103.00	7.20	82.00	363.00	20.00	5.80	49.00	6.90	42.00	.64	218.00	74.00	95.00
13.04.99	.426	10.00	14.00	94.00	7.00	90.00	426.00	23.20	6.80	43.00	7.40	57.00	.62	256.00	86.00	34.00
29.04.99	.448	4.00	40.00	111.00	7.10	88.00	468.00	21.60	6.30	48.00	11.00	70.00	.50	281.00	80.00	110.00
27.05.99	.336	6.00	59.00	95.00	6.60	78.00	425.00	20.00	11.20	46.00	11.30	58.00	.80	255.00	96.00	68.00
08.10.99	.935	10.00	201.00	73.00	7.70	72.00	424.00	19.20	5.80	53.00	10.00	64.00	.44	263.00	72.00	18.00
19.10.99	1.643	6.00	105.00	50.00	8.00	76.00	398.00	19.20	5.30	48.00	10.00	57.00	.52	247.00	70.00	57.00
18.11.99	2.764	30.00	205.00	668.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00
13.12.01	2.342	10.00	47.00	9.00	7.60	250.00	474.00	999.00	999.00	999.00	999.00	999.00	999.00	294.00	999.00	999.00
05.01.02	1.150	30.00	32.00	57.00	8.00	70.00	443.00	999.00	999.00	999.00	999.00	999.00	999.00	275.00	999.00	999.00
20.02.02	.375	5.00	6.00	69.00	7.70	50.00	292.00	999.00	999.00	999.00	999.00	999.00	999.00	181.00	999.00	999.00
28.03.02	1.050	6.00	63.00	20.00	7.20	100.00	502.00	999.00	999.00	999.00	999.00	999.00	999.00	311.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(i-c) Nairobi River at Outering Road bridge downstream Gikomba Open air Market

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
08.06.98	2.420	43.00	212.00	207.00	7.20	88.00	429.00	27.20	5.90	49.00	17.00	33.00	.75	283.00	92.00	97.00
29.06.98	1.815	26.50	187.00	294.00	7.30	144.00	525.00	7.00	3.50	65.00	20.00	54.00	.40	315.00	32.00	45.00
13.11.98	2.764	35.00	109.00	190.00	7.10	120.00	410.00	15.20	7.30	50.00	18.00	38.00	.80	246.00	48.00	68.00
08.12.98	2.893	168.00	508.00	206.00	7.00	176.00	535.00	12.80	9.70	60.00	20.00	48.00	.80	321.00	72.00	25.00
29.01.99	1.064	160.00	338.00	226.00	7.70	206.00	600.00	12.00	8.70	78.00	15.00	39.00	1.50	360.00	66.00	32.00
23.03.99	1.843	210.00	421.00	308.00	6.60	198.00	525.00	19.20	8.30	53.00	11.00	35.00	.64	315.00	82.00	129.00
13.04.99	2.850	90.00	140.00	113.00	6.90	120.00	546.00	23.20	8.70	48.00	9.70	49.00	.80	300.00	94.00	27.00
29.04.99	2.986	170.00	381.00	773.00	6.60	220.00	625.00	24.80	9.20	63.00	18.80	57.00	.84	375.00	100.00	90.00
23.06.99	1.246	250.00	495.00	302.00	7.10	228.00	662.00	21.60	11.70	64.00	17.50	60.00	.80	410.00	102.00	95.00
13.10.99	1.120	280.00	222.00	366.00	7.30	296.00	725.00	16.00	10.70	60.00	20.00	57.00	.65	450.00	84.00	47.00
16.11.99	2.563	220.00	653.00	286.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00
14.12.01	3.358	20.00	340.00	76.00	7.60	130.00	374.00	999.00	999.00	999.00	999.00	999.00	999.00	232.00	999.00	999.00
05.01.02	2.350	100.00	146.00	196.00	7.80	220.00	602.00	999.00	999.00	999.00	999.00	999.00	999.00	373.00	999.00	999.00
20.02.02	.675	39.00	98.00	210.00	7.00	180.00	635.00	999.00	999.00	999.00	999.00	999.00	999.00	393.00	999.00	999.00
16.03.02	.720	42.00	450.00	82.00	7.00	130.00	710.00	999.00	999.00	999.00	999.00	999.00	999.00	440.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(i-d) Nairobi River at Njiru 1 (Njiru/Kasarani road bridge) downstream Mathare River Confluence

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
25.06.98	6.224	34.00	255.00	197.00	6.90	146.00	320.00	13.60	4.90	35.00	7.20	32.00	.50	211.00	54.00	25.00
29.06.98	6.032	11.00	176.00	97.00	6.80	118.00	260.00	12.80	3.40	28.00	5.80	26.00	.50	172.00	46.00	96.00
08.10.98	4.523	83.00	620.00	87.00	7.40	136.00	445.00	15.20	6.30	36.00	16.00	37.00	.65	267.00	64.00	45.00
26.10.98	5.393	42.00	71.00	173.00	7.10	144.00	451.00	16.00	5.30	50.00	23.00	36.00	.45	271.00	62.00	103.00
23.03.99	4.678	60.00	126.00	107.00	6.80	134.00	418.00	17.60	5.30	45.00	10.00	26.00	.60	250.00	66.00	70.00
13.04.99	6.545	40.00	70.00	635.00	6.90	200.00	432.00	17.60	7.80	40.00	8.10	37.00	.60	260.00	76.00	23.00
18.05.99	4.908	155.00	427.00	481.00	7.00	168.00	481.00	20.00	9.70	45.00	18.80	40.00	.55	289.00	90.00	120.00
23.06.99	4.256	150.00	276.00	188.00	7.00	172.00	542.00	24.00	11.20	60.00	16.30	45.00	.80	336.00	106.00	90.00
13.10.99	3.192	170.00	257.00	236.00	7.70	256.00	782.00	16.80	10.70	80.00	23.00	77.00	.52	485.00	86.00	38.00
15.12.01	4.687	10.00	19.00	89.00	7.80	190.00	549.00	999.00	999.00	999.00	999.00	999.00	999.00	340.00	999.00	999.00
05.01.02	1.543	20.00	334.00	78.00	7.90	90.00	620.00	999.00	999.00	999.00	999.00	999.00	999.00	384.00	999.00	999.00
20.02.02	1.200	45.00	588.00	135.00	7.50	250.00	646.00	999.00	999.00	999.00	999.00	999.00	999.00	401.00	999.00	999.00
16.03.02	.571	23.00	190.00	86.00	7.00	210.00	682.00	999.00	999.00	999.00	999.00	999.00	999.00	375.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(i-e) Nairobi River at Njiru 2 after all river confluence near Ruai

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
29.06.98	6.981	46.00	70.00	102.00	7.10	120.00	369.00	16.80	5.30	44.00	12.00	28.00	.55	244.00	64.00	42.00
13.07.98	5.236	57.00	80.00	106.00	7.00	78.00	301.00	16.00	3.40	41.00	9.00	30.00	.68	199.00	54.00	15.00
15.12.01	4.643	40.00	268.00	157.00	7.80	200.00	561.00	999.00	999.00	999.00	999.00	999.00	999.00	348.00	999.00	999.00
05.01.02	3.546	60.00	64.00	82.00	7.80	200.00	620.00	999.00	999.00	999.00	999.00	999.00	999.00	384.00	999.00	999.00
20.02.02	1.231	26.00	254.00	94.00	7.20	260.00	500.00	999.00	999.00	999.00	999.00	999.00	999.00	310.00	999.00	999.00
16.03.02	2.505	21.00	63.00	32.00	7.20	90.00	498.00	999.00	999.00	999.00	999.00	999.00	999.00	308.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(ii-a) Ngong River at Langata Road bridge downstream Nairobi Dam and Kibera slums

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
18.05.98	1.158	11.00	131.00	182.00	6.90	76.00	340.00	22.40	5.30	32.50	14.00	28.00	.70	224.00	78.00	198.00
24.08.98	.952	21.00	34.00	150.00	10.20	108.00	464.00	24.80	4.90	41.00	18.00	40.00	.60	306.00	82.00	70.00
28.09.98	.714	1.90	73.00	36.00	7.80	96.00	436.00	15.20	2.90	41.00	24.00	50.00	1.10	262.00	50.00	15.00
21.10.98	.067	11.70	32.00	20.00	7.70	94.00	503.00	27.20	8.30	58.00	30.00	49.00	.85	302.00	102.00	22.00
13.11.98	.201	2.70	4.40	32.00	7.70	138.00	562.00	19.20	6.80	59.00	30.00	63.00	.60	337.00	76.00	19.00
08.12.98	.283	6.00	67.00	31.00	7.50	204.00	668.00	24.00	9.70	70.00	40.00	63.00	.80	401.00	100.00	14.00
29.01.99	.097	85.00	361.00	20.00	7.50	116.00	798.00	28.80	10.20	73.00	25.00	51.00	.95	480.00	114.00	8.00
18.02.99	.016	8.00	34.00	13.00	7.60	168.00	736.00	37.60	9.70	70.00	25.00	50.00	.90	445.00	134.00	12.00
20.03.99	.048	10.00	112.00	130.00	7.00	264.00	747.00	36.00	10.20	75.00	23.00	50.00	1.00	448.00	132.00	80.00
23.03.99	.168	11.00	70.00	85.00	7.30	262.00	685.00	33.60	11.20	68.00	20.00	47.00	.72	411.00	130.00	59.00
13.04.99	.096	10.00	80.00	28.50	7.50	220.00	627.00	27.20	10.20	51.00	16.00	53.00	1.00	376.00	110.00	17.00
27.04.99	.241	5.00	53.00	54.00	7.50	168.00	510.00	23.20	6.80	44.00	20.00	49.00	.75	306.00	86.00	36.00
11.05.99	.362	7.00	36.00	20.00	9.80	124.00	588.00	26.40	8.30	50.00	23.80	49.00	.84	353.00	100.00	46.00
27.05.99	.272	48.00	158.00	68.00	7.00	238.00	710.00	34.40	13.10	60.00	31.30	59.00	1.00	426.00	140.00	18.00
14.10.99	.056	30.00	81.00	19.00	7.50	158.00	780.00	33.60	11.20	85.00	40.00	84.00	.62	484.00	130.00	13.00
13.12.01	.210	20.00	55.00	57.00	7.50	240.00	581.00	999.00	999.00	999.00	999.00	999.00	999.00	360.00	999.00	999.00
05.01.02	.190	10.00	36.00	58.00	8.00	130.00	366.00	999.00	999.00	999.00	999.00	999.00	999.00	228.00	999.00	999.00
20.02.02	.160	50.00	127.00	104.00	7.70	270.00	675.00	999.00	999.00	999.00	999.00	999.00	999.00	419.00	999.00	999.00
17.03.02	.172	27.00	38.00	13.00	7.00	120.00	602.00	999.00	999.00	999.00	999.00	999.00	999.00	372.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(ii-b) Ngong River at Embakasi bridge downstream Industrial area

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
28.05.98	2.180	5.00	123.00	328.00	7.20	86.00	330.00	24.80	4.90	33.00	9.70	20.00	1.50	218.00	82.00	208.00
08.06.98	2.240	42.00	263.00	117.00	7.30	138.00	505.00	28.80	3.90	63.00	16.00	51.00	1.10	335.00	88.00	86.00
29.06.98	2.560	19.00	138.00	137.00	7.30	266.00	598.00	27.60	6.30	63.00	15.00	56.00	.70	395.00	94.00	80.00
24.08.98	1.680	42.00	209.00	118.00	8.40	143.00	415.00	22.40	9.00	43.00	13.00	28.00	.85	274.00	112.00	93.00
28.09.98	.945	48.00	274.00	326.00	7.60	210.00	710.00	24.00	6.30	90.00	23.00	60.00	1.30	426.00	86.00	35.00
26.10.98	.563	66.00	413.00	98.00	7.10	176.00	531.00	20.00	6.80	63.00	18.00	41.00	1.50	319.00	78.00	11.00
29.01.99	.097	200.00	647.00	461.00	7.40	268.00	835.00	18.40	7.80	105.00	15.00	55.00	.50	510.00	78.00	45.00
20.03.99	.194	150.00	435.00	228.00	6.90	280.00	750.00	23.20	8.30	80.00	15.00	33.00	1.20	450.00	92.00	80.00
23.03.99	.250	60.00	168.00	110.00	7.00	242.00	605.00	24.00	9.70	74.00	13.00	33.00	1.50	363.00	100.00	59.00
13.04.99	.580	40.00	56.00	48.00	7.10	190.00	555.00	23.20	9.20	54.00	9.50	43.00	1.20	335.00	96.00	38.00
18.05.99	.475	35.00	83.00	94.00	7.00	122.00	611.00	28.00	12.60	66.00	18.80	56.00	1.15	367.00	122.00	53.00
23.06.99	.356	16.00	162.00	202.00	7.00	174.00	655.00	30.40	9.70	86.00	16.30	63.00	1.50	406.00	116.00	112.00
13.10.99	.267	50.00	489.00	79.00	7.80	288.00	777.00	21.60	7.30	83.00	20.00	63.00	.70	482.00	94.00	28.00
14.12.01	.476	50.00	363.00	96.00	7.40	280.00	687.00	999.00	999.00	999.00	999.00	999.00	999.00	426.00	999.00	999.00
05.01.02	.395	130.00	473.00	65.00	7.20	280.00	813.00	999.00	999.00	999.00	999.00	999.00	999.00	504.00	999.00	999.00
20.02.02	1.032	140.00	290.00	81.00	7.80	240.00	940.00	999.00	999.00	999.00	999.00	999.00	999.00	580.00	999.00	999.00
16.03.02	1.764	49.00	158.00	128.00	7.40	260.00	760.00	999.00	999.00	999.00	999.00	999.00	999.00	474.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(iii-a) Mathare River at Thika Road Bridge

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
22.06.98	.822	39.00	183.00	43.00	6.50	80.00	298.00	27.20	11.70	36.00	5.90	152.00	.38	196.00	116.00	44.00
28.09.98	1.563	18.60	62.00	78.00	7.50	70.00	316.00	16.00	4.40	34.00	7.80	32.00	.50	190.00	58.00	5.00
13.11.98	1.736	.80	26.00	45.00	7.50	98.00	325.00	15.20	4.90	48.00	15.00	35.00	.60	195.00	58.00	23.00
08.12.98	1.815	15.00	22.00	16.00	6.90	102.00	350.00	14.20	6.30	50.00	13.00	33.00	.60	210.00	62.00	5.00
18.02.99	.145	50.00	118.00	104.00	7.00	126.00	355.00	15.20	10.20	40.00	7.80	19.00	.50	213.00	80.00	62.00
23.03.99	.133	70.00	112.00	43.00	6.60	148.00	352.00	15.20	6.30	44.00	6.90	20.00	.60	211.00	64.00	33.00
13.04.99	.178	13.00	19.00	43.00	6.90	120.00	366.00	20.00	6.30	41.00	6.00	31.00	.60	220.00	76.00	42.00
27.04.99	.227	7.00	71.00	30.00	7.20	100.00	330.00	16.00	6.80	30.00	8.80	33.00	.85	198.00	68.00	56.00
23.06.99	.570	50.00	103.00	68.00	7.20	110.00	350.00	16.00	7.30	32.00	9.40	35.00	.70	217.00	70.00	30.00
13.10.99	.433	50.00	539.00	59.00	7.50	140.00	412.00	13.60	5.30	41.00	11.00	26.00	.55	254.00	56.00	20.00
19.10.99	.467	70.00	742.00	1245.0	7.10	158.00	424.00	20.00	5.30	40.00	13.00	26.00	.52	263.00	72.00	65.00
14.12.01	.921	100.00	190.00	36.00	7.00	100.00	283.00	999.00	999.00	999.00	999.00	999.00	999.00	175.00	999.00	999.00
05.01.02	.158	20.00	202.00	147.00	7.80	130.00	370.00	999.00	999.00	999.00	999.00	999.00	999.00	229.00	999.00	999.00
20.02.02	.180	28.00	302.00	56.00	7.00	120.00	355.00	999.00	999.00	999.00	999.00	999.00	999.00	221.00	999.00	999.00
28.03.02	2.500	23.00	70.00	46.00	7.00	240.00	397.00	999.00	999.00	999.00	999.00	999.00	999.00	247.00	999.00	999.00

APPENDIX I-(WATER QUALITY DATA)

(iii-b) Mathare River at outering road bridge downstream Mathare slums

Date	Discharge	BOD5	COD	TSS	pH	T.Alka	COND	Ca	Mg	Na	K	Cl	F	TDS	T.Hard	Turb.
29.05.98	1.630	10.00	157.00	183.00	7.40	86.00	326.00	19.20	4.90	39.00	9.50	31.00	.57	215.00	68.00	118.00
22.06.98	1.656	60.00	167.00	194.00	6.90	108.00	329.00	42.40	16.00	22.00	5.90	25.00	.38	217.00	172.00	24.00
28.09.98	2.563	29.00	169.00	156.00	6.60	68.00	339.00	14.40	6.30	31.00	12.00	37.00	.62	203.00	62.00	19.00
08.12.98	2.697	20.00	167.00	144.00	7.20	114.00	415.00	16.00	5.30	40.00	15.00	42.00	.60	249.00	62.00	11.00
14.12.98	2.863	100.00	441.00	147.00	6.80	136.00	448.00	13.60	8.30	50.00	20.00	39.00	.45	269.00	68.00	20.00
18.02.99	.081	230.00	487.00	351.00	68.00	170.00	520.00	16.80	8.30	50.00	14.00	33.00	.35	312.00	76.00	74.00
23.03.99	.134	340.00	646.00	436.00	6.50	218.00	546.00	16.80	9.20	58.00	14.00	33.00	.54	328.00	80.00	159.00
13.04.99	.216	330.00	690.00	434.00	6.50	190.00	545.00	15.20	11.20	46.00	10.00	46.00	.55	327.00	84.00	140.00
27.04.99	.227	40.00	134.00	63.00	7.60	112.00	268.00	12.00	10.20	25.00	9.00	10.00	1.50	161.00	72.00	86.00
23.06.99	.217	260.00	365.00	266.00	7.20	212.00	587.00	20.00	12.60	53.00	18.80	48.00	.60	364.00	102.00	82.00
13.10.99	.189	370.00	4300.0	390.00	7.40	278.00	753.00	20.00	10.70	60.00	25.00	54.00	.35	467.00	132.00	99.00
19.10.99	2.453	560.00	225.00	104.00	7.00	366.00	934.00	28.80	12.60	75.00	33.00	68.00	.60	580.00	126.00	190.00
16.11.99	2.892	150.00	360.00	192.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00	999.00
14.12.01	1.861	100.00	774.00	254.00	7.50	240.00	782.00	999.00	999.00	999.00	999.00	999.00	999.00	484.00	999.00	999.00
05.01.02	1.750	320.00	947.00	560.00	7.60	320.00	862.00	999.00	999.00	999.00	999.00	999.00	999.00	534.00	999.00	999.00
20.02.02	.588	350.00	474.00	109.00	7.00	290.00	877.00	999.00	999.00	999.00	999.00	999.00	999.00	544.00	999.00	999.00
16.03.02	.680	70.00	403.00	187.00	7.00	220.00	430.00	999.00	999.00	999.00	999.00	999.00	999.00	695.00	999.00	999.00