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CHAPTER 1: INTRODUCTION

1.1 Introduction

In the past two decades, Upper Kafubu River has experienced environmental degradation resulting from rapid urbanisation and industrialisation in the catchment, which required detailed investigation. This study characterised the water of Kafubu River and treated water in the urbanised reach of Ndola town located 20 km upstream of Kafubu Dam (Figure 1.1), in terms of physical, chemical and bacteriological regimes in the period 1992-99. The characterisation of water in Ndola will not only enhance the understanding of the physico-chemical and bacteriological regimes of Zambian streams, but also fill in some gaps that exist in knowledge of the limnology of small and medium streams running through towns. Such streams are recipients of both municipal and industrial effluents. Recent years have experienced a growing awareness in the understanding of the effects of man's activities on all facets of the environment. The 21st century, is likely to be marked by increasing uncertainty, not only by rare catastrophic events, but also in the entire hydrological regimes which control domestic, agricultural, industrial, energy and environmental use of water (Peters and Walling, 1991). Water degradation worsened in the 20th century as industrialisation and urbanisation, accompanied by poor waste treatment practices, strained water resources and sanitation services (UNEP/GEMS, 1991). Thus, there is a particular need to conserve the natural habitat of these waters and find more effective ways of pollution monitoring and control measures put in place. In both developed and developing countries, sewage, nutrients, toxic metals, industrial and agricultural chemicals are the main water pollutants. In developed countries pollution of surface waters by indiscriminate discharge of polluting

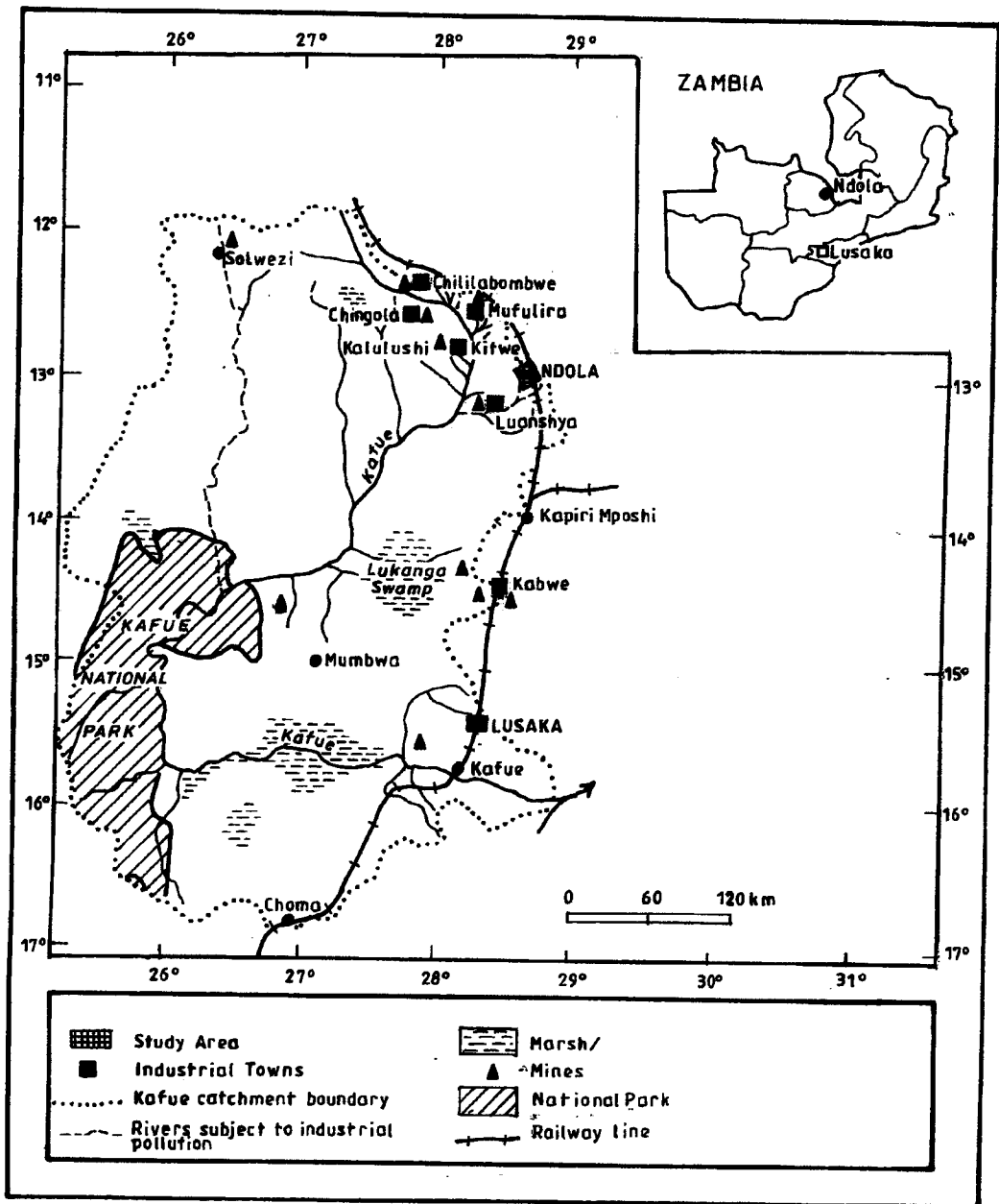


Figure 1.1. Location map of Ndola in Zambia.

substances have almost been fully addressed while it remains a big problem in most of the Third World countries. For instance, it is believed that untreated water in developing countries causes an estimated 25 000 deaths a day either because infected water is consumed or because its use leads indirectly to infection from vector-borne diseases such as bilharzia (UNEP/GEMS, 1991). Municipal and industrial wastewaters are largely being released into the environment, most of which are eventually transferred into water bodies used by various communities. This occurs throughout Third World countries and examples of pollution are numerous. In Zambia, various reports of water pollution exist e.g. (Grava, 1969; Iwugo, 1977; Obrdlik, 1984; Sawula, 1985; Kamona, 1990; Kasonde, 1990; Mwiinga, 1990; Simuunza, 1992; Paterson and Ingri, 1993; Mutale, 1994; Hedstrom and Osterman, 1996; Musonda and Simashikwe, 1997; Berglin, 1997; and Tembo *et al.*, 1997).

1.2 Background to the Study

The Copperbelt region is the most important economic region in Zambia though it occupies just over one percent of the total area of the country. In 1990, it contained about 20% of the country's population with Ndola town, in particular, having a population of 376 000 (Naidoo and Bwalya, 1995). A lot of copper and cobalt is mined in the Copperbelt region. In turn, the mining industry has attracted many secondary and tertiary industries such that it is the most industrialised part of the country.

The Kafue River and its tributaries draining the Copperbelt region, including Kafubu River in Ndola, are believed to be highly contaminated by mining, industrial and domestic wastewaters (Iwugo, 1976; Sawula, 1985; Kasonde, 1990; Nsomi, 1991; Mwiinga, 1990; Water Pollution Control Unit, 1994; Backstrom and Jonsson, 1996; Hedstrom and Osterman, 1996; Musonda and Simashikwe, 1997; and Steffen and

Kirstern, 1997). According to Kasonde (1990), in the study of the Upper Kafue basin, the Kafubu River is the second grossly polluted stream in Zambia after the Kafue River. It is this background that prompted this study to investigate the physico-chemical and bacteriological characteristics of Kafubu River for the purposes of determining its characteristics, assessing the quality of its water and the quality of treated water provided to Ndola town residents.

1.3 Research Objectives

The aim of this study was to characterise the nature of Kafubu River in terms of physico-chemical and bacteriological constituents. The specific objectives were to:

- (i) characterise the hydrological regime of Kafubu River;
- (ii) characterise raw and treated river water in terms of physico-chemical and bacteriological constituents;
- (iii) assess the relationship between stream discharge and quality parameters of raw river water;
- (iv) determine sources and pollutants in wastewaters;
- (v) determine the factors controlling the quality of water in the urbanised reach of Kafubu River;
- (vi) assess the efficiency of pre-treatment and treatment facilities for industrial plants, sewage works and the water treatment plants in Ndola.

1.4 Scope

The quality of river water is dependent on the natural processes of weathering of rocks, atmospheric processes of evapotranspiration and deposition of dust and salt by wind, natural leaching of organic matter and nutrients from soils and by hydrological

factors that lead to runoff as well as anthropogenic influences which generate various types of pollution including domestic, agricultural and industrial wastes from point or non-point sources. Consequently, determination of the water quality in this study involved analysis of the following water quality parameters i.e. temperature, total suspended solids (TSS), total dissolved solids (TDS), total hardness, total alkalinity, calcium and magnesium hardness, turbidity, chloride, colour, chemical oxygen demand (COD), total coliforms, *E.coli*, taste and odour. The main activities involved collection of water samples of both raw and treated river water for physico-chemical and bacteriological analyses to ascertain the degree of deterioration in its quality and the palatability of drinking water offered to consumers by the civic authorities in Ndola. The selection of quality parameters highly depended on the availability of laboratory equipment and reagents, time for analysis, and financial resources. Additionally, water quality standards needed for both discharging effluents in the aquatic environment (ECZ, 1993) and the criteria needed for “first class” uses of water such as drinking, cooking and washing (WHO, 1971; JICA, 1995 and International Programme on Chemical Safety (IPCS), 1997) were taken into account.

In order to assess the magnitude of pollution on Kafubu River and to evaluate both spatial and temporal variations in water quality, the following considerations were taken into account:

- (i) Water quality analyses on physico-chemical constituents were to be within Ndola at Kanini and Indeni laboratories using standard laboratory methods.
- (ii) Sampling stations used for river and tap water had to include existing Ndola City Council sampling stations due to the secondary data included in this study.

- (iii) The process of self-purification was to be taken into account through proper selection of sampling stations over a stretch of approximately 20 km due to the important role it plays in water quality changes in the downstream direction.
- (iv) Stream discharge was to be measured at two-week intervals in conjunction with Water Affairs, Hydrological Branch, Kitwe office.
- (v) Rainfall data from the station at Ndola Airport were to be used for medium term analysis of rainfall variations in the study area.

1.5 Justification of the study

A supply of clean water is an essential requirement for the establishment and maintenance of a healthy community. There is evidence that Kafubu River in Ndola is highly polluted by municipal and industrial wastewater (Kasonde, 1990; Nsomi, 1991 and Mwiinga, 1990). Most of the industries in the town either have no pre-treatment plants or have one but is insufficient to remove constituents to recommended levels. The discharge of effluents directly into the river or via the three sewage treatment plants which are also ineffective, have caused deterioration in the quality of Kafubu River water and to the quality of drinking water provided to Ndola residents (Kasonde, 1990; Nsomi, 1991). Consequently, there has been a growing awareness of the environmental problem in the area. For instance, there is a rising number of consumer complaints to the Ndola City Council on the unwholesomeness of water it provides, which is a major concern requiring a comprehensive study on the potability of Kafubu River water (e.g., the author saw letters from the general public to the Director Ndola Water and Sewerage Department). Upper Kafubu River has also recently become eutrophic in some places such as Itawa Swamps and Kafubu Dam due to pollution.

Data gaps also exist in the knowledge of the characteristics of Kafubu River. For instance, recent studies undertaken in Kafubu catchment have not covered some aspects of the water quality surveillance largely because they either looked at pollution in the whole Kafue basin (Kasonde, 1990; Mwiinga, 1990) or concentrated on particular human activities (Nsomi, 1991; Musonda and Simashikwe, 1996). Additionally, the data on physico-chemical and bacteriological characteristics of Kafubu River, which is available at Ndola City Council Water and Sewerage Department, has not been analysed and properly documented. As such, the present study has utilised this existing data available at these institutions in order to fill in the gap in knowledge of Kafubu River. It is hoped that the study will help in finding optimal solutions to current water quality problems in Ndola.

The chapter following reviews relevant literature to the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter gives an overview of water as a resource and the dynamic nature of the global fresh water. It reviews the problem of pollution and its sources, the types of pollution and effects of pollution on human health and the natural environment.

2.2 Water Quality at Global Level

The amount of water on earth is said to be constant and cannot be increased or decreased. Of the global total of 1360 million km³ of water that covers about seventy percent of the earth's surface, only three percent is fresh and of that, less than one percent is available for human use in rivers and lakes (UNEP/GEMS, 1991). Many arid and semi-arid parts of the world are already without reliable resources of fresh water due to uneven distribution of rainfall, surface water and ground water. Worse still, the amount of water of acceptable quality available for human use is reduced further due to anthropogenic influences, which result into water degradation by domestic, industrial and agricultural pollution. Chenje and Johnson (1996) predicted that severe water shortages are likely to afflict much of southern Africa, including Zambia, by the year 2050, causing poverty and child malnutrition to mushroom. Countries like South Africa and Malawi will have suffered acute water shortages and others like Zimbabwe, Mozambique and Tanzania will experience water stress. Zambia, Angola, Namibia and Botswana will experience water quality and dry season problems. This will be so not because of the region being drought-prone and the common periodic water scarcity but mainly due to water wastage at every stage of its management. According to Chenje and Johnson (1996), water harvesting techniques are generally poor; the delivery system is wasteful;

the pricing regimes are generally not cost effective; consumption levels are high (particularly in urban areas); pollution control is generally ineffective and actual management is fragmented, often among institutions with competing interests.

The demand for water is expected to increase in most urban areas in direct proportion to the growth of the standards of living, industrialisation and urbanisation due to the expected increase in population. In most cases, the demand for water supply in urban areas already outstrips supply mainly due to population increase and obsolete infrastructure. Most urban areas, especially in Third World countries, are already facing such problems of inadequate and insufficient water supplies despite the plenty fresh water resources these countries have (Chenje and Johnson, 1996).

Other environmental problems faced by urban areas include that of insufficient clean drinking water and lack of sewage treatment or minimally treated sewage from both domestic and industrial activities. These human and other wastes have impacted on the quality of water due to growth in population and industrial development which ultimately calls for increased number of sewage treatment plants, pit latrines as well as industrial and agricultural activities. This increases the levels of health hazards that can cause water-borne diseases. A report by UNEP/GEMS (1991), states that water pollution in these Third World countries worsened in the 20th century as industrialisation and urbanisation, accompanied by poor waste treatment practices, have strained water resources and sanitation services. For instance, more than eighty percent of all illnesses in the developing world was said to be due to inadequate, unsafe water supply and sanitation facilities, such that four million children die each year from diarrhoea caused by water-borne pathogens. Two-thirds of the world population lack adequate sanitation facilities, and only fifty percent of urban dwellers have proper sewage disposal (UNEP/GEMS, 1991). Zambia, like many Southern Africa countries, faces problems of

inadequate and insufficient water supplies. The quality of Zambian river water is further discussed in the succeeding sections below.

2.3 Quality of Zambian River Waters

Zambia has at least four main rivers i.e. Zambezi, Kafue, Luangwa and Chambeshi- Luapula that dissect the country and run throughout the year. These rivers drain areas with low population densities and their physico-chemical status is unobserved. For instance, the Luangwa River passes through a tsetse-infested region with extremely low population densities and virtually no industries. The water condition of the Luangwa has been said to be of good quality except for the high turbidity arising out of high erosion that results in high levels of suspended solids (JICA, 1995). The Chambeshi similarly drains an area of low population and industrial density. Its waters are generally of good quality though Sharma (1982) indicates that the waters of the Chambeshi displayed a tendency of being acidic in nature particularly in the rain season. The same study showed that there were also incidences of iron content exceeding the permissible limits (0.3 ppm) in some places within the basin. Symoens (1968) published results on the analyses of the leading cation and anions in natural waters of Bangweulu and Luapula basins. The waters were found to be of good quality in most parts of the basins except in the lower reaches of the Luapula River where population densities are high and the fishing and use of water transport resulted in faecal contamination resulting in the first major reported outbreaks of cholera in the late seventies (Mucheleng'anga, 1998).

The Zambezi River, the most important river in the generation of hydro-electricity and also a source of water for rural and urban communities along it, is said to have good water quality except below the Victoria Falls (Mucheleng'anga, 1998). The major studies done in the lower Zambezi include that by Coche (1968) that mainly

involved descriptions of physico-chemical aspects of Lake Kariba. Choche, (1968:202) described the lake as “a warm monomictic reservoir whose physical characteristics are dependent upon the Zambezi River (upper third of the lake) and the climatic conditions (lower half of the lake).” Chemically, the lake water was described as being mesotrophic with the epilimnion water having pH of 8.0, total alkalinity of 40 ppm and specific conductivity of about 90 μ mhos/cm. Similarly, Sichingabula (1997; 1999) reported on some point sediment yields of the Zambezi River in the Lower Zambezi National Park and on five rivers in the Lake Tanganyika basin.

Although there is little available data on the physico-chemical regimes of small streams affected by urbanisation in Zambia, some of studies have been carried out on the Chongwe-Ngwerere river system, a subcatchment of the Zambezi. Iwugo (1977) indicated that the wastewaters and river water of the Ngwerere-Chongwe river system was extensively used for both “first class” purposes such as drinking, cooking, washing and also “second class” purposes such as gardening and irrigation. At this time although the relatively large volumes of sewage effluents discharged into Ngwerere stream were only slightly diluted by the river water, the hydraulics of the system was such that considerable self-purification occurred within 20 km of flow from the point of major pollution input into the system. Therefore, the chemical quality was still within the WHO quality standards for water sources. Obrdlik (1984) observed the same trend in the water chemistry of the Chongwe-Ngwerere river system but observed high occurrence of high numbers of coliform and psychrophilic bacteria. Though pollution was gradually eliminated due to self-purification of the Ngwerere downstream of the Manchinchi sewage treatment plant, the water of the upper catchment were originally polluted by municipal wastewaters from Lusaka which was significantly reflected in the oxygen regime, an increase in the total mineralization of water and the occurrence of pathogens.

Five years later, pollution levels in the Ngwerere were found to have increased due to domestic and trade effluents that resulted into almost complete deoxygenation of waters in the source tributaries of Ngwerere (Kamona, 1990). Kamona (1990) found *E. Coli* concentrations also ranged from 1,100 to 6 200; total coliforms ranged from 1,100 to 6 810. A similar trend on the same river was observed by Tembo *et al.* (1997). Self-purification was still evident in downstream sampling stations though all physico-chemical and bacteriological parameters carried out in the study area were higher than the WHO standards for drinking water, watering cattle, irrigation and could hardly support any fish population.

2.3.1 Water Quality Characteristics in the Kafue River Basin.

The Kafue River basin plays a very important role in the national economy of Zambia for it contains major mining installations (for copper, cobalt, zinc, manganese, lead etc), and towns (Ndola, Kitwe, Chingola and Luanshya), and important industrial plants such as Indeni Petroleum Refinery, Kafue Nitrogen Chemicals, Kafue textiles, Bata Tannery and many others situated in its basin.

The Kafue basin covers an area of 154 000 km² spread entirely within the Zambian territory (Mwiinga, 1990) (Figure 1.1). Hydrological information is available for Lower Kafue basin at the Kafue Gorge and Itezhitezhi Dams and information on hydrological and water balance characteristics for Upper Kafue River also exists (Balek 1970; 1971; 1977 and Sharma, 1984). But little analyses have been done on the physico-chemical and bacteriological regimes for most of the river basin.

Iwugo (1976) indicated that pollution on Kafue River was from industrial and agricultural activities around Kafue town and concluded that the Kafue River was threatened by eutrophication and the profuse growth of aquatic weeds that may adversely

and less downstream (Mucheleng'anga, 1998). Similarly, the Copperbelt had higher concentrations of metals such as cobalt, chromium, silver, nickel, tin, zinc, lead, cadmium and vanadium which were found to be 4 to 100 times higher than those between Itzhitezhi Dam and the Kafue town (Mucheleng'anga, 1998).

Tributaries of the Kafue River on the Copperbelt such as Kitwe, Mufulira, Mwambashi, Kafubu and those draining Chingola town serve as recipients of widely varying effluents from mining, domestic and industrial sources. For instance, an extensive study carried out by Mwiinga (1990) covering 130 km on the Kafue (Raglan's farm to Wusakile Bridge) and in which all major streams between Chililabombwe and Luanshya were monitored. The study indicated that effluents of differing nature and character resulting from various activities such as mining, industrial and domestic waste disposal polluted these streams. Based on colour, turbidity, total hardness, iron, manganese and copper concentrations, Mwiinga's (1990) study recommended that the water of this area was not to be consumed in its untreated form and that the river's natural dilution of effluents could not be relied on as there were indications that the capability to handle effluent was decreasing.

Sawula (1985) characterised the nature and quality of Kafue River water in Chingola and the quality of treated water provided to the residents. The study indicated that water quality was adversely affected by discharged mine effluents from tributary streams and mine dumps containing copper, cobalt and manganese. The runoff from mine dumps and tributary inputs, especially in the rain season, had contributed significantly to the adverse increases in the river water concentrations of total solids, total hardness, conductivity, colour, turbidity, copper, cobalt, manganese and iron which exceeded maximum WHO recommended levels in raw water. The chemical additive dosage levels provided by the Chingola water treatment plant was said to be insufficient,

affect the wholesomeness of the water supplied to Lusaka and Kafue towns. Today water weed is a major problem to fishing, recreation and transport on Lower Kafue River.

The Kafue and its numerous tributaries such as Mwambashi, Kitwe, Mufulira, Luanshya and the Kafubu-Kafulafuta serves as a source of water for agricultural, industrial and municipal water supply as well as waste depository for several towns in the Copperbelt. The river is also a source of water for several peasant farmers for drinking water and livestock, and it also supports extensive areas for fishing.

In this regard, the protection of water resource and proper water and waste management are of paramount importance. Water resources, including water supplies, are naturally subjected to some degree of long-term degradation in the quality due to seasonal hydrological changes. The Kafue and its tributaries are believed to be greatly polluted by mining, industrial and domestic wastes. Kasonde (1986) alluded to the lowering of the quality of the water in the Kafue in the period 1978 to 1985. In another surveillance network between 1987 and 1996 Kasonde (1990) identified eutrophication of Kafubu Dam, siltation of the Kafue River below Hippo Pool and lack of maintenance of sewers as major environmental problems in the Upper Kafue basin. Paterson and Ingri (1996) alluded to an increase in both the dissolved and suspended solids in the water of the Kafue on the Copperbelt and also observed an increase in trace elements. Mwase *et al.* (1994) also indicated that there were higher concentrations of copper in sediments (8000 ppm) in the Copperbelt area of the Kafue River and that these concentrations dropped significantly in downstream direction. Sinkala and Simukanga (1996) later indicated that the same area had at least 1000 ppm of copper in the sediment samples of the Kafue. The same trend was observed in fish as it was found that there was a higher concentration levels of copper in fish from Kafue River on the Copperbelt (2310 ppm)

contributing to excessive treated water colour of up to 25 colour units, high turbidity (38 NTU), iron (4.75 mg/L), copper (0.75 mg/L) and manganese (0.16 mg/L) all above recommended WHO maximum acceptable concentration levels in drinking water.

Another extensive study was carried out by Nsomi (1991). This study was an evaluation of all water treatment plants in the Copperbelt region. Though the waters were chemically suitable for drinking, all the water works studied were highly contaminated by pathogens. The presence of “indicator” bacteria namely, coliforms, *E. coli* and faecal streptococci in treated water indicated inadequate disinfection while the presence of faecal clostridia provided evidence of inefficient sand filters which could have been due to clogging. The Kafubu and Itawa water works were found to be grossly contaminated with *E. coli* with one hundred percent of the water sampled at Itawa Water Works having faecal bacteria present while at Kafubu Water Works eighty percent of the water samples had *E. coli* and sixty percent had faecal streptococci and clostridia present (Nsomi, 1991).

Studies done on the Kafubu River basin, other than those previously mentioned (Kasonde, 1985; Mwiinga, 1990; Nsomi, 1991) include that of Musonda and Simashikwe (1996) that was basically on the impact of Ndola Lime mining area on Kafubu aquatic environment. The study only covered a very small area in the Itawa Swamps and indicated that the mine effluents had no adverse effect on the river system.

A qualitative report carried out by the Environmental Council of Zambia (Water Pollution Control Unit, 1994) on Kaloko and Munkulungwe River proved the allegations and indicated that the quality of water was not compliant with relevant discharge standards due mainly to oil contamination.

The present study investigated the most important part of the Kafubu River, the Upper Kafubu, which provides the bulk water used by the two water treatment plants,

which provide drinking water to Ndola residents. In doing this type of study there is need to look at existing measures of controlling pollution.

2.4 Water Pollution Control Standards in Zambia.

The Environmental Council of Zambia (ECZ) is responsible for establishing water quality and pollution control standards, and carrying out investigations of actual or suspected water pollution including the collection of data. The Environmental Protection and Pollution Act (1990), states:

No person may discharge or apply any poisonous, toxic, ecotoxic, obnoxious or obstructing matter, radiation or other pollutant or permit any person to dump or discharge such matter or pollutant in the aquatic environment in contravention of water pollution control standards established by the Council under this part.

The ECZ Inspectorate has the authority to grant licenses for discharge of effluent. Basically these regulations are set to help reduce water pollution in Zambia and on drawing and discharging water and wastewater into the natural environment. The list of standards is presented in Appendix I. The water quality standards set by the regulations lists 59 items, including limits to physical, bacteriological and chemical content and specify conditions for metal, organic and radioactive materials. Some international drinking water standards on the parameters tested in this research are listed in Appendix II.

In Zambia, under the environmental regulatory system, manufacturers and individuals that do not meet the regulations are fined or penalised. These regulations set by ECZ are already in place though reinforcement in most cases still remains “a pipe

dream". Although these regulations are a statutory instrument of the Environmental Protection and Pollution Control Act of 1990, the absence of an established system in the enforcement of pollution control policies has contributed to perpetual negligence, and indiscriminate discharge of industrial effluents into the aquatic environment. These regulations require the polluter to obtain a license to discharge effluents, keep records and samples of effluents and analysis, and the registration of license and enforcement notices. The license to discharge effluents or to withdrawal water for treatment of effluent costs about US\$40. The procedure of reinforcement is in such a way that ECZ will call upon the polluter to take adequate measures to prevent the contamination. A penalty is imposed upon failing to take action within the specified period (Personal communication with ECZ Director). The problem with this Act is that the polluter cannot police himself and provide data that are incriminating. As such the practice should cease, rather independent institutions or individuals should do the monitoring work.

2.5 Legal Framework for Commercial Utilities in Zambia.

The water supply and sanitation sector is undergoing a revolution. Having once been thought to be a "free service" sector, it is now being considered as a possible investment sector from private enterprise both local and foreign (Mucheleng'anga, 1998). The passing of the water supply and sanitation Bill in 1997 was a great achievement in the sector reforms. The bill included creation of commercially viable water supply and sanitation utilities by various local authorities and also the National Water and Sanitation Council (NWASCO) (National Water Supply and Sanitation Act, 1997).

The government, by adopting a policy of community participation and ownership of water supply and sanitation facilities, also promoted the participation of the private

sector. The formation of commercially viable water supply and sanitation utilities by the local authorities is an appropriate way of providing service that is not free but paid for.

With the deterioration in the quality of water in this country, monitoring of the quality of water being supplied to the residents by the commercial utilities becomes inevitable. Therefore, the merging of Ndola, Luanshya and Masaiti which share one water resource, the Kafubu River may help to improve the water quality problems currently prevailing and make it more commercially viable. To achieve this, increased knowledge of the character of Kafubu River through research was vital.

The chapter following describes the physical setting of the study area, the Upper Kafubu River basin.

CHAPTER 3: THE STUDY AREA

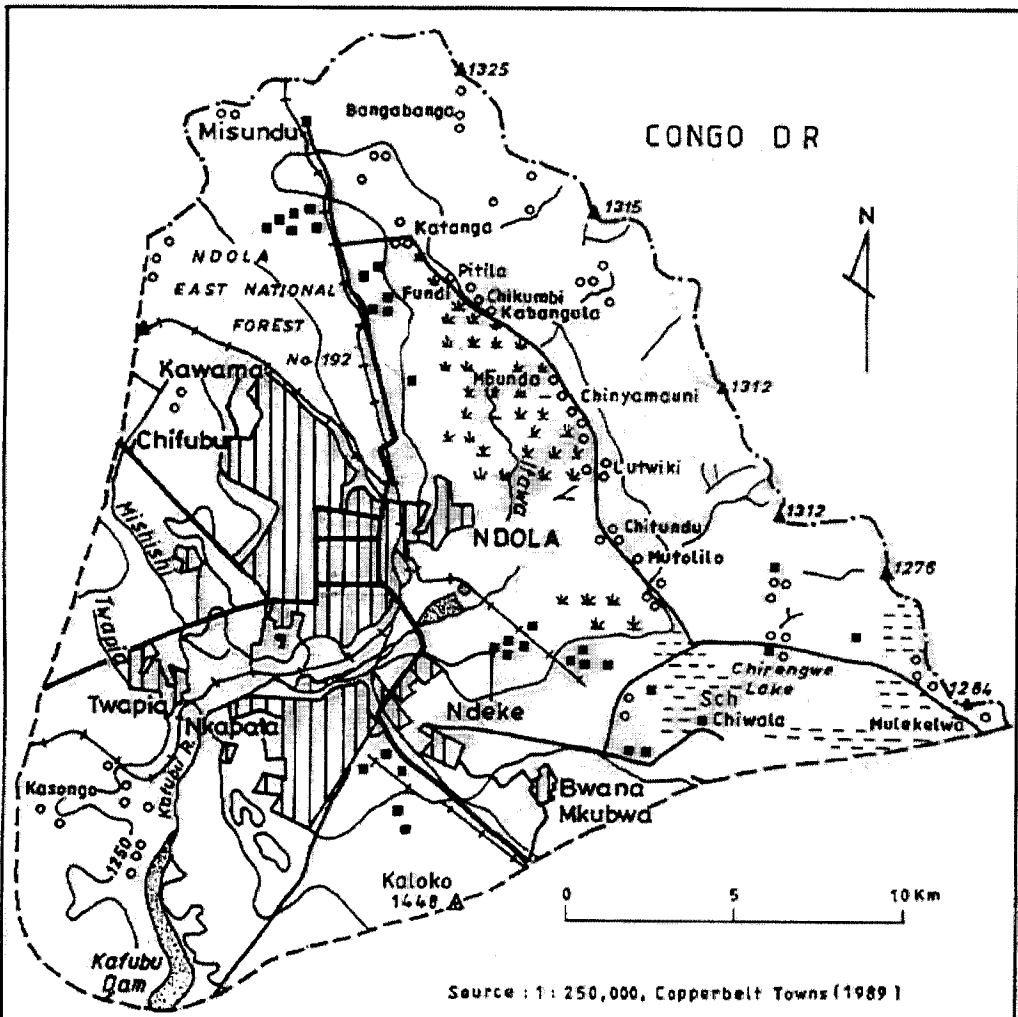
This chapter describes the physical setting of the study area, which includes lithology, hydrology, climate, vegetation and landuse of the Upper Kafubu River system.

3.1 Location and Size

The Upper Kafubu River basin is located upstream of Kafubu Dam, and has a drainage area of 60km² (Figure 3.1). It lies between 12° 50' and 13° 04' south of the equator and Longitudes 28° 35' and 28° 49' east. Kafubu River is a subcatchment of Kafulafuta River that drains into the Kafue River. The Kafubu originates from Itawa Swamps located north of Ndola on the Zambia-Congo D.R. border (Figure 1.1). It is about 40 km long and starts as Itawa stream in the north and only becomes Kafubu River after the Itawa Dambo. The Kafubu River flows southwestwards and joins Kafulafuta River south of Luanshya. The main tributaries found in Upper Kafubu catchment are Kansengi, Kansenshi, Twapia, and Mushili and Kabushi streams.

3.1.1 Topography

Most of Upper Kafubu River lies on a plateau varying in elevation from about 1200 m in the south to 1300 m in the north (Figure 3.1). The topography of the basin ranges from undulating highlands to flats, with isolated hills such as the Kaloko Kopje. A very noticeable feature of the basin is the presence of the Itawa Dambo that covers about one third of Upper Kafubu basin. This is a highland dambo system lying above 1200 m above sea level (Acres *et al*, 1985; Mackel, 1985; 1986).



KEY

- | | |
|-----------------------------------|--|
| ----- Upper Kafubu Catchment Area | - - - - - International Boundary |
| ▣ City, Town or Large Settlement | ▲ Trigonometrical Point, Boundary Pillar |
| ○ Village | -1250- Contour Line (Metres) |
| ■ Permanent Building | ~ River |
| — Main Tarmac Road | ~ ~ ~ Swamp, Dambo |
| — Maintained Road | |
| —+— Railway Line | |

Figure 3.1. Map showing the topography and drainage network of Upper Kafubu River basin.

3.1.2 Geology

Although structurally simple, the geology of Upper Kafubu catchment is characterised by numerous rock-types (Figure 3.2). It is mainly underlain by deep weathered sedimentary rocks of the Katanga Super Group further subdivided into Kundelungu Series, Mwashia Group, Roan and Mine Groups (Moore, 1968). The other geological formations include the Basement Complex at Kafubu Dam area and the Post Katanga System in the Bwana Mkubwa area. The area at the border between Zambia and Congo D.R. is underlain by the Lower Kundelungu Border Formation composed of calcareous mudstone and siltstone. Another Lower Kundelungu Series, the Kakotwe Formation, underlies the ill-drained Itawa Dambo. This dambo is composed of limestone, dolomite and shale that have a high storage capacity of water.

The city of Ndola is mainly built on the Upper Roan Group consisting of dolomite, argillite quartzite, and shale, except for residential areas north-west and north of the Central Business District (CBD) which are on the Basement Complex made up of gneiss and foliated granite. Strips of the Lower Roan Group (Footwall Formation), composed of feldspathic quartzite arkose and conglomerate, and the Mine Series (Hangingwall and Ore Formations) that consists of chert, sandstone, siltstone, greywacke, argillaceous and feldspathic quartzite dissect the city of Ndola in a NW to SW direction. Another strip of the Footwall Formation is found in the Bwana Mkubwa area with strips bordering the Basement Complex and the Upper Roan Group. Post-Katanga System consisting of gabbro is found in the Bwana Mkubwa Mine area.

Lastly, the Kafubu Dam is built on the Basement Complex made up of gneisses, foliated granite and the quartz-mica schist. The course of Kafubu River is controlled by anticlinal axes and in places follows the deeply weathered carbonate formation.

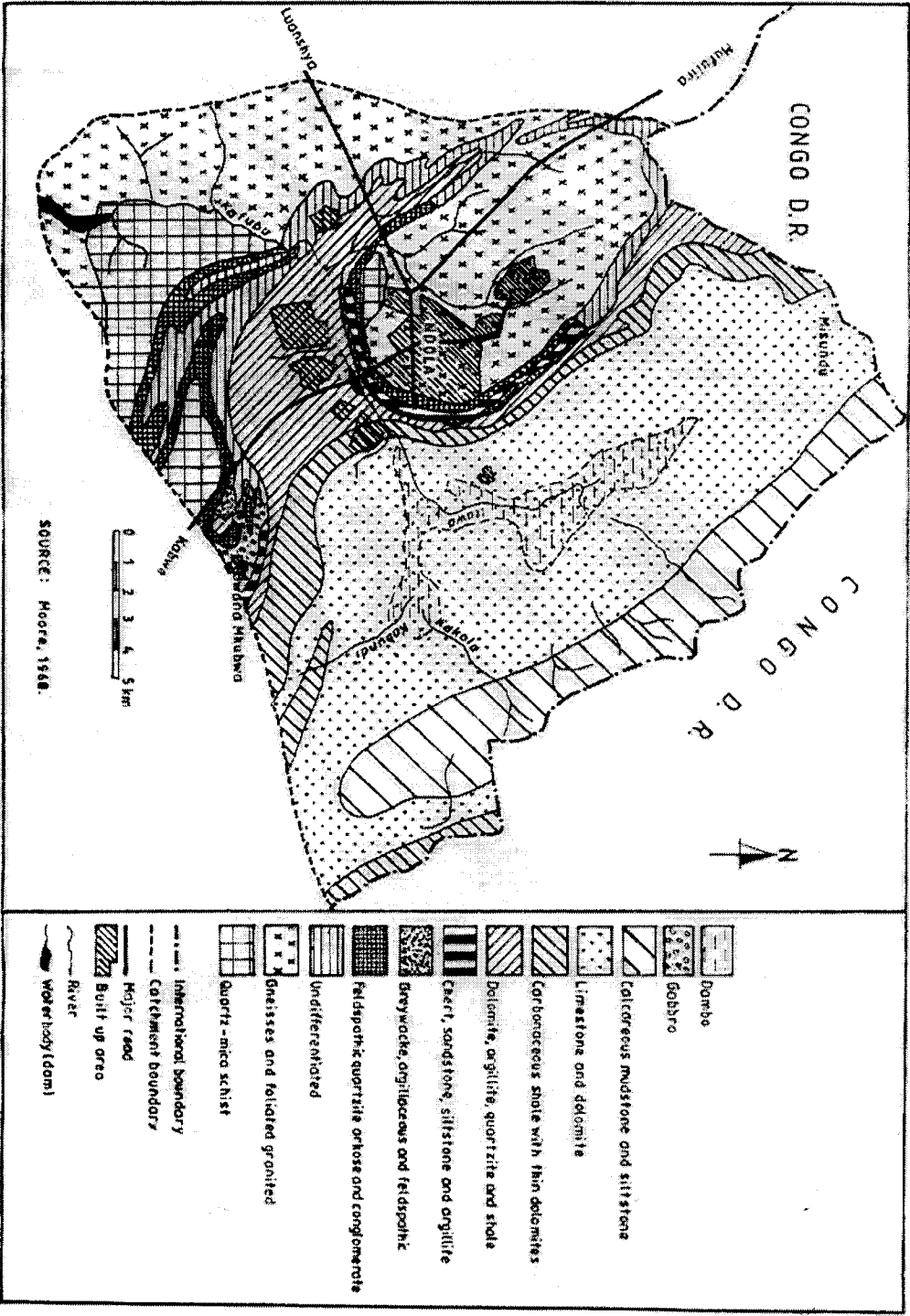


Fig. 3.2 Map showing the geology of the Upper Kafubu River basin.

3.1.3 Climate

Upper Kafubu basin, like any other place in Zambia, experiences a tropical climate characterised by three seasons, namely, wet season (November-April), the cold dry season (May-August) and the hot dry season, which runs from September to November. The months of July to August are cool with minimum temperature dropping to 8°C (Sharma, 1984) while the months of September and October are hot with maximum temperatures reaching 35°C. Proximity to the rain bearing air mass, the Congo Moist Air and its high altitude on the Zambezi-Zaire watershed makes the Copperbelt receive high rainfall. The mean annual rainfall for Ndola is 1098 mm with a range of 800-1200 mm (Sichingabula, 1998).

3.1.4 Hydrology

The Upper Kafubu River drains an area of 60 km². A record of discharge measurements at three gauging stations is available i.e. Kafubu at Itawa Dambo station (4-210); Fisenge (4-240) and the Masaiti Road Bridge Station (4-245) (Water Affairs Department, 1982). These stations have been operational since the 1960s, but due to weed infestation in the Upper Kafubu catchment, only the Masaiti Road Bridge station (4-245), located about 35 km further downstream and outside the study area, is currently operational. It is operated by Water Affairs, Hydrological Branch, in Kitwe.

The mean annual discharge of Kafubu River is 19.54 m³ s⁻¹ with significant rises during the rain season and drops in the dry months. Additionally, runoff in the rainy season could have generally increased in recent decades due to increased impervious surfaces caused by urbanisation, the changed landuse in drainage basins of streams like Mushili and Kabushi, and increased stream discharge due to municipal wastewaters

entering the Kafubu River from Kanini Sewage Works as some of the municipal water is mined from Minsundu boreholes.

3.2 Vegetation and Landuse

Most of the original vegetation in the Upper Kafubu basin has been cleared for either urban development or agriculture. Common type of woodlands is *Brachystegia* and *Combretum* (Fanshawe, 1968). Typical river line trees including some evergreen bush species occur in places along riverbanks away from the urban and swampy areas. The headwater swamp is characterised by aquatic grasses such as wildrice, Hippo grass, reeds and many other aquatic weeds (floating macrophytes). The swampy area is almost devoid of trees and covers about one third of the catchment. The tributaries of Kafubu River, the Kansengi and Ibolole have their headwaters under forest plantation, which provides timber for mining and other related industries.

Kafubu River basin is among the most highly urbanised catchments in Zambia, with approximately forty percent of its drainage basin under urban and peri-urban landuse. It is generally characterised by urban, industrial and peri-urban landuse types which include the Central Business District (CBD), the high and low- density residential areas, on eastern and western sides of the river. Industries with adverse environmental impact are located in the heavy industrial area (Bwana Mkubwa) about 2 km away from the eastern bank of Kafubu River. Other large industries are located on the western bank in the light industrial area, northwest of the CBD. These industries include three textile mills, lubricant-reprocessing plants, vegetable oil production, soap making, sugar refining, petroleum refining, a brewery, tyre and paint manufacturing, and general food processing plants. Other urban related activities found on the fringes of this urban environment are dairy, poultry and fresh vegetable farms specialised in local market

supplies. Subsidiary urban garden system of agriculture by residents is also widely practiced in the area.

Methodological matters of the study are the focus of the next chapter.

CHAPTER 4: METHODOLOGY

4.1 Introduction

Several methods for studying water quality in river and wastewater are available (Water and Environmental Technology, 1993a, 1993b; Arnold *et al.* 1981; ANON, 1971; 1979). The choice of the method used to a large extent depends upon the objectives of the study and also on the strength and weakness of method. This chapter discusses sources of secondary data, techniques of primary data, and some procedures followed in the analysis of the data collected for the study.

4.2 Types and Sources of Secondary Data

The Meteorological Department in both Lusaka and Ndola offices provided published and unpublished rainfall data (1993-1998) (Appendix III). Water levels and discharge data (1993-1998) were obtained from the Department of Water Affairs in Kitwe and Lusaka offices (Appendix III). Secondary data included water sample analysis of various parameters for wastewater, raw river water and treated water collected by the Ndola City Council Water and Sewerage Department (Appendices IVa-IVf). Additionally, some historical data on water quality (unpublished) on sewage and trade effluents by various industries and institutions were also sourced from the Environmental Council of Zambia (ECZ). The National Council for Scientific Research (NCSR) and Zambia Consolidated Copper Mines (ZCCM), Kalulushi Division libraries, were used for collection of relevant data and information. Personal interviews with relevant authorities at ECZ and Ndola City Council Water and Sewerage Department were made on several issues related to water quality and water quality standards in Zambia. The results of analysis of the collected data are discussed in Chapter 5.

Three topographical maps that covered the Copperbelt, and some parts of Ndola, were used i.e., a 1:250 000 sheet dated 1989 and two 1:50 000 sheets 1228 D3 and 1328 B1 dated 1971 and 1972, respectively. These provided information on location, topography, landuse and calculations of the built-up area, drainage basins for the study area and for sampling stations.

To describe the lithology of the study area, three geological maps were used. These included one 1: 500 000 geological map of the Copperbelt for 1961 (Moore, 1968) and two 1:100 000 geological maps of Ndola area (1228 SE) and Bwana Mkubwa (1328 NE) dated 1968. A 1:750 000 landuse map of Zambia (Schultz, 1975) was used to describe the general landuse around Ndola. This was verified with more recent information on landuse changes using the recent 1: 250 000 topographical map dated 1989.

4.3 Primary Data Collection

The primary data used was collected by sampling and by visual observation at sampling sites. Data collected included water samples that were analysed using the parameters pH, TSS, TDS, turbidity, chlorides, colour, COD, temperature, total alkalinity, calcium, magnesium and total hardness and stream discharge.

4.3.1 Water Levels and Discharge Measurements

Discharge measurements were made on routine basis i.e. on bi-monthly interval from 20 January to 24 March 1998 with the help of Kitwe Water Affairs, Hydrological Branch. At Masaiti Road Bridge gauging station (4-245) discharge measurements using velocity-area method (using the Nakasa Current meter) were carried out on bi-monthly

measurements were made in the wet season between January 20 and March 24, 1998. Additional discharge data for the whole study period was obtained from Water Affairs in Lusaka. The compiled water level and discharge data are shown in Appendix III and analysed in Chapter 5.

The Masaiti Road Bridge gauging station (4-245) located south of Luanshya about 35 km outside the study area was used for estimating stream discharge at stations in the study area. This was so because it was not possible to measure discharge within the study area due to weed infestation throughout the study reach. This was done by calculating the drainage areas of Kafubu River at Itawa Swamps railway-bridge and at Kanini footbridge and then finding the ratio between the two drainage basins and that of Masaiti Road Bridge gauging station whose stream discharge was known. The ratios of drainage areas at Itawa Swamps and Kanini stations to the area at Masaiti gauging station (4-245) were found to be 0.13 and 0.20, respectively. Therefore, stream discharge for Kafubu River at Itawa Swamps and at Kanini was estimated by reducing the discharges at Masaiti by the respective catchment ratios. The estimation of stream discharges by this method was based on the assumption that discharge increased downstream proportionally with drainage area. The estimated discharge was then used to calculate the total dissolved loads in tonnes per day and finding relationships with discharge.

4.4 Field Observations and Water Sample Collection

The first field survey conducted was to select and locate sampling stations. Then, several other field investigations were done to locate the point sources of pollution such as sewage and industrial discharges and to assess some physical quality

characteristics of river water such as colour and odour. Sewage outflows and industrial discharge points were identified as point sources of pollution.

4.4.1 Sampling Points

Six sampling points were selected along the whole stretch of the urbanised reach of Upper Kafubu River over a distance of about 20 km from Itawa Swamps railway bridge in the northeast to Kafubu Dam in the southwest. Fieldwork was carried out from 20 January to 29 September 1998 with 13 campaigns carried out for each of the six sampling stations. The sampling stations were (Itawa Swamps (ST1), Itawa Dam (ST2), Itawa Water Works (ST3), Kanini (ST4), Kafubu Dam (ST5) and Kafubu Water Works (ST6) (Figure 4.1). Considerations taken into account in the selection of sampling stations were various. These included the existence of station baseline data used by the Ndola City Council, easy accessibility in terms of presence of motorable road, and railway, road or footbridges, existence of point sources of pollution such as Kanini and Lubuto sewage, and industrial effluent discharge points. Each of the sampling points is discussed below.

4.4.1.1 Itawa Swamps Station (ST1)

This is located at a railway bridge along the Kafubu River right in the Itawa Swamps. Itawa Swamps station was used as a control station since it was deemed free from major pollution activities in the area. It was also the only accessible point north of the city of Ndola through the ZESCO-Ndola Lime-Chilanga Cement road (Figures 4.1; 4.2a).

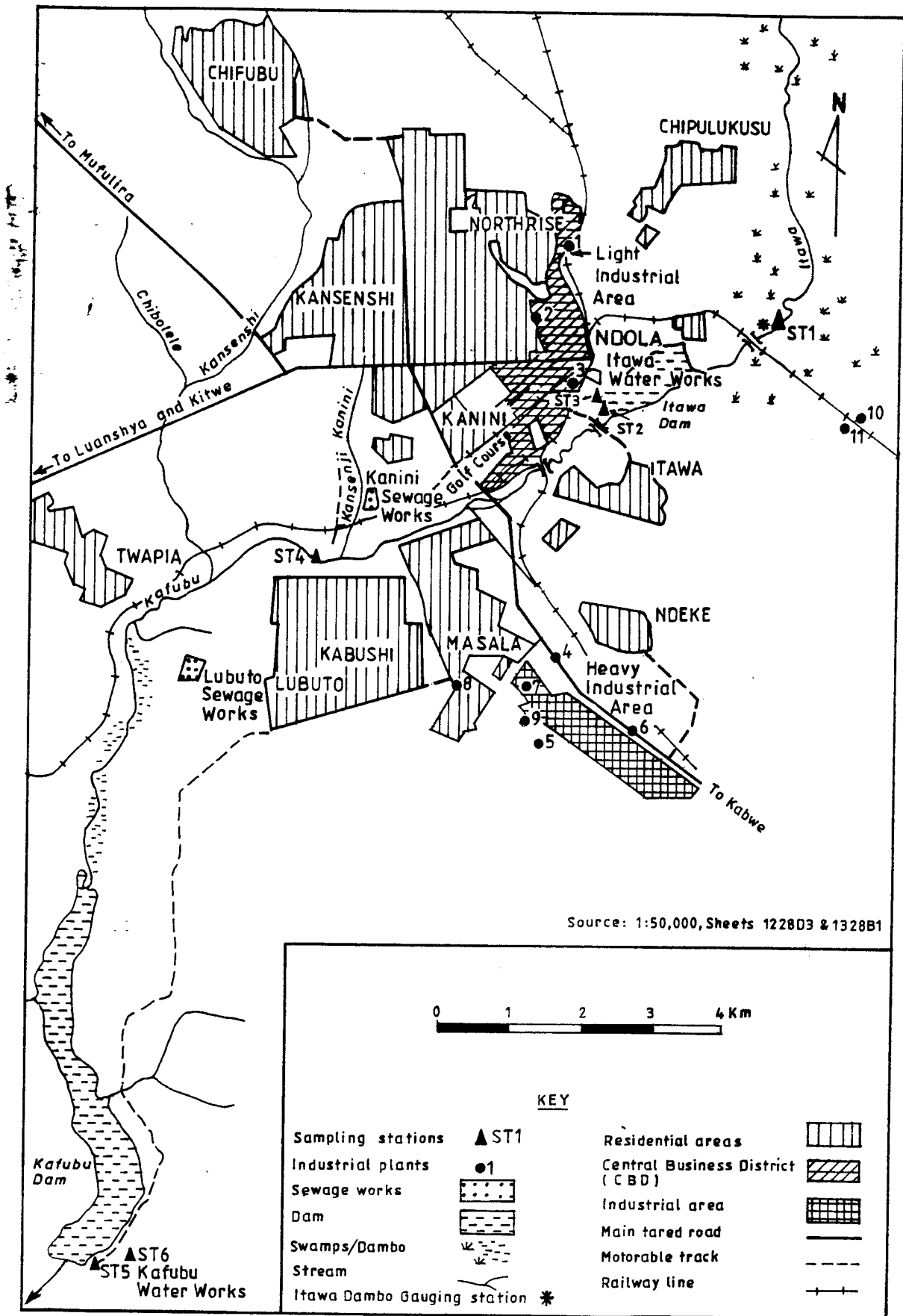
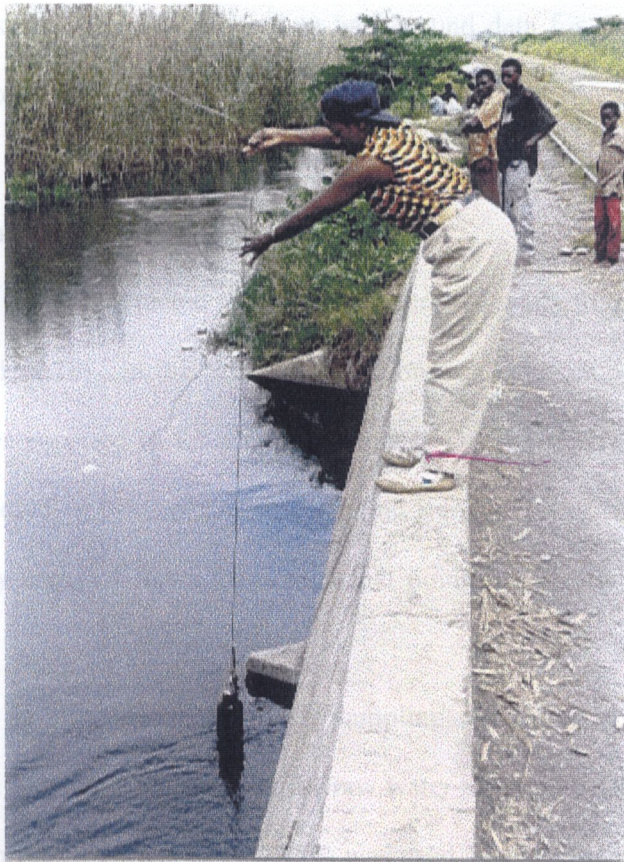


Figure 4.1 Map showing the water sampling stations along Kafubu River in relation to major urban activities in Ndola town.



(a)



(b)

Figure 4.2 Kafubu River at Itawa (a) Itawa Swamps Sampling Station (STI) and (b) Itawa Dambo, a low earth dam providing raw water for Itawa Water Works.

The data from this site, therefore, served as background data for the quality of the river in natural state.

4.4.1.2 Itawa Dam Station (ST2)

This is a low earth dam constructed to serve as a source of water for the Itawa Water Works (Figures 4.1; 4.2b). In this study, this station was regarded as raw water for Itawa treated water supplied to the Central Business District (CBD) and high cost residential areas including Northrise, Kansenshi and Kanini. There were many urban activities in nearby areas of Itawa Dam such that point and diffuse pollution were possible.

Itawa Dam is also one of the oldest sampling stations used by Ndola City Council Water and Sewerage Department for raw water sample analysis. The intake point from the dam into the waterworks (ST2) was used as a representative sampling point for the dam (Figures 4.1; 4.3a).

4.4.1.3 Itawa Water Works Station (ST3)

This was a tap within Itawa Water Works (Figure 4.1; 4.3b) and was selected in order to ascertain the quality of treated water immediately after treatment before any possible secondary contamination took place before reaching consumers. It is also one of the oldest sampling stations for treated water at Itawa Water Works by the Ndola City council.



(a)



(b)

Figure 4.3 Itawa Water Works Sampling Station for Raw and Treated Water (a) Intake point from Itawa Dam (ST2) and (b) tap Water Within the water Works (ST3).

4.4.1.4 Kanini Station (ST4)

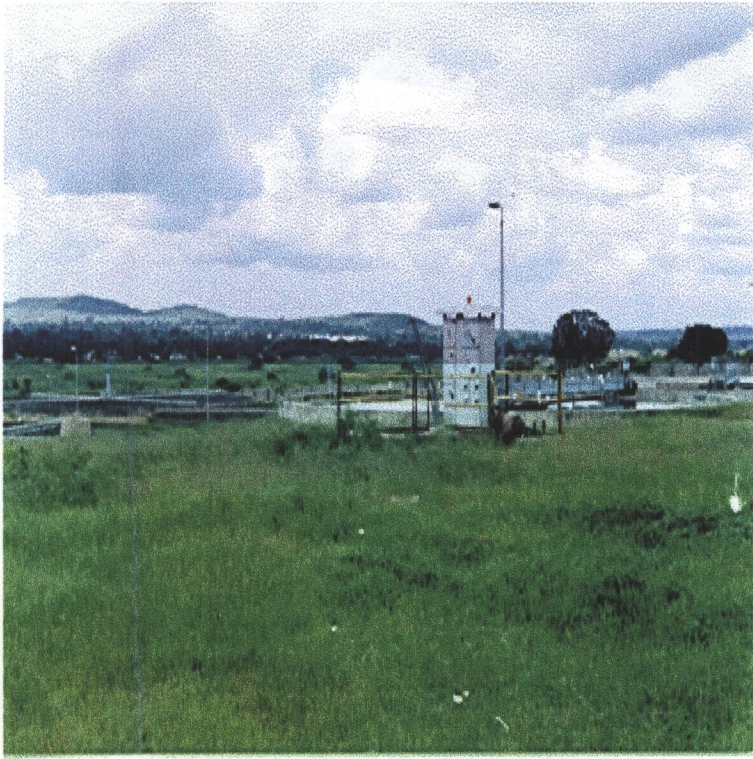
This site falls within the vicinity of Kanini Sewage works just after the sewage outflow (Figures 4.1; 4.4a). The site was selected to indicate whether concentrations here differed from those of upstream stations Itawa Swamps (ST1) and Itawa Dam (ST2). The presence of a footbridge and a motorable track made the point easily accessible (Figures 4.4b).

4.4.1.5 Kafubu Dam Station (ST5)

This is the source of water for the Kafubu Water Works. It is also a waste depository for all sewage and industrial wastewater from sewage works and numerous industries located in the heavy industrial area. As raw water for Kafubu Water Works, it was considered important for analysis of the quality of treated water supplied to some parts of Ndola such as Mushili, Kabushi, Masala, Lubuto, Ndeke, Itawa residential areas and the Bwana Mkubwa Industrial area. Kafubu Dam (ST5) is an old sampling station for Ndola City Council Water and Sewerage Department. The intake point from the dam into the water works was used as sampling point for the dam water (Figures 4.1; 4.5a).

4.4.1.6 Kafubu Water Works Station (ST6)

This is a treated (tap) water sampling station located within Kafubu Water Works (Figures 4.1; 4.5b). Secondary data for the station was available in the 1990s collected by the Ndola City Council Water and Sewerage Department. This station was used in assessing the differences in means between raw (ST5) and treated (ST6)



(a)



(b)

Figure 4.4 Kafubu River at Kanini Foot-Bridge (a) Kanini Sewage Works on the Western bank of Kafubu River (b) Kanini Foot-Bridge (ST4)



(a)



(b)

Figure 4.5 Kafubu Water Works Sampling Stations (a) Intake point from Kafubu Dam into the Water Treatment Plant (ST5), (b) Tap Water (ST6) Located within Kafubu Water Treatment Plant.

water using the t-test so as to ascertain the quality of treated water provided to the consumers.

4.5 On-Site Sampling Procedure

Grab samples of river water were collected at a depth of approximately 0.7 m below the water surface from four sampling stations and were transferred on to clean one-liter plastic sampling bottles. Two samples were collected for analysis from each station for each of the two laboratories at Kanini and Indeni Oil Refinery. Sampling was done in the morning between 9 hours and 12 hours, so that some of the laboratory tests could be conducted in the afternoon of the same day. In the rain season, sampling was done once per week and only once per month in the dry season. The period of sampling was from 14 January to 29 September 1998.

4.6 Water Quality Determination

Varieties of methods for determining water quality are available. Laboratories that analysed water samples collected for this study used standard laboratory techniques for physico-chemical analysis of stream water. These included, titration method, spectrophotometric, electro-chemical using a meter, gravimetric and atomic absorption (Water and Environmental Technology 1993a, 1993b; Arnold *et al.* 1981; and ANON, 1971, 1979). Supplementary water quality data was obtained for physico-chemical and bacteriological quality from Ndola City Council Water and Sewerage Department. The physico-chemical data obtained is shown in Appendices IVa to IVd for raw river water and Appendices IVe, IVf, Va and Vb for treated water, which are further analysed in Chapter five.

4.6.1 Measurements of Physical Parameters

Except for the field measurements of temperature, all samples were analysed at Ndola City Council Water and Sewerage Department laboratory at Kanini and Indeni Petroleum Refinery Company laboratory using standard methods for the analysis of water and wastewater (Water and Environmental Technology, 1993a, 1993b; Arnold *et al.* 1981; and ANON, 1971, 1979). For each sampling station, water samples were analysed for several parameters. Kanini laboratory analysed for pH, alkalinity, colour, conductivity, TDS, TSS, chlorides, magnesium and calcium hardness while Indeni Laboratory analysed Chemical Oxygen Demand (COD), Zinc, Lead and Copper. The choice of the parameter to be tested was dictated by the ability of the laboratory to conduct the test and by the relevance of the parameter to the research objectives. Types of tests conducted are briefly described below.

4.6.1.1 Temperature, Colour, Turbidity and Conductivity

Temperature was measured in degrees Celsius on the spot with a glass thermometer. This was observed for each sample at the time of collection. Colour of water was expressed in hazen units using comparison tubes. Turbidity was measured with a Hellige turbidimeter in the laboratory for all samples. Turbidity results were expressed in nephelometric turbidity units (NTU). The method was based on a comparison of the intensity of light scattered by a standard reference suspension under similar conditions. Conductivity was measured using an electrolytic conductivity meter (4956 model) or $\mu\text{S}/\text{TDS}$ meter (C6 model) and was expressed in terms of micro mhos per centimeter ($\mu\text{mhos}/\text{cm}$).

4.6.1.2 Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)

TSS was measured using the gravimetric method. The sample was filtered through a filter paper, which was dried and re-weighed. The TSS was expressed in parts per million by weight (ppm). TDS were measured using us/TDS meter (C6 model) or by using an electrolytic conductivity meter (4956 model). TDS was expressed in ppm.

4.6.2 Measurements of Chemical parameters

4.6.2.1 pH, Chemical Oxygen Demand (COD), Magnesium hardness (CaCO₃), Calcium hardness (CaCO₃), Total hardness, Total Alkalinity, and chlorides

pH was determined using a laboratory pH meter (Potentograph E536 model) at the laboratory and results were expressed in pH units. COD was expressed in parts per million using the Reflux Digestion and Spectrophotometric procedure (Water and Environmental Technology, 1993b). COD was used as an alternative to BOD, which could not be determined due to lack of reagents. The titration method was used to determine magnesium hardness concentration in river and treated water with results expressed as ppm. Similarly, the titration method was used to determine calcium hardness of both river and treated water and was expressed in ppm. Total hardness was expressed in ppm and titration method was used for the determination of total hardness in raw river and treated water. Electrometric titration was used for the determination of total alkalinity and the results were expressed in ppm. Concentrations of chlorides were determined using the silver nitrate titration method, and expressed in ppm.

4.6.3 Trace Metals

Three trace metals (zinc, copper and lead) were determined using the atomic absorption method and results were expressed in ppm.

4.9 Quantitative Analysis Methods

Collected data was statistically summarised by measures of dispersion and central tendency (ranges and means) and presented in tables and graphs. To establish quantitative relationships between discharge and total dissolved load a simple regression analysis approach was used. Total dissolved load (TDL) in tonnes per day, was calculated using the following formula:

$$\text{TDL (t/d)} = 0.0864Q \times \text{TDS}$$

Where TDL is total dissolved load, t/d is tonnes per day, Q is stream discharge ($\text{m}^3 \text{s}^{-1}$), TDS is total dissolved solids concentration (ppm) and 0.0864 is a constant for converting the value to metric tonnes per day.

In order to predict loading of dissolved loads of zinc, copper and lead the regression approach was used with discharge as the independent variable. To test the difference in means between raw river and treated water at both Itawa and Kafubu water works, a t-test was employed.

The removal efficiency was calculated for sewage works the sewage works with respect to constituents in wastewater to desirable levels (ECZ, 1992). The removal efficiency in percentage of pollutants in sewerage effluents was determined using the formula below given by Simuunza (1992):

$$\text{Removal efficiency (\%)} = \frac{100 (\text{Influent Concentration} - \text{Effluent Concentration})}{\text{Influent Concentration}}$$

Results of these quantitative statistics are shown in Appendices VIa to VIe and discussed in Chapters 5 and 6, respectively.

4.8 Limitations

Bacteriological analyses were not done during the whole study period due to lack of appropriate media and chemicals at Kanini laboratory. Consequently, secondary data was used to supplement the two sampling occasions conducted by Ndola Council Water and Sewerage Department during the study period. Therefore, only treated water for ST3 and ST6 stations were analysed for bacteriological constituents and none for raw river water. Sampling frequency in the dry season was reduced to once per month due to serious financial constraints. Similarly, measurement of stream discharge was terminated in the dry season because of lack of funds. Total sediment load in tonnes per day was not calculated due to absence of suspended solids in river water almost throughout the study period.

The next chapter discusses analysis of data and results.

CHAPTER 5: RESULTS AND ANALYSIS

This chapter describes and analyses primary and secondary data obtained during the study using measures of central tendency, tables, graphs and some quantitative statistics. The data analysed included stream discharge, water quality and rainfall of Upper Kafubu catchment.

5.1 The Hydrological Regime of Kafubu River

Between 1993/1994 and 1997/98 hydrological years, the mean annual discharge for Kafubu River at Masaiti gauging station (4-253) was varied (Appendix III). During this period the mean annual discharge was $11.39 \text{ m}^3 \text{ s}^{-1}$ while the maximum discharge was 43.74 m^3 , with a minimum of $1.4 \text{ m}^3 \text{ s}^{-1}$. The hydrological regime of Kafubu River basin showed a unimodal distribution controlled by the single rainfall season experienced in the country (Figure 5.1a). Peak discharge occurred in the month of February (mean $29.25 \text{ m}^3 \text{ s}^{-1}$). This high discharge was as a result of the effects of rainfall that occurs after the month of December (Figure 5.1b). Minimum discharge was recorded in the month of October with an average flow of $3.52 \text{ m}^3 \text{ s}^{-1}$. The 1997/98 hydrological year had a mean discharge of $13.01 \text{ m}^3 \text{ s}^{-1}$. Peak discharge ($35.20 \text{ m}^3 \text{ s}^{-1}$) in the 1997/98 hydrological year was recorded in the month of January. This high discharge was generated by the high rainfall (358.1 mm) recorded in the month of December (Appendix III). Thus, stream flow in Kafubu River basin was highly dependent on rainfall received in the catchment, which was basically seasonal in nature (Figure 5.1). Low flows in the river occurred in the dry season months of April to October while effective rainfall occurred mainly in the months of December to March.

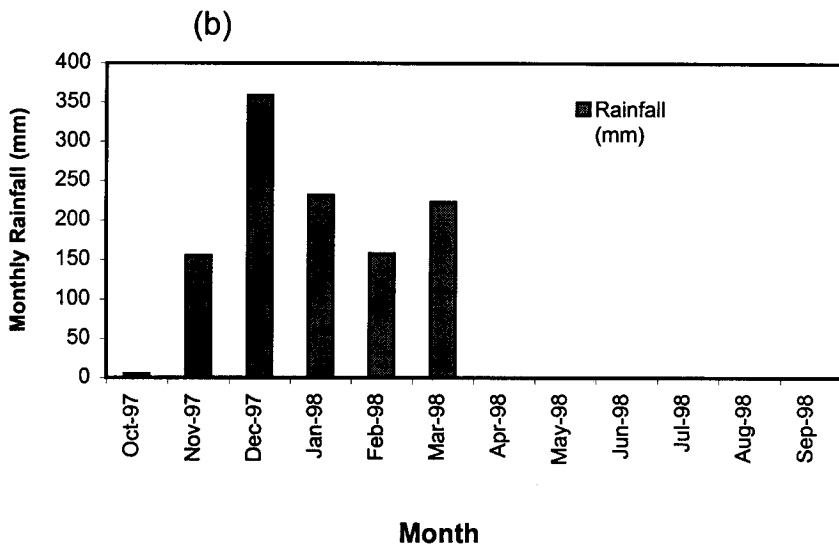
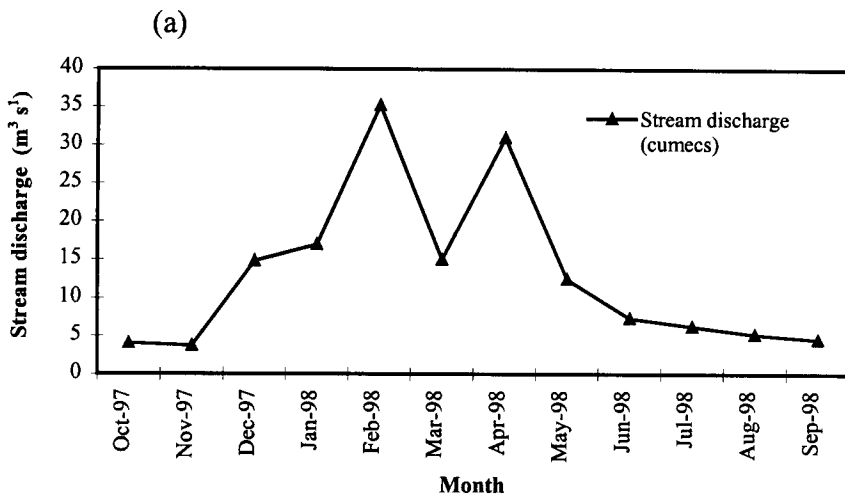


Figure 5.1 Hydrological (a) and Rainfall (b) regimes of Kafubu River in Ndola in the period 1997-1998, respectively.

5.1.1 Stream Hydrograph and Hyetograph Characteristics

Stream hydrograph is a measure of the variations of stream flow with time. The annual hydrographs of Kafubu River were flashy in character and peaked mostly in March (Figure 5.2). Peak flows in the 1995-1998 period on Kafubu River ranged from $17 \text{ m}^3 \text{ s}^{-1}$ to $29 \text{ m}^3 \text{ s}^{-1}$. These are referred to as floods 'whether or not they caused inundation' of the flood plain (Dury, 1973). The sudden rise between December and March for most hydrological years were caused by effective rainfall that occurred in the month of December. The highest flood ($43.74 \text{ m}^3 \text{ s}^{-1}$) occurred in the 1996/97 hydrological year while the lowest flood of $20.87 \text{ m}^3 \text{ s}^{-1}$ occurred in the 1994/95 hydrological year.

Kafubu River is a perennial stream with dry season low flows of about $4 \text{ m}^3 \text{ s}^{-1}$. This is relatively higher than expected from base flow, which should be lower than this due to increases in impervious surfaces within the headwaters and also due to excessive evapotranspiration through reservoirs and aquatic weeds which have invaded most parts of the river system (Kasonde, 1990). Additional flows during the dry season came from several sources within the catchment and include Ndola Lime Mine (500 m^3 to $40,000 \text{ m}^3$ per day) Lubuto and Kanini Sewage Works which discharge 30 and 20 mega litres of sewage water per day, respectively. Other unknown quantities of wastewater also enter the main channel from tributaries and open drains originating from various industries within the catchment. Due to lack of data, base flow could not be separated from runoff and other sources of runoff. For this study, natural stream flow was of special interest as it could easily be related to stream quality. This is because the dilution factor is an important factor in fixing suitable chemical standards for the discharge of effluents into the river.

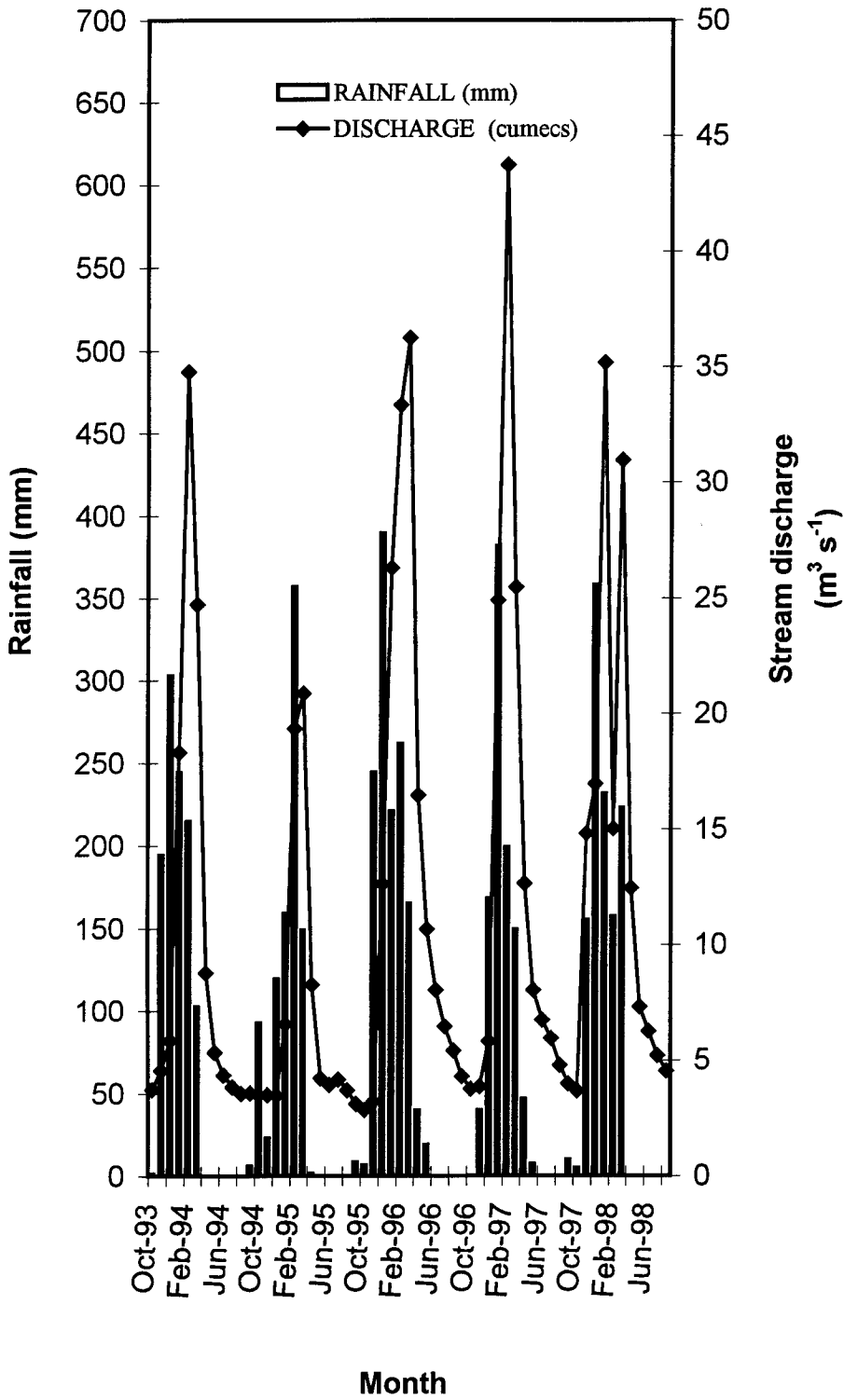


Figure 5.2. Plot of hyetograph and hydrograph for Kafubu River, 1993-1998.

Dilution factor can be calculated as the ratio of river flow to effluent flow (Klein, 1966). According to Klein, (1966) dry weather flow of a stream is what is used as the minimum flow that is important for formulating standards for effluent discharges. Therefore, the dilution factor is a very important factor in river quality for it determines the self-cleansing ability any river can have in a given period of time. Thus, river quality in dry season discharge shows that a river can assimilate effluents discharged into it.

5.2 River Water Quality

The results from physico-chemical analyses obtained during the study period are presented in Appendices IVa to IVd as raw river data and in Tables 5.1 and 5.2 as summary data. River water in Upper Kafubu catchment was highly mineralised with total dissolved solids ranging from 213.3 ppm (ST5) to 373 ppm (ST4). Total suspended solids were almost absent in the dry season at all sampling stations but averaged from 48 ppm at ST4 to 65.3 ppm at ST2 in the wet season. River water was hard and alkaline in nature throughout the study period (Tables 5.1 and 5.2). Temperature, chloride and pH were the most stable parameters throughout the study period with temperature falling within the sub-tropical range of between 18 and 32 °C. The chloride concentration levels were low and averaged from 2.5 ppm to 5.0 ppm in the wet season and from 2.46 ppm to 11.17 ppm in the dry season. Trace metal concentration levels were higher in the wet season than dry season (Tables 5.1 and 5.2). Spatial and temporal variations in trace metal concentration was very evident during this study with upstream station ST1 and ST2 having the highest mean concentrations of copper, lead and zinc (Tables 5.1 and 5.2).

Table 5.1 Wet season Physico-chemical characteristics of raw river water in Upper Kafubu River (1998).

Table 5.1 Wet season Physico-chemical characteristics of raw river water in Upper Kafubu River (1998).

Parameter	Number of Samples	Itawa Swamps (ST1)	Itawa Dam (ST 2)	Kanini (ST 4)	Kafubu Dam (ST5)
A. PHYSICAL					
Temperature (°c)	4	25	22.5	26	26
Conductivity (µmhos/cm)	8	442.86 (530-320)	491.88 (530-460)	440.71 (510-360)	328 (330-320)
TSS (ppm)	8	0.0	0.0	0.1 (0.0-8.0)	0.0
TDS (ppm)	8	295.23 (213.3-353.3)	315.38 (226.6-353.3)	293.99 (286.6-373)	218.7 (213.3-220.2)
Colour (hazen units)	8	10.00 (20-5.0)*	18.75 (15-25)*	14.29 (10-20)*	22* (10-30)
Turbidity (NTU)	8	0.71 (0.30-2.10)	1.03 (0.7-1.5)	5.49 (0.9-10.4)	3.42 (1.0-5.5)
B. CHEMICAL					
pH units	8	8.38 (7.61-8.97)	8.19 (7.26-9.10)*	8.42 (7.82-9.21)*	8.96 (8.13-9.36)*
Total alkalinity (ppm)	8	230.00 (214-250)	242.25 (170-315)	194.57 (164-240)	152.2 (148-158)
Chloride (ppm)	8	2.50 (2.0-3.0)	2.50 (2.0-3.01)	7.57 (2.0-12.0)	5.00 (4.00-7.00)
COD (ppm)	8	65.66 (5.3-82.3)	65.66 (5.3-82.0)	63.57 (24-82)	57.60 (35.05-80.00)
Magnesium hardness (ppm)	8	66.06 (1.9-167.2)	113.35 (10.54-340.8)	30.69 (3.9-104.0)	41.53 (3.9-88.0)
Calcium hardness (ppm)	8	127.06 (231.6-44)	100.35 (10.54-340.8)	167.09 (40-337.6)	117.2 (80-187.2)
Total hardness (ppm)	8	271.51 (152-401)	294.88 (120-486.4)	221.37 (84.8-371.2)	146.56 (96.0-256.0)
C. TRACE METALS					
Lead (ppm)	8	1.58* (0.0-4.55)	1.29* (0.12-2.68)*	1.09* (0.00-2.90)	0.78* (0.0-2.70)
Copper (ppm)	8	0.29 (0.0-0.68)	0.34 (0.18-0.45)	0.20 (0-0.22)	0.33 (0.0-0.32)
Zinc (ppm)	8	0.79 (0.0-2.68)	1.03 (0.45-1.72)	0.55 (0.0-0.01)	0.030 (0.0-0.21)

Figures in parenthesis are minimum and maximum values

* Above maximum ECZ permissible levels (ECZ, 1993)

Table 5.2 Dry season Physico-chemical characteristics of raw river water in the Upper Kafubu River (1998)

Parameter	Number of Samples	Itawa Swamps (ST1)	Itawa Dam (ST 2)	Kanini (ST 4)	Kafubu Dam (ST5)
A. PHYSICAL					
Temperature (°C)	4	20.5 (17-24)	21.2 (20-24)	21.2 (19-24)	21.7 (20-25)
TSS (ppm)	8	55.3 (0.0-260)*	65.30 (0.0-304)*	48.00 (0.0-220)	51.00 (0.0-208)*
TDS (ppm)	8	324.42 (236-390)	325.03 (253-468)	326.35 (286.6-373)	253.16 (206.8-280)
Conductivity (µmhos /cm)	8	453.33 (400-480)	462.91 (420-546)	435.0 (400-480)	336.0 (280-380)
Turbidity (NTU)	8	1.55 (0.5-4.4)	3.28 (0.9-10.0)	5.83 (4.0-7.4)	12.94 (1.2-35.0)*
Colour (hazen units)	8	6.67 (5.0-10.0)	14.38 (15-20)	14.29 (10-30)	32* (15->70)*
B. CHEMICAL					
pH units	8	7.72 (7.10-8.56)	7.2 (6.95-8.77)	7.44 (7.00-7.86)	8.37 (7.50-8.95)
Total alkalinity (ppm)	8	228.83 (214-269)	259.04 (245-334)	205.5 (180-250)	164.00 (152.0-198.0)
Chloride (ppm)	8	2.46 (2.0-3.0)	2.46 (2.0-3.0)	11.17 (8-14)	8.2 (3.0-13.0)
COD (ppm)	8	65.66 (5.30-82)	39.73 (24-72)	44.67 (24-100)*	48.8 (24-100)*
Magnesium hardness (ppm)	8	16.05 (1.6-34.2)	17.91 (10.74-25.5)	15.92 (4.2-23.0)	11.25 (3.4-17.4)
Calcium Hardness (ppm)	8	127.23 (44.5-155.2)	119.25 (110.0-152.0)	80.67 (40-104)	80.36 (70.4-103.8)
Total hardness (ppm)	8	180.73 (164.8-203)	188.52 (174.2-252.0)	144.83 (120-184)	133.28 (118.0-148.0)
C. TRACE METALS					
Lead (ppm)	8	0.045 (0.02-0.35)	0.46 (0.0-2.62)*	0.035 (0.03-0.43)	0.13 (0.0-0.22)
Copper (ppm)	8	0.03 (0.0-0.11)	0.12 (0.01-0.77)	0.02 (0.02-0.09)	0.03 (0.0-0.22)
Zinc (ppm)	8	0.05 (0.03-0.07)	0.03 (0.0-0.18)	0.04 (0.02-0.04)	0.06 (0.04-0.21)

Figures in parenthesis are minimum and maximum values

* Above maximum ECZ permissible levels (ECZ, 1993)

Other parameters such as water colour, turbidity and chemical oxygen demand (COD) were high in the dry season months than in the wet season (Tables 5.1 and 5.2). The parameters used generally to describe characteristics of water quality are discussed below.

5.2.1 Physical Characteristics of River Water

5.2.1.1 Temperature

The Kafubu River water was found to gradually warm up in the downstream direction from Itawa Swamps to Kafubu Dam from a mean value of 21.5 up to 26 °C (Table 5.3). Throughout the study period, Itawa Dam station (ST2) was cooler (18.1 °C) than all downstream stations. This could have been due to underground water and springs contributions that were not influenced by anthropogenic activities. But occasionally, Itawa Swamps (ST1) was cooler than Itawa Dam (ST2). This could have been due to the lower depth (7 meters) of the uptake point of Itawa Water Works that was used for sampling whereas water sampling stations were taken from a depth of 0.7 meters. The addition of municipal and trade effluents after Itawa Dam (ST2), meant the downstream stations ST4 and ST5 were warmer than the upstream ones (ST1 and ST2). Downstream stations ST4 (Kanini) and ST5 (Kafubu Dam) had much higher temperatures most likely due to warmer wastewater with temperatures between 22 °C and 50 °C being discharged from various industries. Again, as temperature is proportional to metabolic rate, it was expected to reduce with the decreasing content of organic nutrients as these directly determine the metabolic rate (Tembo *et al.*, 1997). Generally, there was a minimal inter-stational variation in temperature during the study period. The temperature also reduced with seasons with minimum temperatures ranging from 17 °C to 20 °C during winter

(cold) months (May to August) and 26 °C in the hot rainy season (January to April).

Overall, the temperature of Kafubu River water was therefore within the recommended limit of below 40 °C for watercourse receiving wastewaters (ECZ, 1993).

Table 5.3 Temperature Variations in Raw and Treated River Water in the Upper Kafubu River Basin in Ndola.

Date	River Water				Treated Water	
	Itawa Swamps (ST1) (°C)	Itawa Dam (ST2) (°C)	Kanini (ST4) (°C)	Kafubu Dam (ST5) (°C)	Itawa Water Works (ST3) (°C)	Kafubu Water Works (ST6) (°C)
10-02-98	25.0	22.5	26.0	26.0	26.0	26.0
05-05-98	22.5	22.2	22.5	22.5	22.0	24.0
22-05-98	19.0	20.0	20.5	21.0	20.0	21.5
29-07-98	17.0	20.0	19.0	20.0	20.0	20.0
19-08-98	20.0	20.0	20.0	20.0	20.0	20.0
29-09-98	24.0	24.0	24.0	25.0	24.0	25.0
Mean	21.5	18.1	22.0	22.0	22.4	22.8

5.2.1.2 Total Suspended Solids (TSS)

TSS may be considered a pollutant when it exceeds natural concentrations and has a detrimental effect on water quality in biological and aesthetic sense (Leopold, 1978). During the study period, TSS concentration levels in Kafubu River were mostly zero for most parts of the year except for a few months in the dry season of 1998 and infrequently in the 1993/1994 rain season (Appendices IVa to IVd; Tables 5.1 and 5.2). Temporal variations in TSS concentrations depict high variability (Figures 5.3 a, b). These

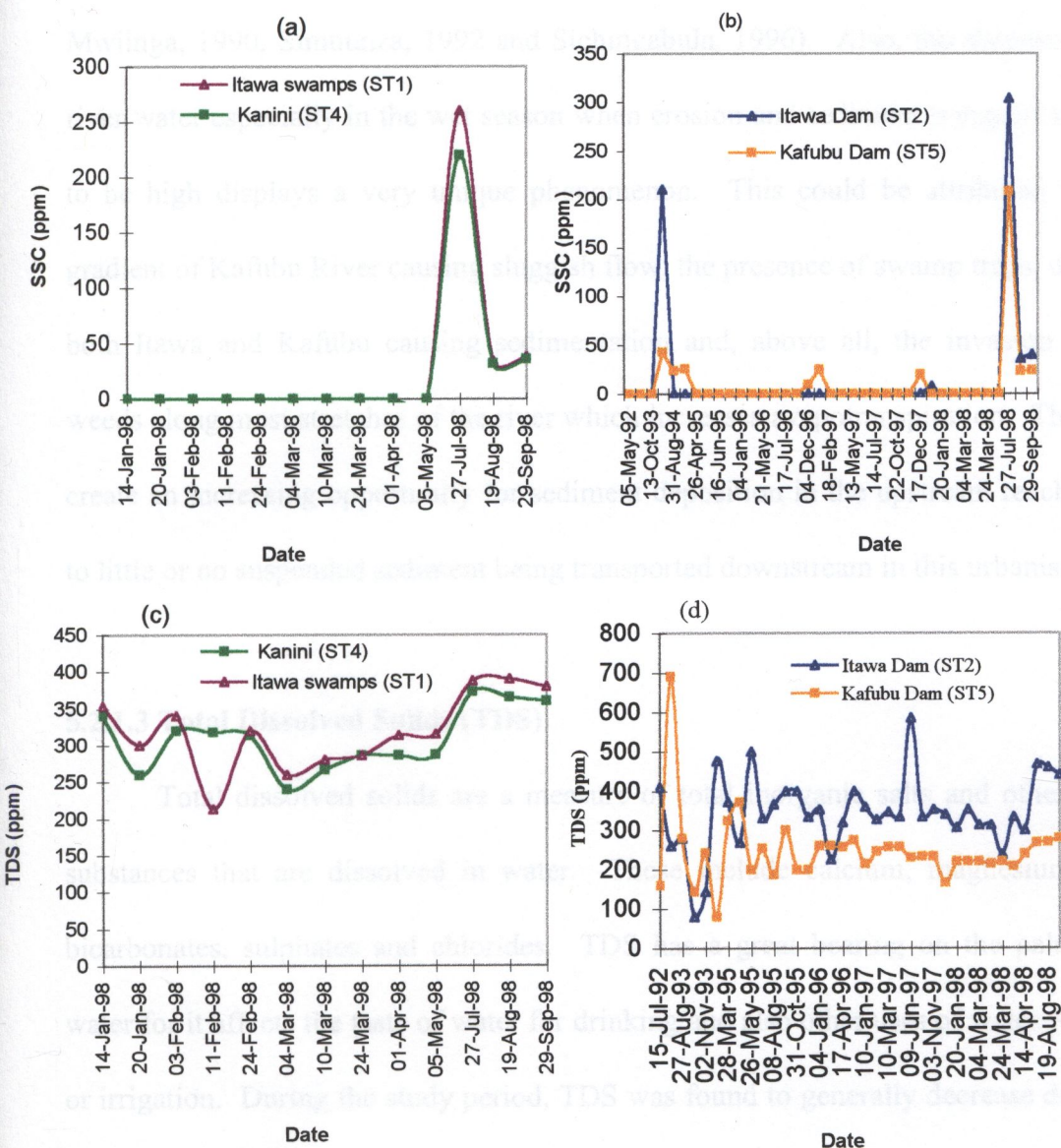


Figure 5.3. Temporal variations in sediment concentration levels in raw river water in Upper Kafubu River basin (a) SSC (ST1 and (ST4), (b) SSC (ST2 and ST5), (c) TDS (ST1 and ST4), and (d) TDS (ST2 and ST5).

concentration levels on average were very low according to present knowledge of sediment yields in the Kafue River basin (Iwugo, 1976; Sawula, 1985; Kasonde, 1990, Mwiinga, 1990, Simuunza, 1992 and Sichingabula, 1996). Also, the absence of TSS in river water especially in the wet season when erosion and sediment transport is supposed to be high displays a very unique phenomenon. This could be attributed to the low gradient of Kafubu River causing sluggish flow, the presence of swamp traps, damming at both Itawa and Kafubu causing sedimentation and, above all, the invasion of aquatic weeds along most stretches of the river which increases evapotranspiration. These factors create an increasing opportunity for sediment deposition in the upstream reaches leading to little or no suspended sediment being transported downstream in this urbanised reach.

5.2.1.3 Total Dissolved Solids (TDS)

Total dissolved solids are a measure of total inorganic salts and other inorganic substances that are dissolved in water. These include calcium, magnesium, sodium, bicarbonates, sulphates and chlorides. TDS has a great bearing on the palatability of water for it affects the taste of water for drinking and also other uses of water for industry or irrigation. During the study period, TDS was found to generally decrease downstream with Itawa Swamps (ST1) and Itawa Dam (ST2) having the highest average concentrations. Concentrations ranged from 218.7 ppm (ST5) to 315.38 ppm (ST2) in the wet season and from 253.16 ppm (ST5) to 326.35 ppm (ST4) in the dry season (Tables 5.1 and 5.2). Temporal variations in TDS concentration levels were high throughout the study period with unstable concentrations throughout (Figures 5.3c, d). The relationship between TDS and stream discharge was very weak with $r^2 = 0.12$ at Itawa Swamps and

$r^2 = 0.27$ at Kanini (ST4). Nevertheless, this relationship improved tremendously when total dissolved load (TDL) was used instead of TDS (Table 5.4). The relationship between TDS and TDL is presented on page 40 regression of $r^2 = 0.96$ (ST1) and $r^2 = 0.99$ (ST4) was obtained, showing a very strong relationship between stream discharge and TDL (Figure 5.4).

Table 5.4 Estimated total dissolved loads in the Upper Kafubu River basin, Ndola.

Date	Itawa Swamps (ST1)		Kanini (ST4)	
	TDS (ppm)	TDL (tonnes/day)	TDS (ppm)	TDL (t/d)
14.1.98	353.3	144.0	340.0	318.7
20.1.98	300.0	127.8	260.0	174.6
03.2.98	340.0	95.8	320.0	78.6
11.2.98	213.3	33.3	318.0	59.8
24.2.98	320.0	38.7	313.3	73.8
04.3.98	260.0	50.8	240.0	139.8
10.4.98	280.0	93.1	266.6	86.0
05.5.98	315.6	83.9	286.9	34.0
27.7.98	387.0	19.4	373.0	29.3
19.2.98	390.0	18.2	365.0	26.8
29.9.98	380.0	6.9	360.00	10.3

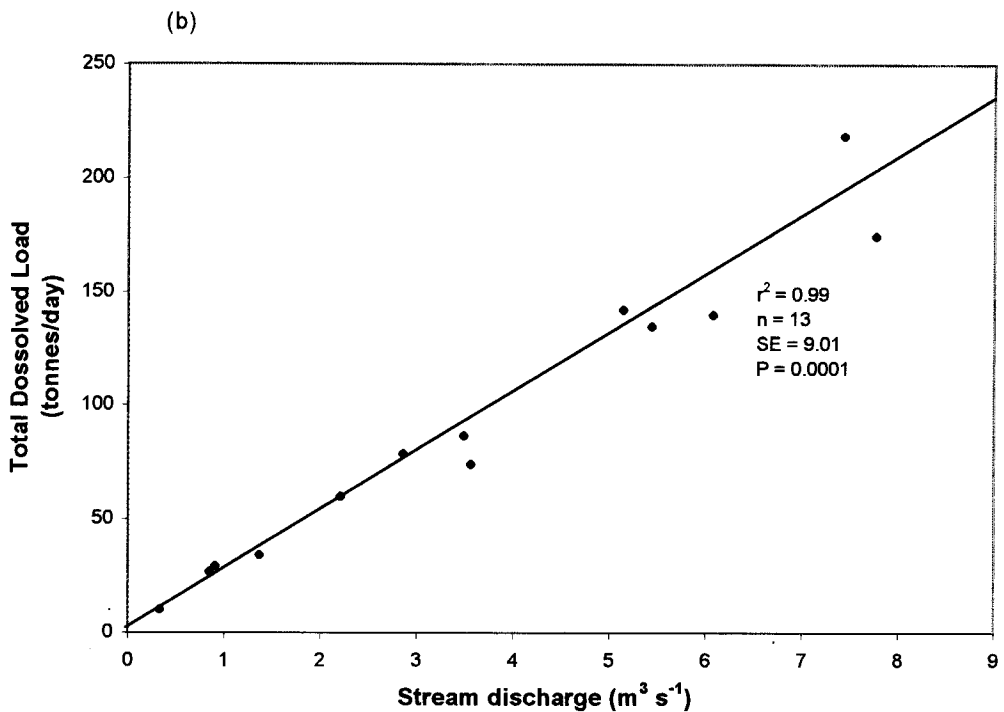
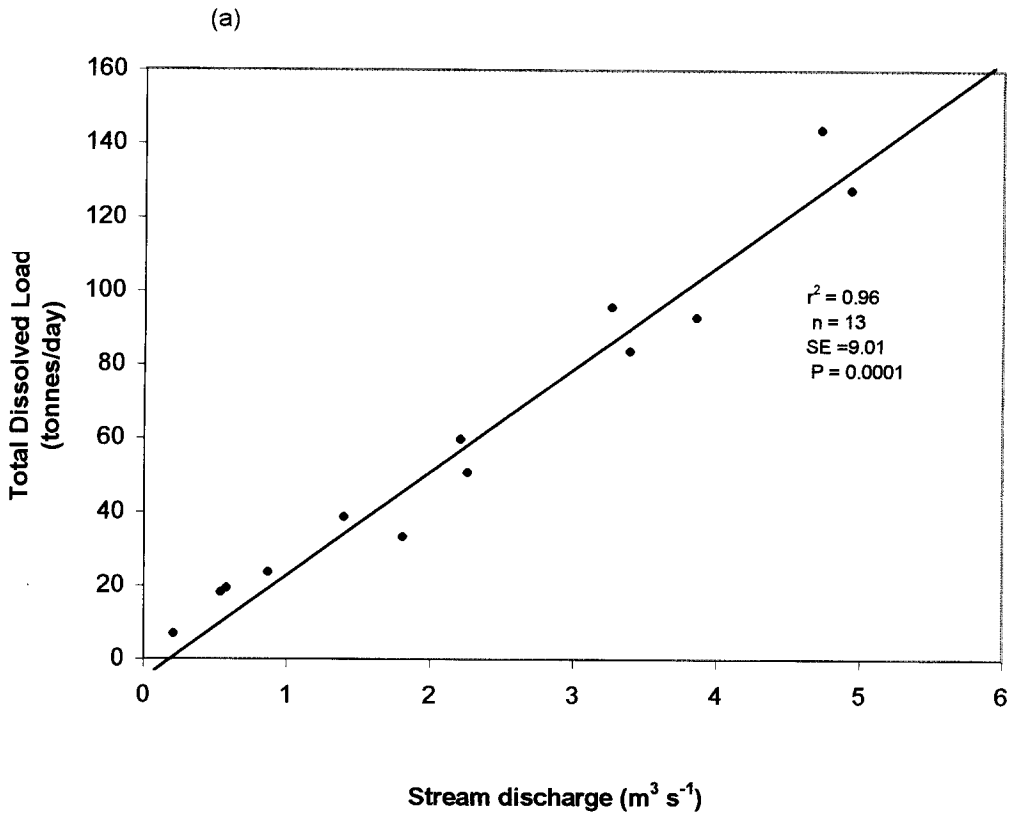


Figure 5.4 Relationships between estimated stream discharge and measured total dissolved load at (a) Itawa Swamps (ST1) and (b) Kanini (ST4), 1998, Ndola.

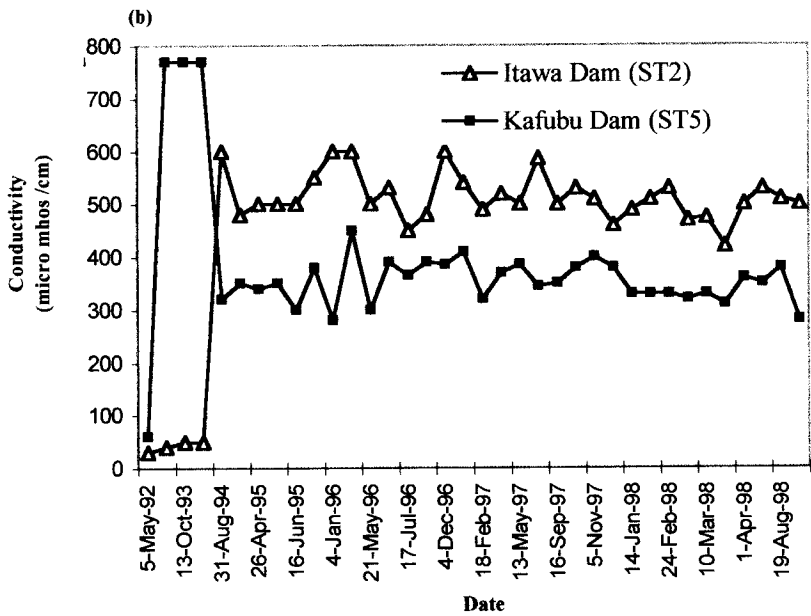
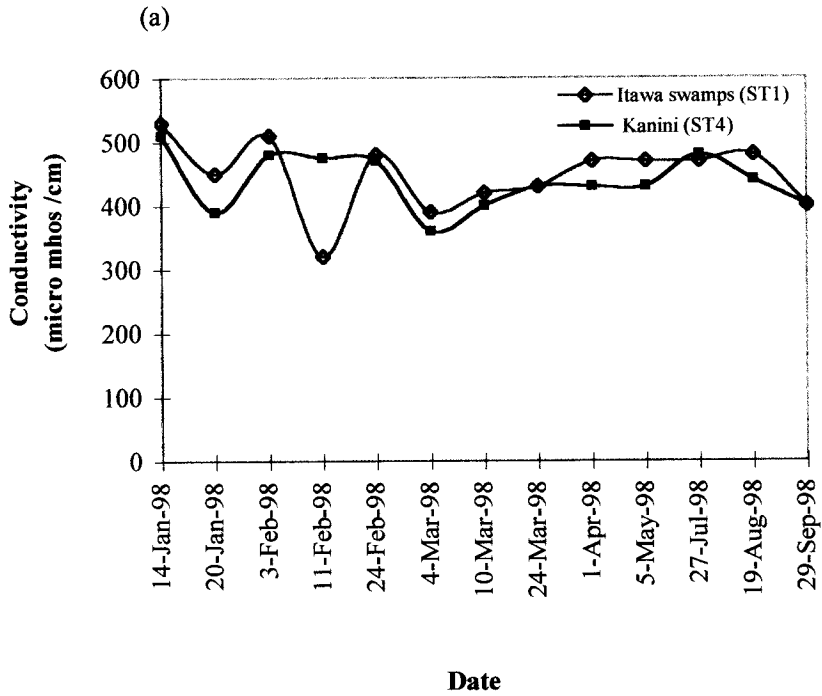


Figure 5.5. Temporal variations in conductivity concentration levels in Kafubu River water at (a) Itawa Swamps (ST1) and Kanini (ST4), and (b) Itawa (ST2) and Kafubu (ST5) Dams.

had an average of 50 $\mu\text{mhos/cm}$. Throughout the period under discussion, Itawa Dam water had a slightly higher conductivity than Kafubu Dam except in 1992/93 when it had 50 $\mu\text{mhos/cm}$ (Figures 5.5 a, b). There were very little inter-stational variations between Itawa Swamps, Itawa Dam and Kanini sampling stations compared to that of Kafubu Dam (Tables 5.1 and 5.2).

5.2.1.5 Turbidity and Colour of Water

Turbidity increased gradually from Itawa Swamps to Kafubu Dam (Tables 5.1 and 5.2; Figures 5.6a, b). From an average of 0.71 to 1.55 NTU in the wet and dry seasons respectively, at Itawa Swamps (ST1), turbidity increased to an average of between 1.03 and 3.28 NTU at Itawa Dam (ST2). The downstream stations Kanini (ST4) and Kafubu Dam (ST5) had average turbidity units of 5.49 and 3.42 NTU in the wet season and 5.83 to 12.94 NTU in the dry season, respectively, (Tables 5.1 and 5.2). The last station downstream (ST5) had the highest turbidity units ranging from 3.4 NTU to 12.94 NTU.

The colour of water has an effect on the aesthetic value of the river. The colouration of water in Kafubu River increased downstream from Itawa Swamps Station (ST1) to Kafubu Dam (ST5). The colour of river water averaged from 10 units (ST1) to 22 units (ST5) in the wet season (Table 5.1) and from 6.7 units (ST1) to 32.0 units (ST5) in the dry season (Table 5.2). Temporal and spatial variations were depicted throughout the study period with wet season months having higher colour units than dry season months (Figure 5.6c, d). Itawa Swamps (ST1) had the minimum colour units averaging 10 units and 6.6 units, respectively. Kanini station (ST4) had a reasonably low range of

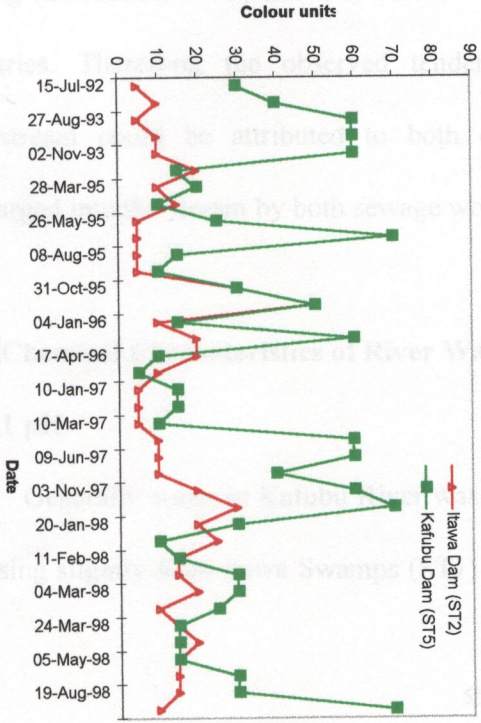
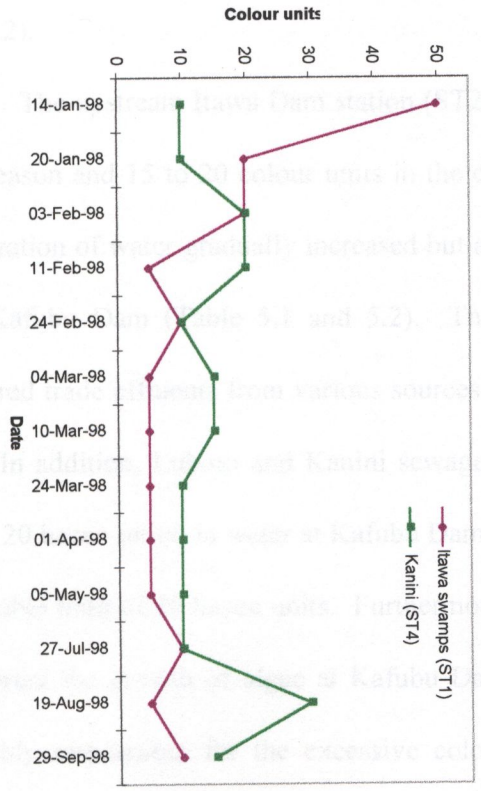
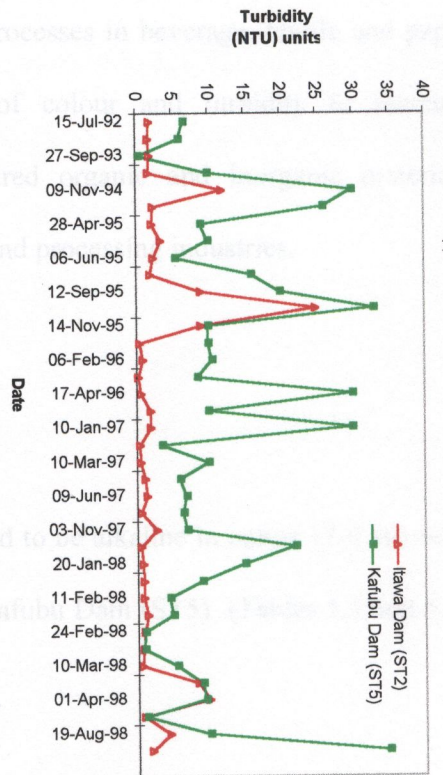
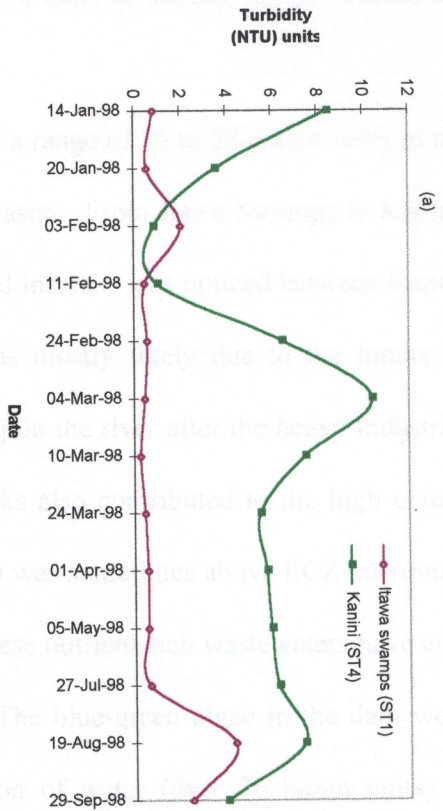


Figure 5.6 Temporal Variations in Turbidity and colour units in raw river water in Upper Katubu Catchment (a) Turbidity (ST1) and (ST4), (b) Turbidity (ST2) and (ST5), (c) colour (ST1 and ST4) and (d) colour (ST2 and ST5).

10 to 20 colour units in the wet season and 10 to 30 units in the dry season (Tables 5.1 and 5.2).

The upstream Itawa Dam station (ST2) had a range of 15 to 25 colour units in the wet season and 15 to 20 colour units in the dry season. From Itawa Swamps to Kanini, colouration of water gradually increased but a rapid increase was noticed between Kanini and Kafubu Dam (Table 5.1 and 5.2). This was mostly likely due to the inputs of coloured trade effluents from various sources that join the river after the heavy industrial area. In addition, Lubuto and Kanini sewage works also contributed to the high colour (over 20 hazen units) in water at Kafubu Dam such as sometimes above ECZ maximum allowable limit of 20 hazen units. Furthermore, these nutrient-rich wastewaters have also supported the growth of algae at Kafubu Dam. The blue-green algae in the dam were probably responsible for the excessive colouration of water (over 70 hazen units) at Kafubu Dam especially in the dry season (Figure 5.6c and d).

Colour and turbidity are usually produced by compounds such as lignin and tanning (Simuunza, 1992) and may result from processes in beverage, textile and paper industries. Therefore, the observed tendency of colour and turbidity to increase downstream could be attributed to both coloured organic and inorganic materials discharged into the stream by both sewage works and processing industries.

5.2.2 Chemical Characteristics of River Water

5.2.2.1 pH

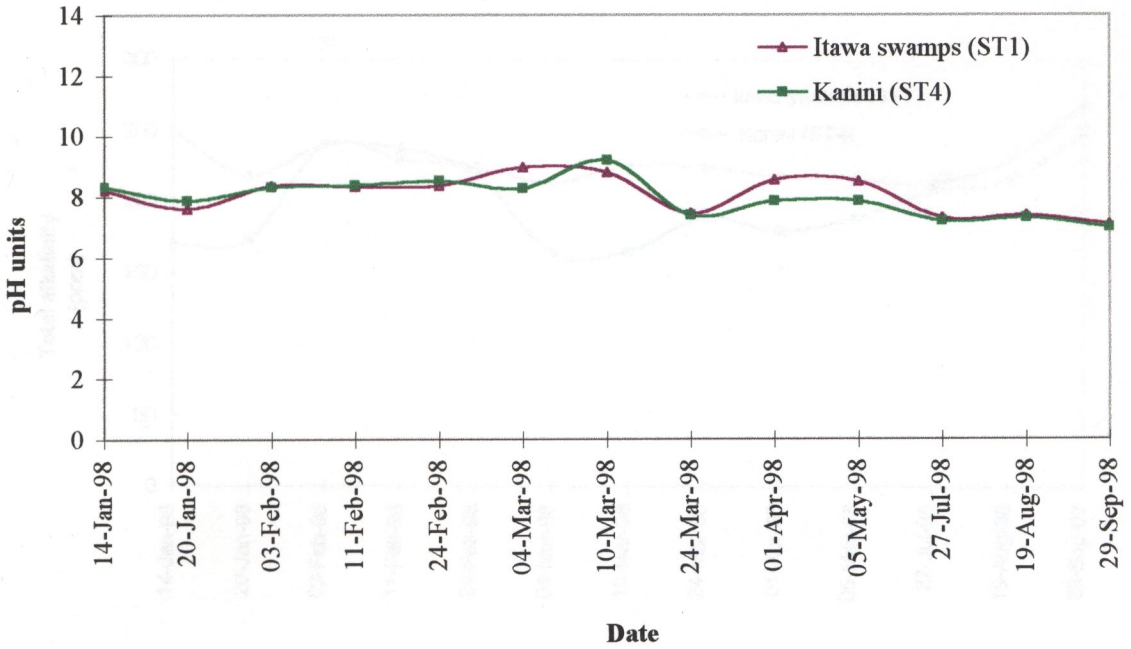
Generally water in Kafubu River was found to be alkaline in nature (7-9.36) with pH rising slightly from Itawa Swamps (ST1) to Kafubu Dam (ST5) (Tables 5.1 and 5.2)

(Figures 5.7a, b). Kafubu Dam recorded the maximum pH levels ranging between 8.13 to 9.36 units in the wet season and 7.50 to 8.95 units in the dry season, (Tables 5.1 and 5.2). This was probably due to the presence of algal bloom and photosynthetic activities. Itawa Swamps (ST1) had pH levels averaging from 8.38 to 7.72 units in the wet and dry season, respectively. Itawa Dam (ST2) and Kanini (ST4) stations had pH averaging 8.19 and 7.2 units (ST2) in the wet and dry seasons, and 8.42 and 7.44 units (ST4) in the wet and dry seasons, respectively (Tables 5.1 and 5.2; Appendices IVa and IVd). The pH of river water was sometimes above ECZ maximum allowable limit of 6.0-9units.

5.2.2.2 Total Alkalinity

The alkalinity of Kafubu River water could be attributed to the outcrops of dolomitic limestone existing within the catchment. At Itawa Dambo, quarrying along the Kafubu River banks could have accelerated this, because it allows leaching of bicarbonates and carbonates. Itawa Swamps (ST1) and Itawa Dam (ST2) had the highest concentration levels of 230 and 228.83 ppm for Itawa Swamps in the wet and dry seasons, and 242.25 ppm and 259.04 ppm for Itawa Dam in the wet and dry seasons, respectively. Downstream stations had total alkalinity averaging 194.57 and 205.5 ppm (ST4) in the wet season and dry seasons and 152.2 ppm and 164.0 ppm (ST5) in the wet and dry seasons, respectively (Tables 5.1 and 5.2). Temporal variation in alkalinity of Kafubu River water was very high with concentration levels declining downstream from Itawa Swamps (ST1) to Kafubu Dam (ST2) and being slightly higher in the wet than in dry season months (Tables 5.1 and 5.2; Figure 5.8 a, b).

(a)



(b)

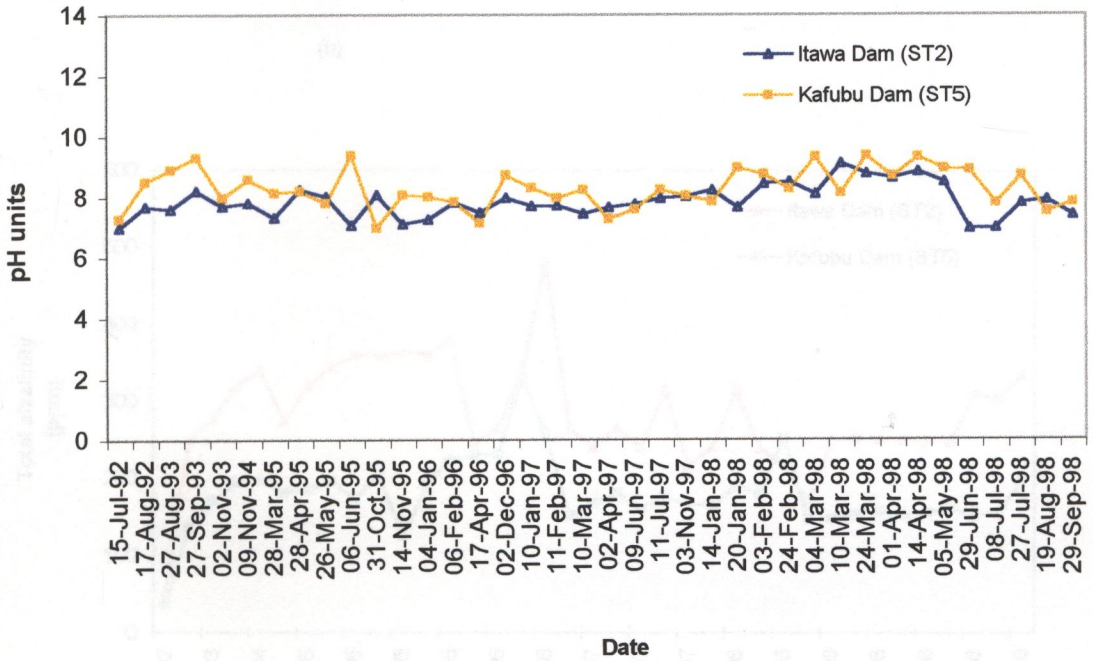


Figure 5.7. Temporal variations in pH Units in Raw River Water at (a) Itawa Swamps (ST1) and Kanini (ST4) and (b) Itawa ST2) and Kafubu (ST5) Dams.

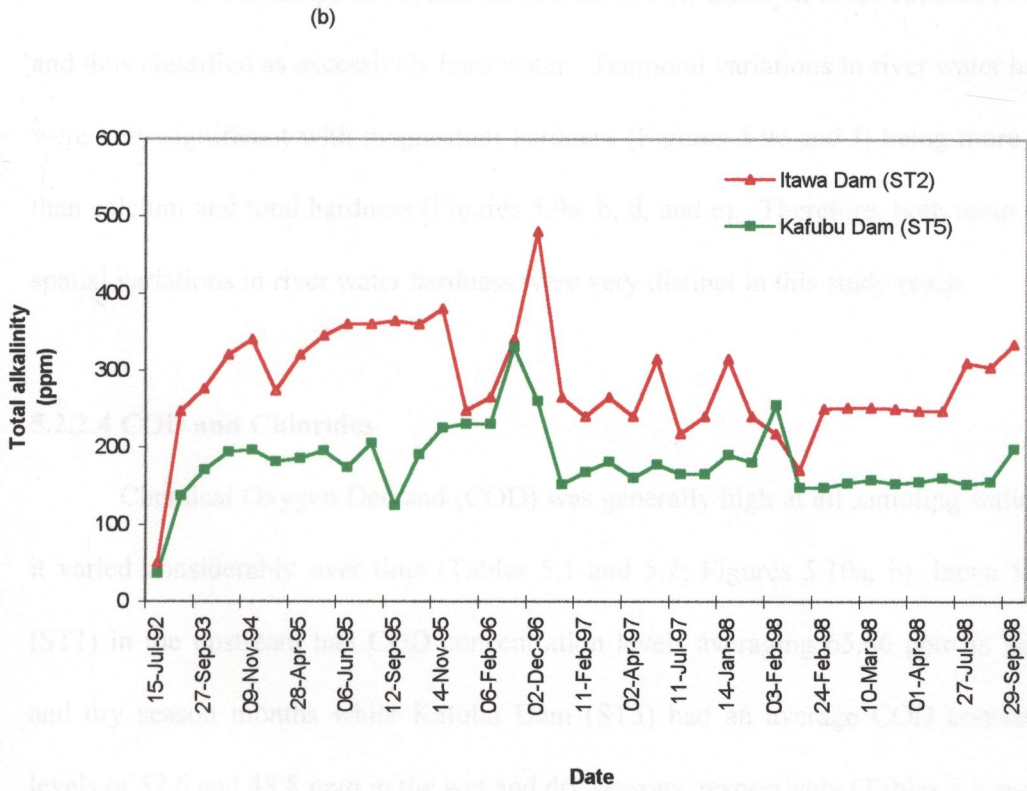
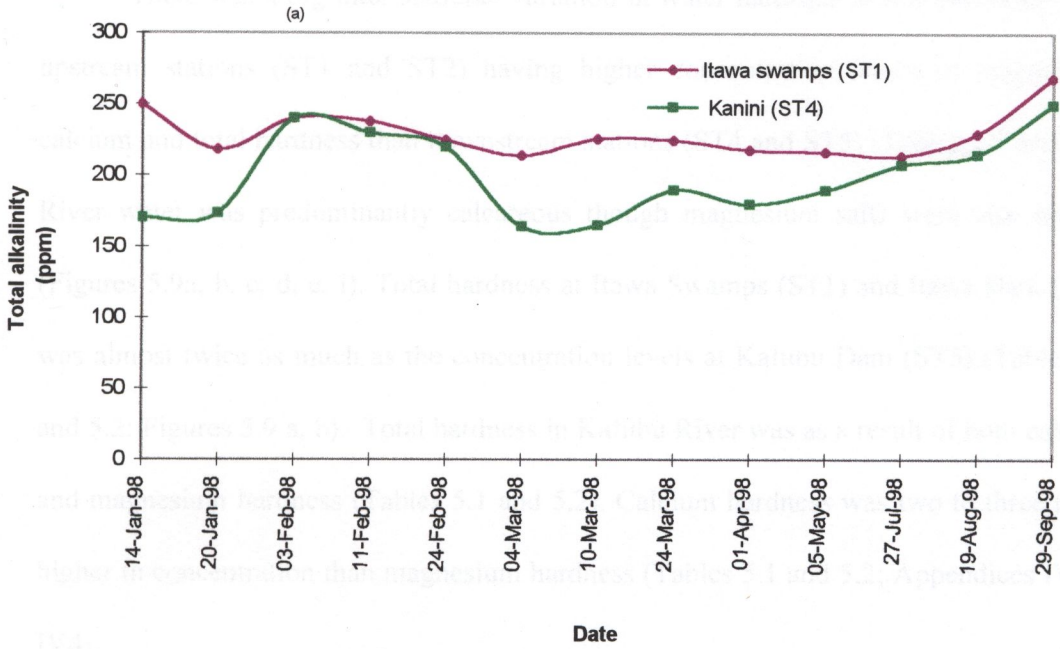


Figure 5.8 Temporal Variations in Total alkalinity concentration levels in raw river water at Itawa Swamps (ST1) and Kanini, (ST4) and Itawa (ST2) and Kafubu (ST5) dams.

5.2.2.3 Calcium, Magnesium and Total Hardness

There was a big inter-stational variation in water hardness in this catchment with upstream stations (ST1 and ST2) having higher concentration levels of magnesium, calcium and total hardness than downstream stations (ST4 and ST5) (Tables 5.1 and 5.2). River water was predominantly calcareous though magnesium salts were also present (Figures 5.9a, b, c, d, e, f). Total hardness at Itawa Swamps (ST1) and Itawa Dam (ST2) was almost twice as much as the concentration levels at Kafubu Dam (ST5) (Tables 5.1 and 5.2; Figures 5.9 a, b). Total hardness in Kafubu River was as a result of both calcium and magnesium hardness (Tables 5.1 and 5.2). Calcium hardness was two to three times higher in concentration than magnesium hardness (Tables 5.1 and 5.2; Appendices IVa to IVd).

At Itawa Swamps (ST1) and Itawa Dam (ST2), CaCO_2 at times exceeded 350 ppm and thus classified as excessively hard water. Temporal variations in river water hardness were very significant with magnesium hardness (Figures 5.9c and f) being more variant than calcium and total hardness (Figures 5.9a, b, d, and e). Therefore, both temporal and spatial variations in river water hardness were very distinct in this study reach.

5.2.2.4 COD and Chlorides

Chemical Oxygen Demand (COD) was generally high at all sampling stations and it varied considerably over time (Tables 5.1 and 5.2; Figures 5.10a, b). Itawa Swamps (ST1) in the upstream had COD concentration levels averaging 65.66 ppm in both wet and dry season months while Kafubu Dam (ST5) had an average COD concentration levels of 57.6 and 48.8 ppm in the wet and dry seasons, respectively (Tables 5.1 and 5.2).

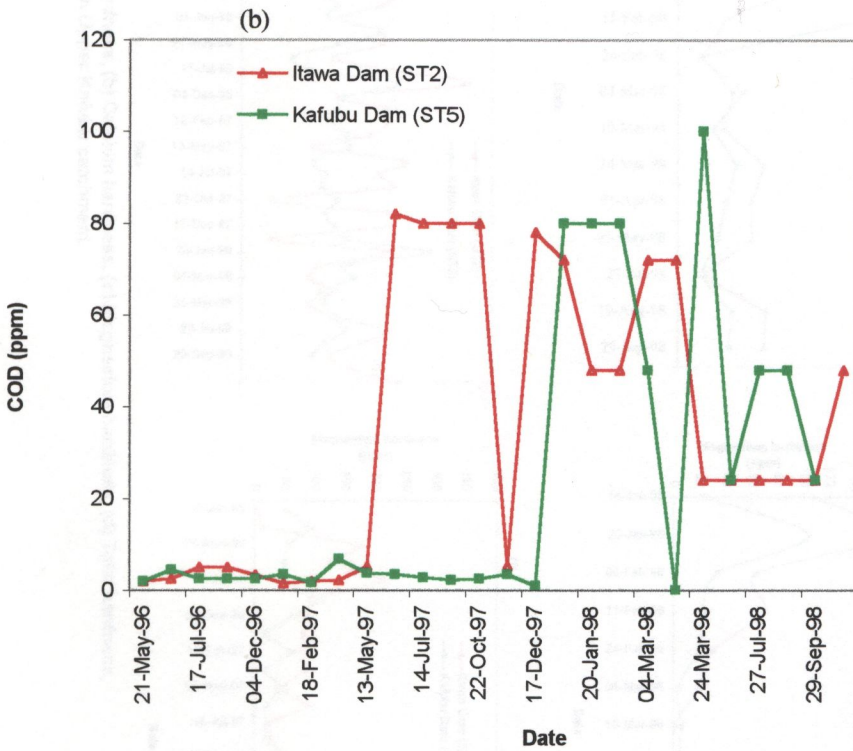
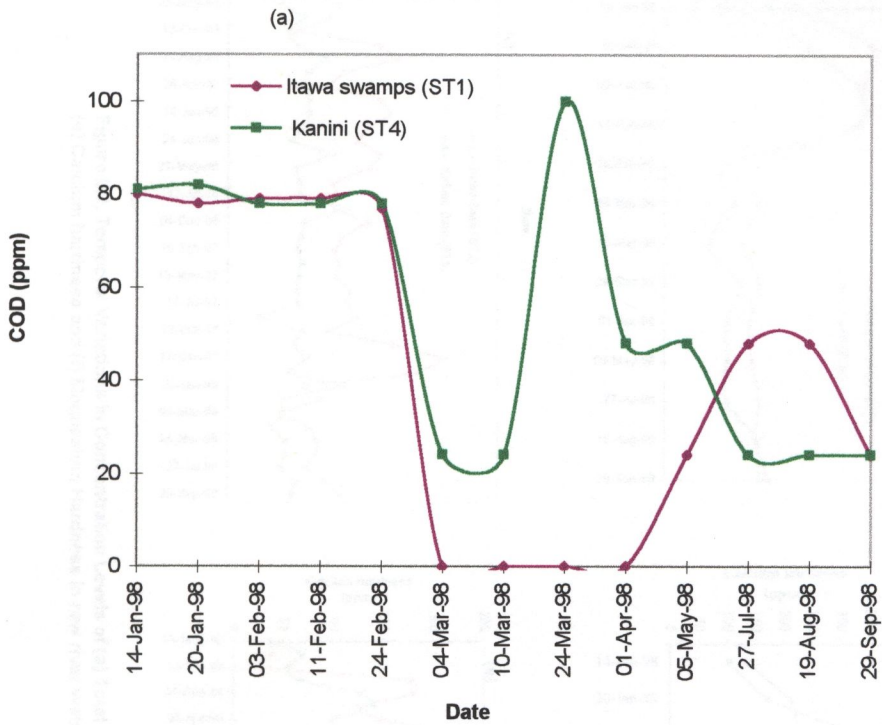


Figure 5.10. Temporal Variations in COD Concentration Levels in raw river water at (a) Itawa Swamps (ST1) and Kanini (ST4) and (b) Itawa (ST2) and Kafubu (ST5) Dams.

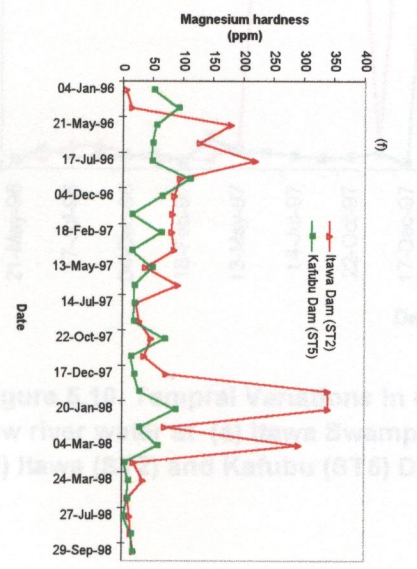
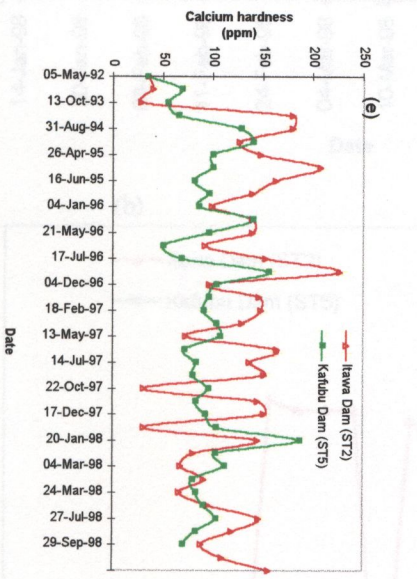
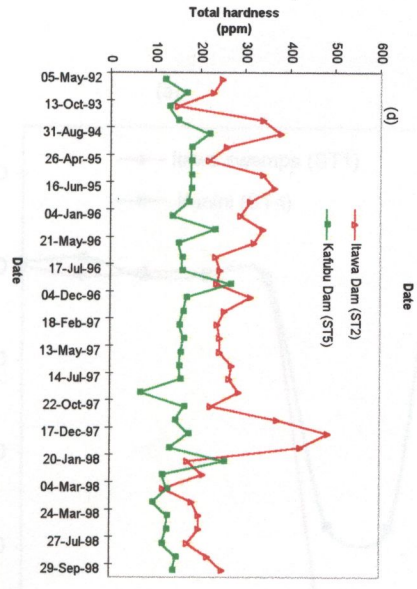
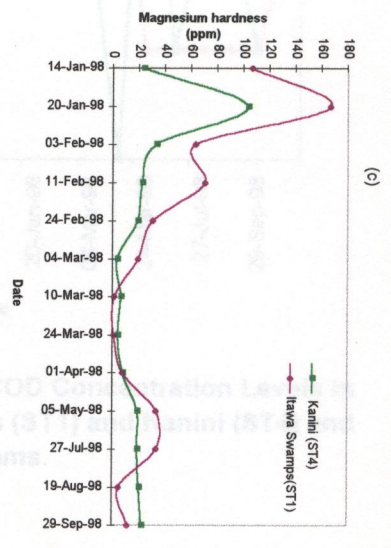
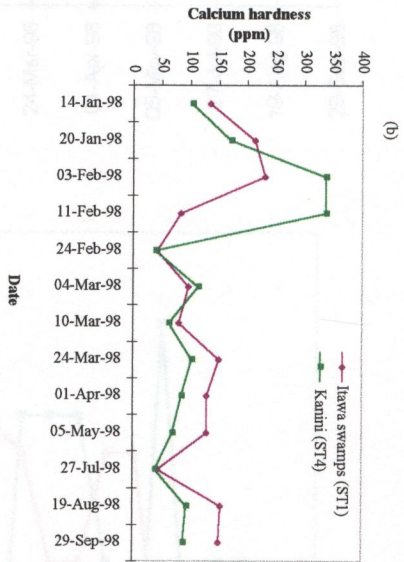
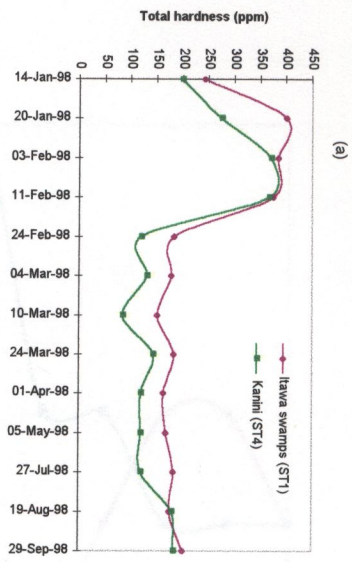


Figure 5.9. Temporal Variations in Concentration Levels of (a) Total hardness, (b) Calcium hardness, (c) Magnesium hardness, (d) Total hardness, (e) Calcium hardness and (f) Magnesium Hardness in raw river water in Upper Kaitabu catchment.

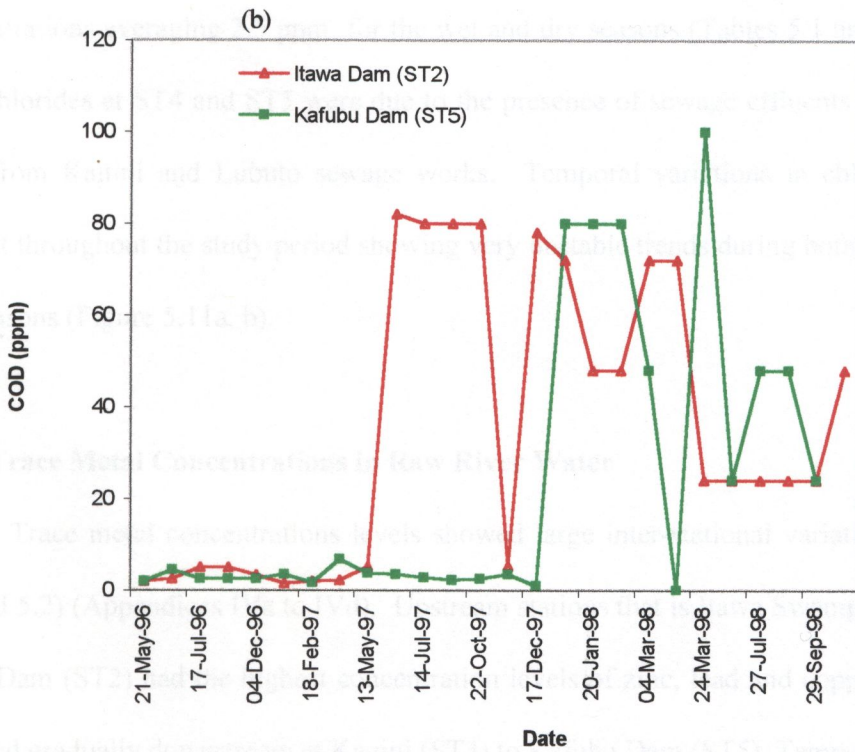
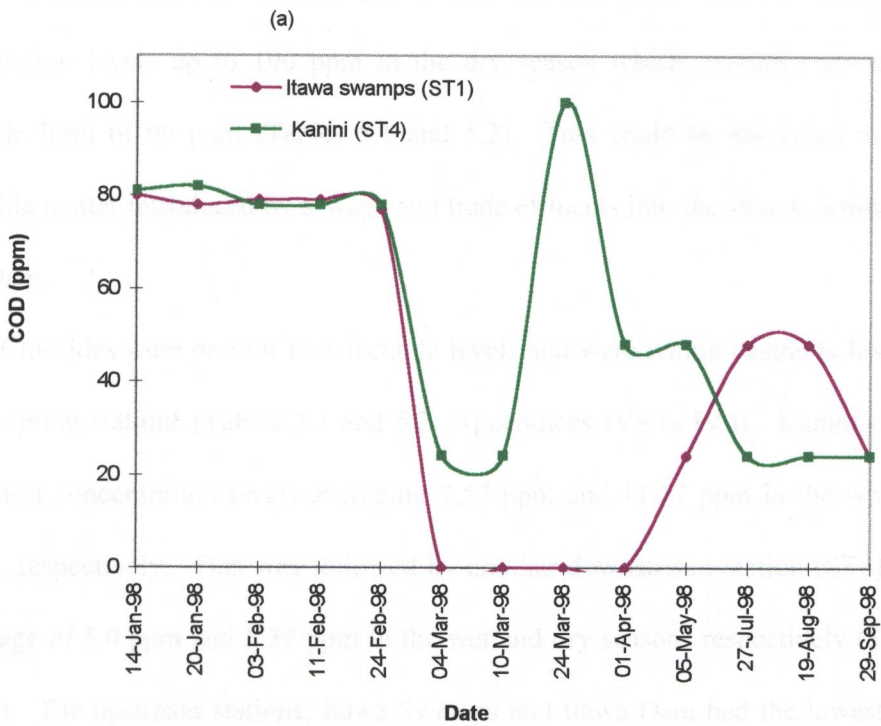


Figure 5.10. Temporal Variations in COD Concentration Levels in raw river water at (a) Itawa Swamps (ST1) and Kanini (ST4) and (b) Itawa (ST2) and Kafubu (ST5) Dams.

The downstream stations, Kanini (ST4) and Kafubu Dam (ST5) recorded COD concentration levels up to 100 ppm in the dry season which exceeded the maximum allowable limit of 90 ppm (Tables 5.1 and 5.2). This could be attributed to the high oxidizable matter introduced by sewage and trade effluents into the stream downstream of Itawa Dam.

Chlorides were present in detectable levels and were within desirable levels at the four sampling stations (Tables 5.1 and 5.2; Appendices IVa to IVd). Kanini (ST4) had the highest concentration levels averaging 7.57 ppm and 11.17 ppm in the wet and dry seasons, respectively. This was followed by another downstream station (ST5) that had an average of 5.0 ppm and 8.37 ppm in the wet and dry seasons respectively (Tables 5.1 and 5.2). The upstream stations, Itawa Swamps and Itawa Dam had the lowest chloride concentrations averaging 2.5 ppm for the wet and dry seasons (Tables 5.1 and 5.2). The high chlorides at ST4 and ST5 were due to the presence of sewage effluents entering the river from Kanini and Lubuto sewage works. Temporal variations in chlorides were distinct throughout the study period showing very unstable trends during both the wet and dry seasons (Figure 5.11a, b).

5.2.3 Trace Metal Concentrations in Raw River Water

Trace metal concentrations levels showed large inter-stational variations (Tables 5.1 and 5.2) (Appendices IVa to IVd). Upstream stations that is Itawa Swamps (ST1) and Itawa Dam (ST2) had the highest concentration levels of zinc, lead and copper but these declined gradually downstream at Kanini (ST4) to Kafubu Dam (ST5). Temporal and

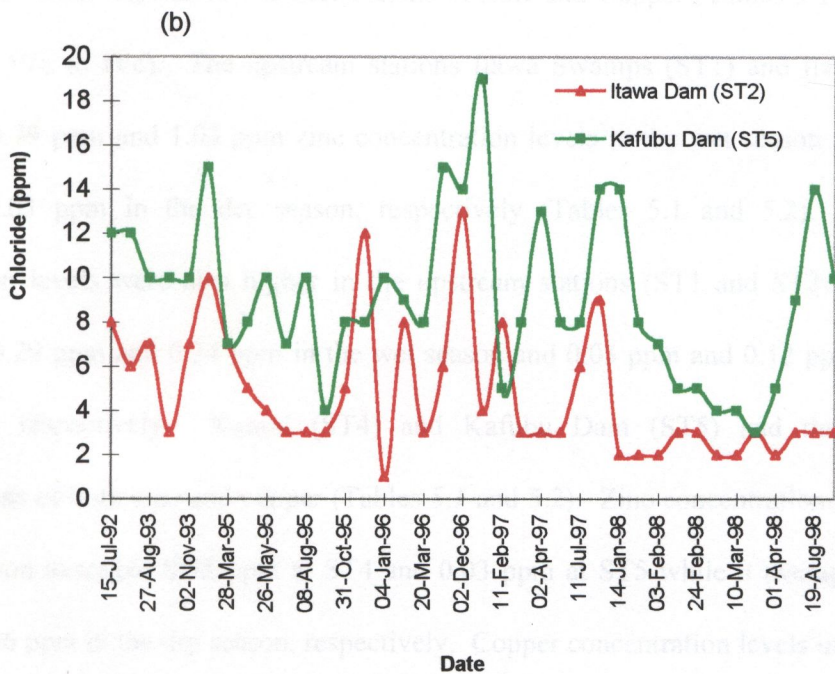
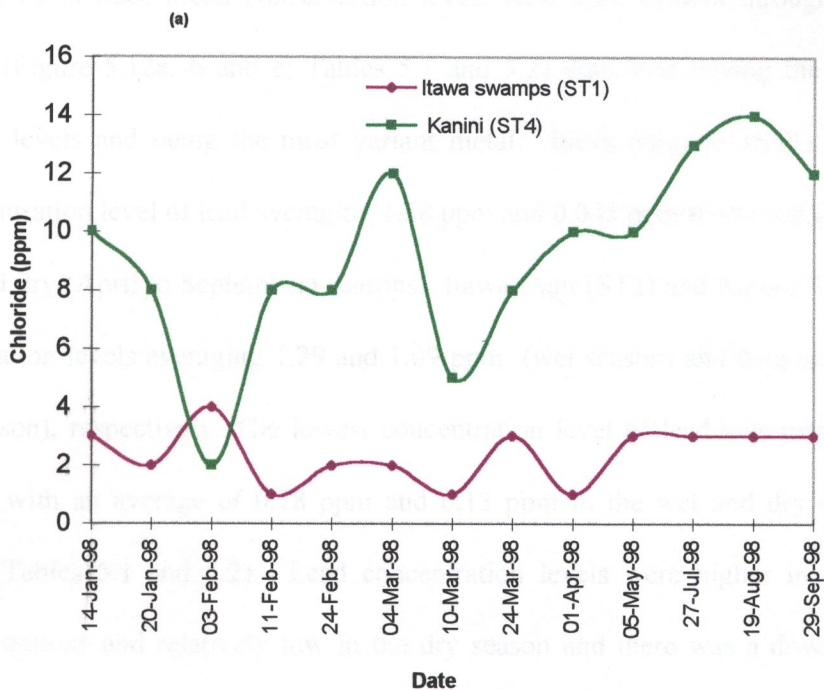


Figure 5.11. Temporal Variations in Concentration levels of Chloride in raw river water at (a) Itawa Swamps (ST1) and Kanini (ST4) and (b) Itawa (ST2) and Kafubu (ST5) dams.

spatial variations in trace metal concentration levels were very evident throughout the study period (Figure 5.12a, b and c; Tables 5.1 and 5.2) with lead having the highest concentration levels and being the most variant metal. Itawa Swamps (ST1) had the highest concentration level of lead averaging 1.58 ppm and 0.045 ppm in the wet (January to March) and dry (April to September) seasons. Itawa Dam (ST2) and Kanini ST4) had lead concentration levels averaging 1.29 and 1.09 ppm (wet season) and 0.46 and 0.035 ppm (dry season), respectively. The lowest concentration level of lead was recorded at Kafubu Dam with an average of 0.78 ppm and 0.13 ppm in the wet and dry seasons, respectively (Tables 5.1 and 5.2). Lead concentration levels were higher in the wet season at all stations and relatively low in the dry season and there was a downstream decline in concentration levels of lead at all seasons (Tables 5.1 and 5.2). In general Kafubu River water showed low concentrations of Zinc and Copper (Tables 5.1 and 5.2; Appendices IVa to IVc). The upstream stations Itawa Swamps (ST1) and Itawa Dam (ST2) had 0.79 ppm and 1.03 ppm zinc concentration levels in the wet season and 0.05 ppm and 0.03 ppm in the dry season, respectively (Tables 5.1 and 5.2). Copper concentration levels were also higher in the upstream stations (ST1 and ST2) with an average of 0.29 ppm and 0.34 ppm in the wet season and 0.03 ppm and 0.12 ppm in the dry season, respectively. Kanini (ST4) and Kafubu Dam (ST5) had the lowest concentrations of both zinc and copper (Tables 5.1 and 5.2). Zinc concentration levels in the wet season averaged 0.55 ppm at ST4 and 0.03 ppm at ST5 while it averaged 0.04 ppm and 0.06 ppm in the dry season, respectively. Copper concentration levels in the wet season averaged 0.2 ppm (ST4) and 0.33 ppm (ST5) while in the dry season it averaged 0.02 ppm (ST4) and 0.03 ppm (ST5).

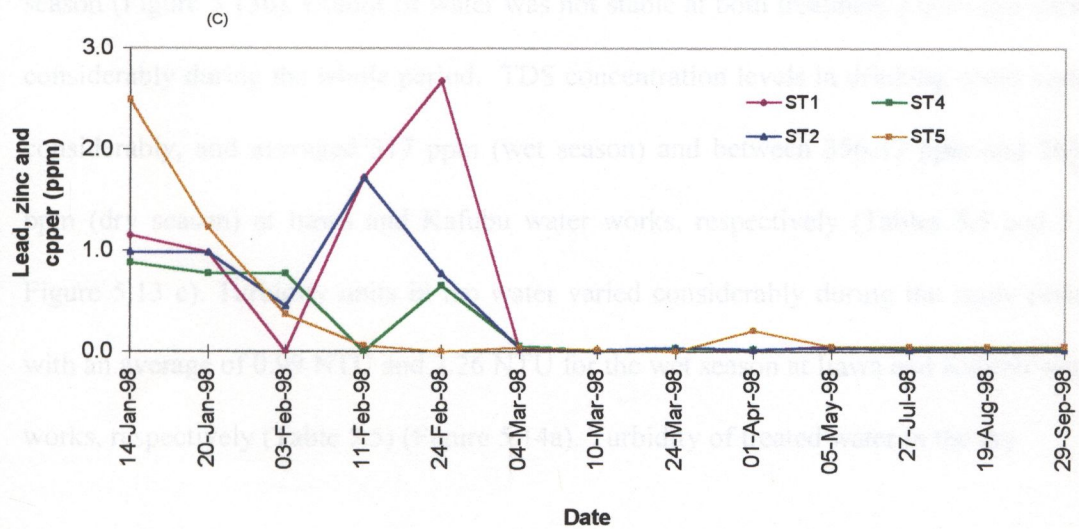
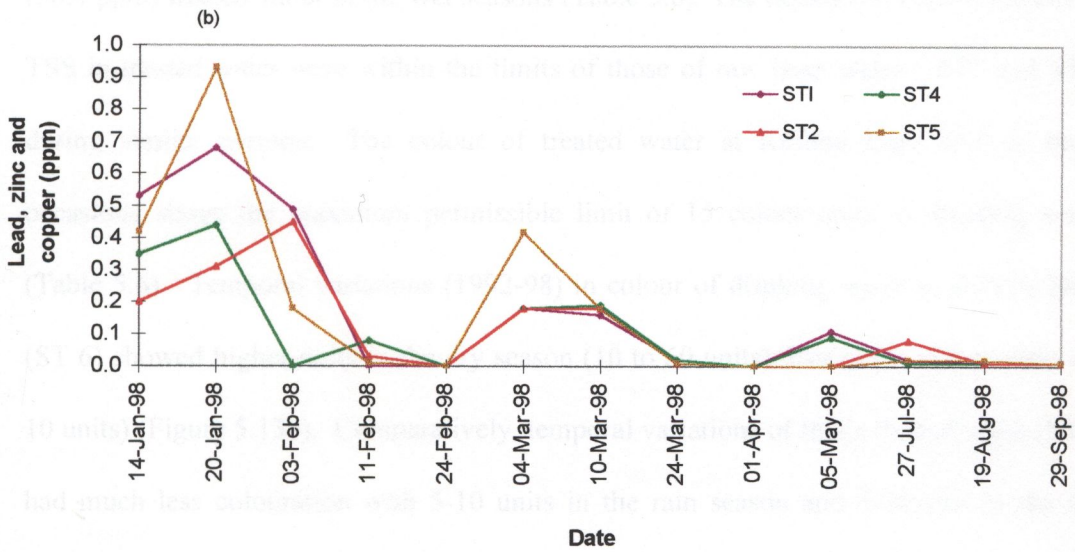
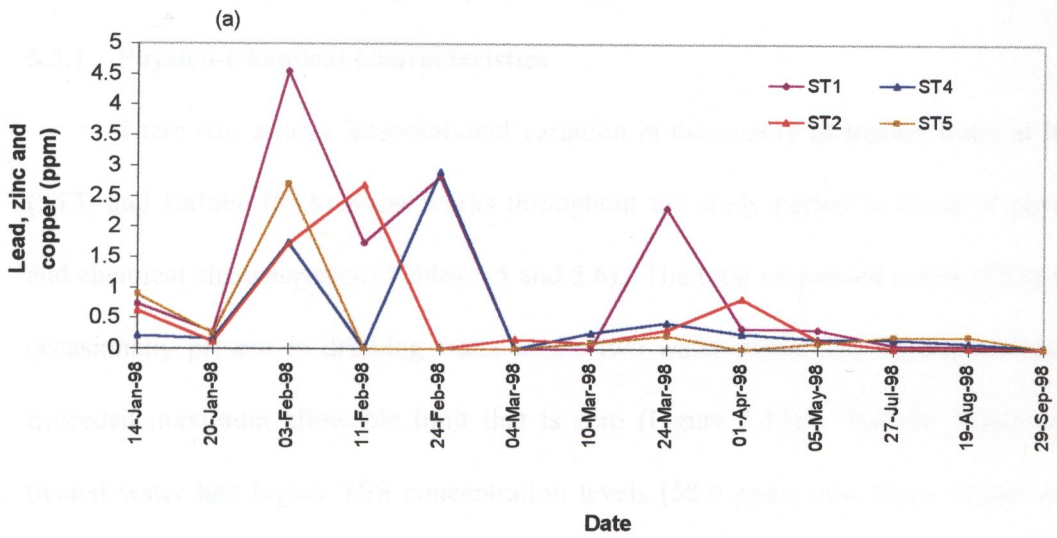


Figure 5.12 Temporal variations in concentration levels of (a) Lead (b) Copper (c) Zinc in raw river water in the Upper Kafubu River basin

5.3 Treated (tap) Water Quality Characteristics

5.3.1 Physico-Chemical Characteristics

There was a large inter-stational variation in the quality of treated water at Itawa (ST3) and Kafubu (ST6) water works throughout the study period in terms of physical and chemical characteristics (Tables 5.5 and 5.6). The total suspended solids (TSS) were occasionally present in drinking water at the two water works and on these occasions exceeded maximum allowable limit that is zero (Figure 5.13a). Kafubu Water works treated water had higher TSS concentration levels (58.0 ppm) than Itawa Water works (36.4 ppm) treated water in the wet seasons (Table 5.6). The occasional concentrations of TSS in treated water were within the limits of those of raw river water (ST2 and ST5) during similar periods. The colour of treated water at Kafubu Dam was on these occasions above the maximum permissible limit of 15 colour units in drinking water (Table 5.6). Temporal variations (1992-98) in colour of drinking water at Kafubu Dam (ST 6) showed higher units in the dry season (10 to 60 units) than in the rain months (5-10 units) (Figure 5.13b). Comparatively, temporal variations of Itawa treated water (ST3) had much less colouration with 5-10 units in the rain season and 5-50units in the dry season (Figure 5.13b). Colour of water was not stable at both treatment plants and varied considerably during the whole period. TDS concentration levels in drinking water varied considerably, and averaged 317 ppm (wet season) and between 356.37 ppm and 263.4 ppm (dry season) at Itawa and Kafubu water works, respectively (Tables 5.5 and 5.6; Figure 5.13 c). Turbidity units in tap water varied considerably during the study period with an average of 0.99 NTU and 2.26 NTU for the wet season at Itawa and Kafubu water works, respectively (Table 5.5) (Figure 5.14a). Turbidity of treated water in the dry

Table 5.5 Physico-chemical Characteristics of Treated Water at Itawa and Kafubu Water Works in the Wet Season.

Parameter	Number of Samples	Itawa water works (ST3)	Itawa water works (ST6)
A. PHYSICAL			
Temperature °c	8	26 (26-26)	26 (26-26)
Conductivity (µmhos/cm)	8	463.75* (390-540)	463.75* (390-540)
TDS (ppm)	8	317.39 (273.3-360.0)	317.39 (273.3-360.0)
TSS (ppm)	8	0 (0-0)	0 (0-0)
Colour units	8	10 (10-10)	10 (10-10)
Turbidity units	8	0.99 (0.5-1.30)	2.26 (0.5-3.10)
B. CHEMICAL			
PH	8	8.83 (7.32-8.83)	8.43 (7.92-8.92)
Total alkalinity (ppm)	8	233.38 (165-264)	151.2 (146-155)
Chloride (ppm)	8	3.63 (2.0-8.0)	6.4 (5.0-8.0)
COD (ppm)	8	60.03 (84.0-4.2)*	48 (0-80)*
Magnesium hardness (ppm)	8	87.35 (10.75-216)	37.31 (40-115.2)
Calcium hardness (ppm)	8	89.31 (38.4-188.8)	105.6 (76.8-152.0)
Total hardness (ppm)	8	245.6 (364.8-245.6)	135.36 (45.6-267.2)
C. TRACE METALS			
Lead (ppm)	8	1.13 (0.26-2.32)*	0.92 (0.01-2.56)*
Copper (ppm)	8	0.40 (0.28-0.47)	0.27 (0.0-0.77)
Zinc (ppm)	8	0.92 (0.68-1.17)	0.59 (0.0-1.4)

Figures in parenthesis are minimum and maximum ranges

* Above maximum permissible level (WHO, 1971)

Table 5.6 Physico-chemical Characteristics of Treated Water at Itawa and Kafubu Water Works in the Dry Season.

Parameter	Number of Samples		Itawa Water Works (ST3)	Kafubu Water Works (ST6)
A. PHYSICAL				
Temperature °c	8		21.0 (20-24)	21.6 (20-25)
Conductivity (µmhos/cm)	8		317.4* (273.3-360)	345.0* (330-350)
TDS (ppm)	8		356.4 (289-470)	263.4 (233.3-291.0)
TSS (ppm)	8		36.44 (0.0-328)*	58.0 (0.0-208)*
Colour units	8		10.0 (5-30)	10.0 (10.0-30-0)
Turbidity units	8		1.3 (0.3- 4.10)	2.7 (0.5-7.40)
B.CHEMICAL				
pH units	8		8.2 (7.30-8.20)	8.1 (7.9-8.3)
Total alkalinity (ppm)	8		311.0 (305-316)	156.0 (143-165)
Chloride (ppm)	8		4.1 (4-5.0)	8.3 (5.0-13.0)
COD (ppm)	8		50.7 (48-72)*	24.0 (0-48)
Magnesium (ppm)	8		19.0 (12.8-26.8)	11.3 (4.2-16.7)
Calcium hardness (ppm)	8		84.3 (26.8-136.0)	99.5 (83.2-122.6)
Total hardness (ppm)	8		180.3 (160-208)	146.6 (140.0-152.0)
C. TRACE METALS				
Lead (ppm)	8		0.5 (0.08-2.18)*	0.2 (0.01-0.32)*
Copper (ppm)	8		0.04 (0.0-0.15)	0.04 (0.0-0.08)
Zinc (ppm)	8		0.1 (0.0-1.4)	0.7 (0.0-0.09)

Figures in parenthesis are minimum and maximum ranges

* Above maximum permissible level (WHO, 1971)

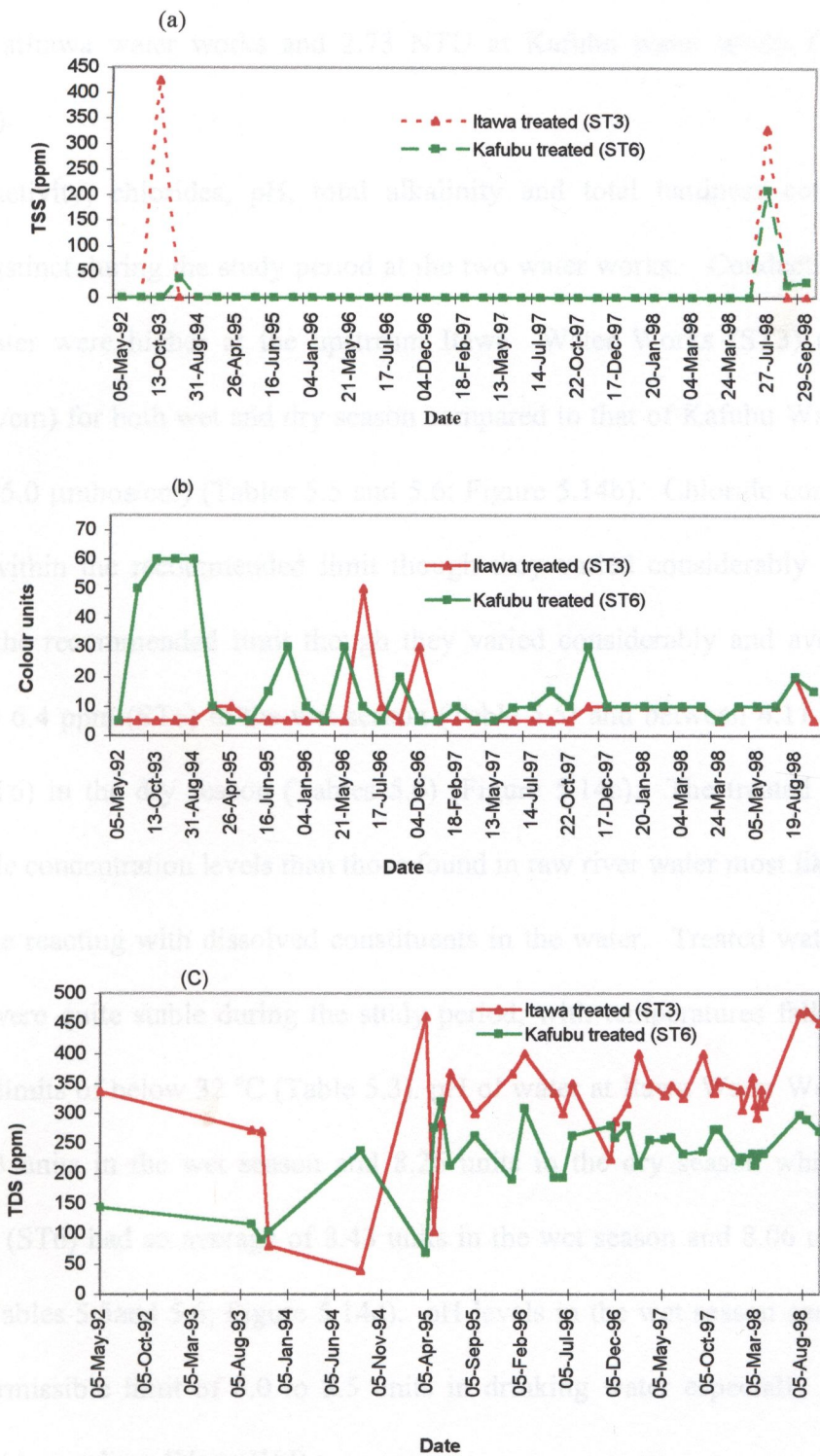


Figure 5.13. Temporal Variations in Concentration levels of (a) Total Suspended Solids and (c) Total Dissolved Solids in drinking water at Itawa and Kafubu water works.

season was slightly higher than in the wet season at the two water works with an average of 1.3 NTU at Itawa water works and 2.73 NTU at Kafubu water works (Table 5.6) (Figure 5.14a).

Conductivity, chlorides, pH, total alkalinity and total hardness concentration levels were distinct during the study period at the two water works. Conductivity levels of treated water were higher at the upstream Itawa Water Works (ST3) (463.75 to 317.39 $\mu\text{mhos/cm}$) for both wet and dry season compared to that of Kafubu Water Works (463.75 to 345.0 $\mu\text{mhos/cm}$) (Tables 5.5 and 5.6; Figure 5.14b). Chloride concentration levels were within the recommended limit though they varied considerably and levels were within the recommended limit though they varied considerably and averaged 3.6 ppm (ST3) to 6.4 ppm (ST6) in the wet season (Table 5.5) and between 4.11 (ST3) and 8.25 ppm (ST6) in the dry season (Tables 5.6) (Figure 5.14c). The treated water had higher chloride concentration levels than those found in raw river water most likely due to added chlorine reacting with dissolved constituents in the water. Treated water pH and temperature were quite stable during the study period, with temperatures falling within the desirable limits of below 32 °C (Table 5.3). pH of water at Itawa Water Works (ST3) averaged 8.83 units in the wet season and 8.26 units in the dry season while Kafubu Water Works (ST6) had an average of 8.43 units in the wet season and 8.06 units in the dry season (Tables 5.5 and 5.6; Figure 5.14d). pH levels in the wet season exceeded the maximum permissible limit of 6.0 to 8.5 units in drinking water especially at Kafubu station (ST6) (Appendices IVa to IVd).

Total alkalinity and total hardness of treated water at the two water works varied considerably over time with Itawa water (ST3) being more alkaline and harder than that of Kafubu Water Works (Tables 5.5 and 5.6; Figures 5.15a, b). These trends in TDS, conductivity, total alkalinity and hardness were similar to those of raw river water at ST2 and ST5.

Trace metal concentration levels in drinking water at both Itawa and Kafubu Water Works stations were high and varied considerably over time at both water works (Figure 5.16a, b, c). Lead concentration levels at both water works were very high especially in the wet season compared to the dry season (Tables 5.5 and 5.6). Lead averaged 1.3 ppm and 0.92 ppm at Itawa and Kafubu Water works in the wet season and from 0.45 ppm to 0.20 ppm in the dry season, respectively. This was as a result of higher lead concentration levels in raw river water at Itawa Swamps (ST2) and Kafubu Dam (ST5) stations in the wet and dry seasons. Concentrations of zinc and copper were mostly within desirable limits of 3 ppm and 2 ppm, respectively, except for one sampling occasion for zinc at Kafubu Water Works (ST6) and also one sampling occasion for copper at the two water works in the rain season (Tables 5.5 and 5.6; Appendices IVa and IVd).

COD concentration levels in drinking water varied considerably during the study period at both water works and had increased from minimum levels in the early 1990's to higher concentration levels after 1997 (Tables 5.5 and 5.6; Appendices IVa and IVd).



Figure 5.14. Temporal Variations in Concentration levels of (a) Turbidity, (b) conductivity, (c) Chlorides and (d) pH in drinking water at Itawa and Kafubu water works.

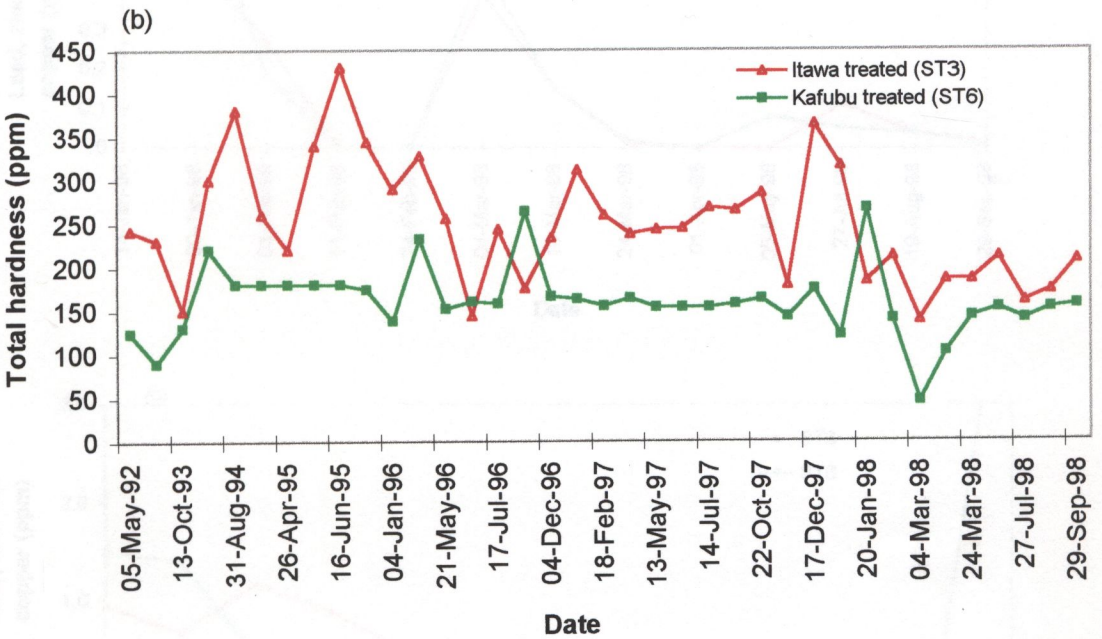
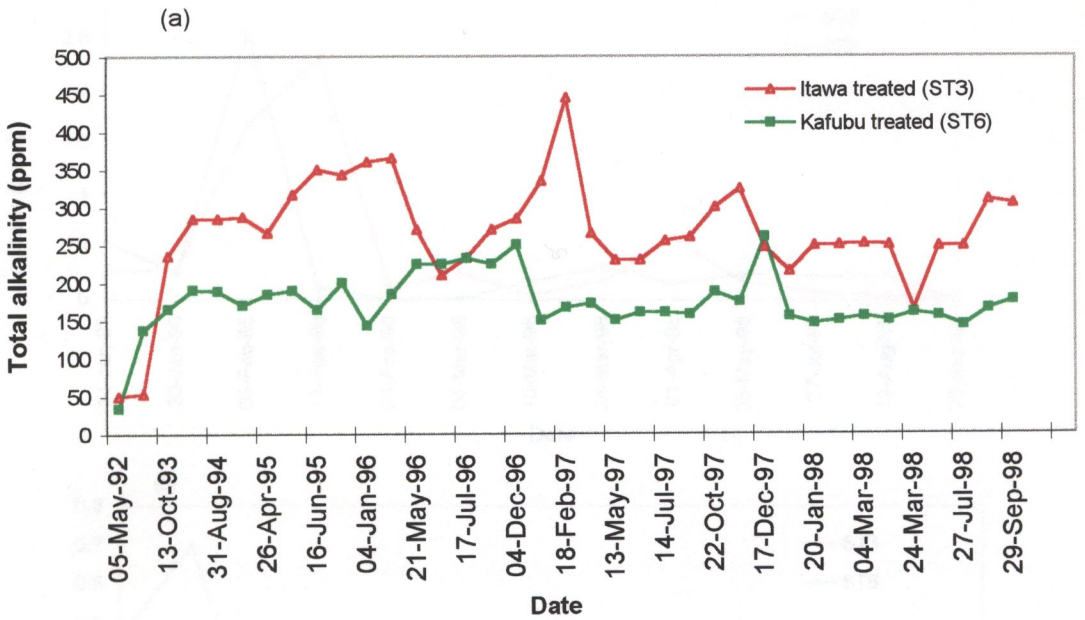


Figure 5.15. Temporal Variations in Concentration levels of (a) Total alkalinity and (b) Total hardness in treated water at Itawa and Kafubu water works.

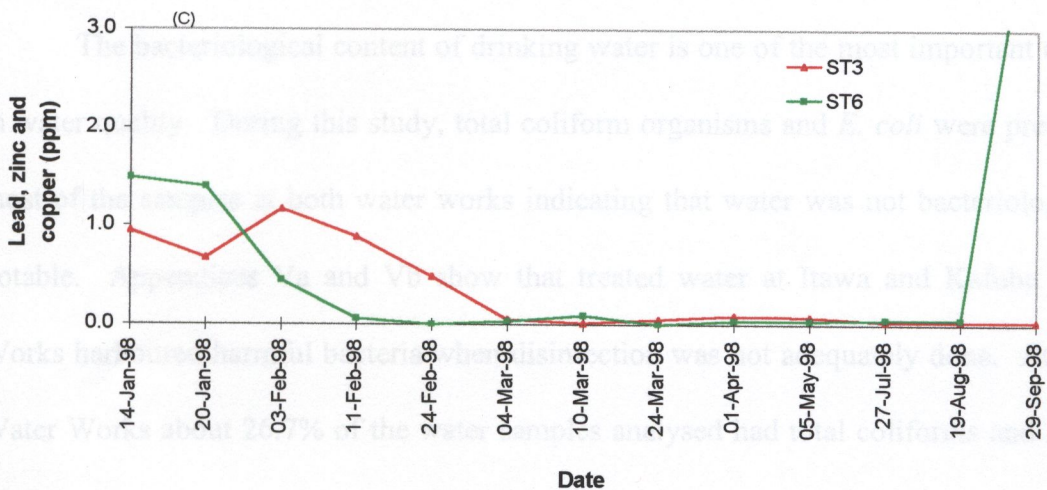
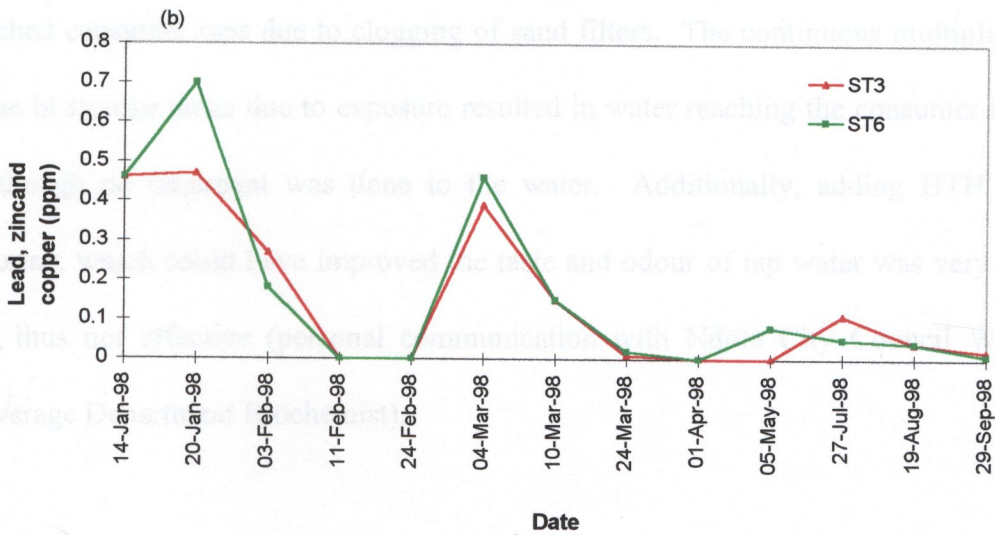
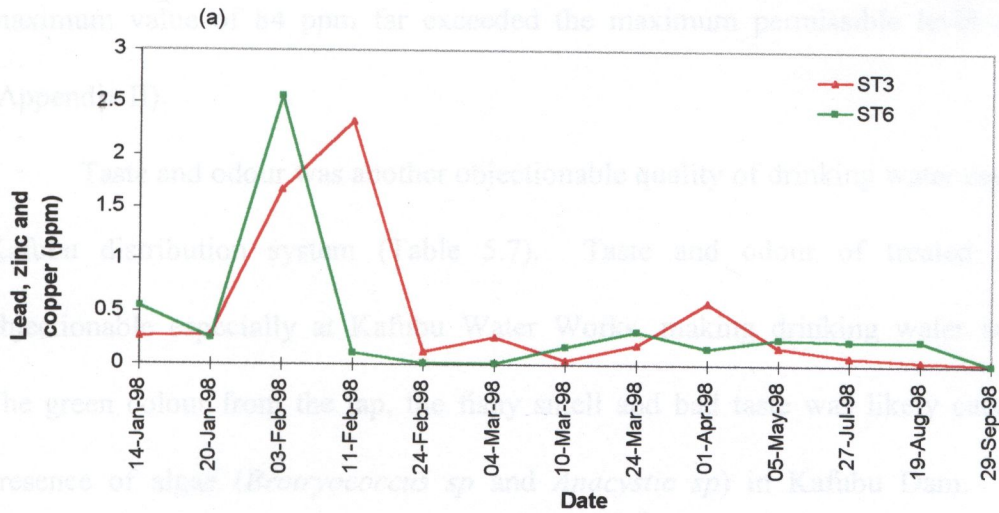


Figure 5.16 Temporal variations in concentration levels of (a) Lead (b) Copper (c) Zinc in drinking water at Itawa and Kafubu water works

COD levels ranged from 0 to a maximum of 84 ppm at both water works. That maximum value of 84 ppm far exceeded the maximum permissible level of 10 ppm (Appendix II).

Taste and odour was another objectionable quality of drinking water especially for Kafubu distribution system (Table 5.7). Taste and odour of treated water was objectionable especially at Kafubu Water Works, making drinking water undesirable. The green colour from the tap, the fishy smell and bad taste was likely caused by the presence of algae (*Brotryococcus sp* and *Anacystic sp*) in Kafubu Dam. The algae reached consumer taps due to clogging of sand filters. The continuous multiplication of algae in storage tanks due to exposure resulted in water reaching the consumer to appear as though no treatment was done to the water. Additionally, adding HTH granular chlorine, which could have improved the taste and odour of tap water was very minimal and thus not effective (personal communication with Ndola City Council Water and Sewerage Department Biochemist).

5.3.2 Bacteriological Characteristic of Drinking Water

The bacteriological content of drinking water is one of the most important criteria in water quality. During this study, total coliform organisms and *E. coli* were present in most of the samples at both water works indicating that water was not bacteriologically potable. Appendices Va and Vb show that treated water at Itawa and Kafubu Water Works harboured harmful bacteria when disinfection was not adequately done. At Itawa Water Works about 26.7% of the water samples analysed had total coliforms and *E. coli* present, whereas at Kafubu Water Works (ST6), 40% of the water samples had coliform organisms and *E. coli* detected (Table 5.8; Appendix Vb). The highest total number of

Table 5.7. Coliform Bacteria, Taste, Odour and Appearance of Treated Water in Relation to Residual Chlorine Concentration Levels at Itawa and Kafubu Water Works and their Distribution Systems (1998/99).

Location	Number of Samples	Coliform Bacteria /100 mls	Taste	Odour	Appearance	Residual Chlorine (ppm)
A. DISTRIBUTION SYSTEMS						
Itawa Filling Station	3	0	++	++	Green	0.1
Main Masala Market	3	0	+++	+++	Green	Nil
Kabushi Market	3	0	+++	+++	Green	Nil
Lubuto Market	3	0	+++	+++	Green	Nil
B. WATER WORKS						
Itawa Water Works	3	0	+	+	Clear	0.6
Kafubu Water Works	3	0	+++	+++	Green	0.2

Key

+ =Trace

++ =Strong

+++ =Very Strong

coliform organisms at both water works recorded was 18 per 100 mls (Appendices Va and Vb). Besides the treatment plants, coliform organisms were also detected in the distribution systems of both water works with some places having 50% contamination of the bacteria. At Itawa distribution network, coliforms and *E.coli* contamination in water samples ranged from 25% (Pine Flats and Light Industrial area) to 40% (CBD, Civic centre, and Zambia Railways) (Table 5.8). Other areas in this distribution system had contamination levels of 30.8 % (Kansenshi, Northrise and Chifubu) and 37.5 % (Henry

Makulu, Kanini and Twapia) (Table 5.8). The Kafubu distribution system, shows that coliform organisms and *E. coli* were more prevalent in Kabushi (50%), Lubuto and Mushili (50 %) and, Main and Mine Masala (37.5 %) (Table 5.8). Only Ndeke and Itawa tap water was bacteriologically safe (Table 5.8; Appendix Vb).

Table 5.8: Percentage of Occurrence of Total Coliforms and *E. coli* in Water Works and their Distribution Systems in Relation to Residual Chlorine Concentrations (1991/98).

Location	Number of Samples	Total Coliforms (%)	<i>E. coli</i> (%)	Average Residual Chlorine (ppm)
A. ITAWA WATER WORKS (ST3)	15	26.7	26.7	0.79
B. ITAWA DISTRIBUTION SYSTEM				
CBD, Civic Center and Zambia Railways	10	40.0	30.0	0.39
Kansenshi, Northrise, and Chifubu	13	30.8	15.4	0.14
Pine Flats and Light Industrial Area	04	25.0	25.0	0.50
Henry Makulu, Kanini and Twapia	08	37.5	37.5	0.12
C. KAFUBU WATER WORKS (ST6)	15	40.0	40.0	0.82
D. KAFUBU DISTRIBUTION SYSTEM				
Kabushi	08	50.0	50.0	0.14
Main and Mine Masala	08	37.5	37.5	0.13
Mushili and Lubuto	12	50.0	41.7	0.16
Ndeke and Itawa	03	0	0	0.17

There were only two bacteriological samples collected in 1998 and both samples showed no coliform organisms present, but two samples could not give conclusive results whether or not the water for the whole year was safe bacteriologically, hence the inclusion of data from previous years (Tables 5.7 and 5.8).

The average concentration levels of residual chlorine were 0.79 ppm and 0.82 ppm at Itawa and Kafubu water works, respectively. The levels reduced tremendously in the distribution systems (Tables 5.7 and 5.8). The presence of coliform bacteria seemed not to have had any relationship with the residual chlorine concentration levels since coliforms were detected in most samples despite the addition of chlorine at the water works. This could be attributed to low chlorine dosage levels that could not effectively disinfect the water.

5.4 Quality of Wastewaters Discharged into the Kafubu River

5.4.1 Municipal Wastewaters

Municipal sewage generally includes wastewaters originating from domestic, mercantile and manufacturing processes. The Upper Kafubu basin has three sewage treatment plants namely, Old and New Kanini Sewage Works and the Lubuto Sewage Works (Figure 4.1). Table 5.9 shows results of laboratory analysis of various parameters in sewage effluents from the three sewage works. Concentrations of most parameters were distinct though most of them were still within permissible levels of discharge effluents into the aquatic environment (ECZ, 1993). For instance, all sewage works efficiently reduced the COD, TDS, conductivity, sulphates and TSS concentration levels to desirable limits of below 90 ppm, 3000 ppm, 4300 $\mu\text{mhos/cm}$, 1500 ppm and 100 ppm, respectively (Table 5.9; Figure 5.17a,b and c). TDS in sewage effluents were high at all sewage works with Old Kanini having the highest concentration levels of 1000 to 1600 ppm (Figure 5.17a, b, and c).

Table 5.9: Results of laboratory analysis for sewage effluents collected at sewage outflows in Ndola.

	Temp (°C)	Colour units	TSS (ppm)	TDS (ppm)	conductivity (unhos/cm)	PH units	Phosphate (ppm)	sulphate (ppm)	COD (ppm)
Old Kanini Sewage Works	23 (20-26)	16.39 (10-25)*	58.92 (30-96)	1246.92 (740-1640)	1629.62 (1533-1821)	6.995 (6.9-24)	2.04* (0.84-3.6)	12.24 (7.02-16.9)	20.62 (7.2-36.8)
New Kanini Sewage Works	23 (20-26)	10.77* (10-15)	20.77 (8-58)	983.77 (700-1213)	1562.85 (1438-1782)	7.07 (6.98-7.18)	1.36* (0.32-3.0)	10.40 (7.02-23.7)	11.09 (2.6-24.4)
Lubuto Sewage Works	23 (20-26)	15 (10-30)*	31.62 (18-60)	1104.77 (862-1562)	1591.39 (1482-1788)	7.09 (7.02-7.15)	3.05* (0.85-6.14)	16.95 (12-20.43)	14.33 (5.1-40.00)

Note: Top values are station mean values while those in parenthesis are lowest and highest observed values.

* = Above ECZ standard (1993).

TDS varied considerably at all sewage works during the study period. Similarly, COD of effluents varied considerably within each treatment plant, though within the recommended level of below 90 ppm, with Lubuto Sewage Works having the highest concentration level of 5.1 to 40 ppm (Table 5.9). Conductivity of sewage effluents was high due to high dissolved solutes at all sewage works and averaged 1562.85 $\mu\text{mhos/cm}$ at New Kanini, 1591.39 $\mu\text{mhos/cm}$ at Lubuto and 1629.62 $\mu\text{mhos/cm}$ at Old Kanini. In terms of trends, conductivity was more stable at New Kanini and Lubuto and varied considerably at Old Kanini sewage works (Figure 5.17a, b, and c). TSS in sewage effluents was low and quit stable and ranged from 8 ppm (New Kanini) to 96 ppm (Old Kanini), (Table 5.9; Figure 5.17a, b, and c).

Temperature and pH of sewage effluents were the most stable parameters and were also within desirable limits of 40 °C and 6-9 units, respectively (Table 5.9; Figure 5.17a, b, and c). During the study period, colour and phosphates from the sewage works were the only undesirable constituents in the effluents. The colour of sewage effluents from Old Kanini and Lubuto sewerage treatment plants was unstable and occasionally above the maximum permissible level of 20 hazen units (Appendix I) except at New Kanini sewage treatment plant (Table 5.9; Figure 5.18 a, b, c). The high coloration of sewage effluents at the two sewage works could have been a reflection of the strength and the condition of sewage and also the presence of coloured industrial effluents. Ndola Knitting Mills and Northern Breweries were some of the industries that discharged raw or minimally treated effluents directly into the Municipal Sewer lines. Phosphate concentration levels were very high and averaged 1.36 ppm (New Kanini), 2.04 ppm

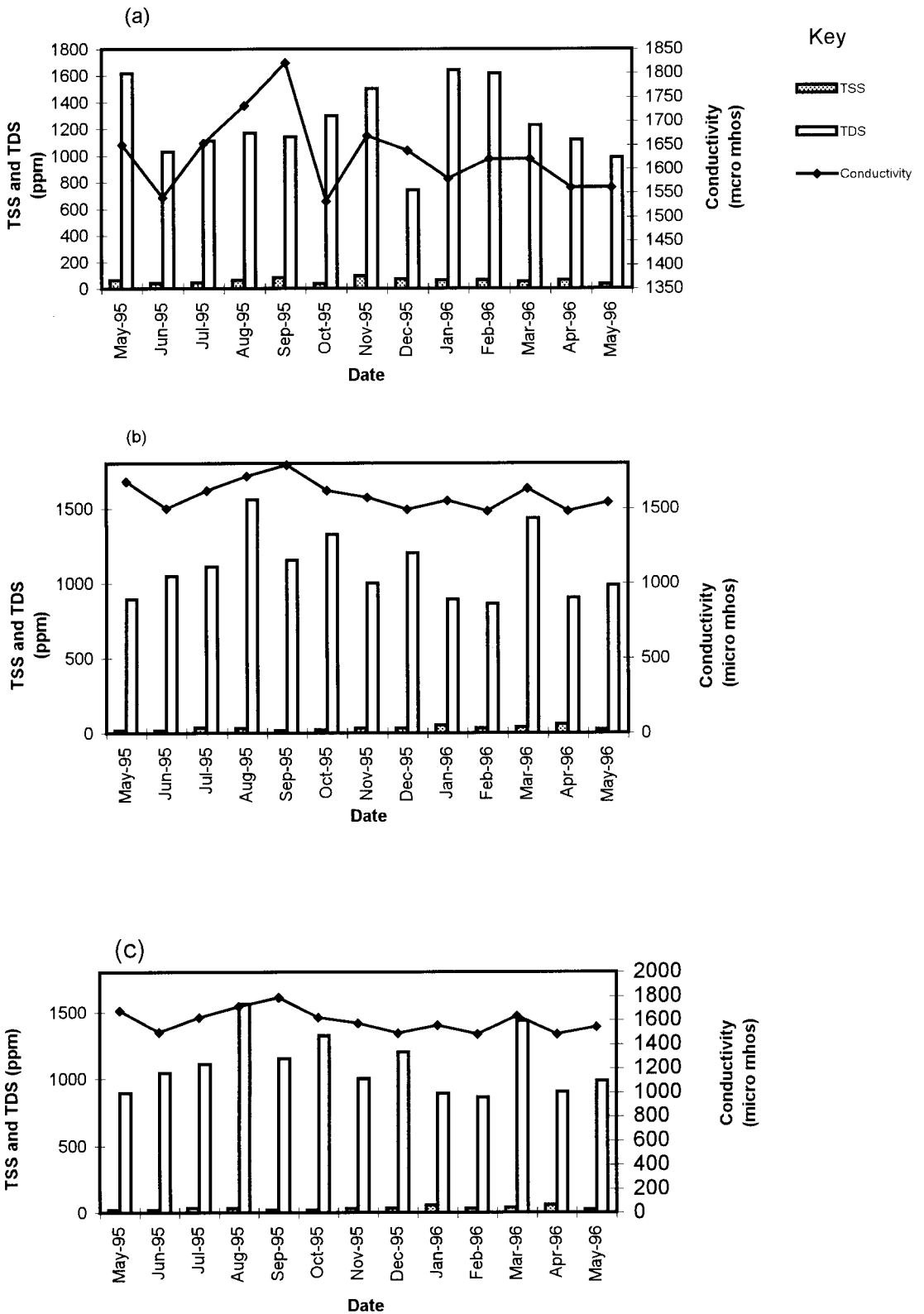


Figure 5.17 Graphs showing temporal variations in TSS, TDS and Conductivity concentration levels in effluents from (a) Old Kanini (b) New Kanini and (c) Lubuto Sewage Works

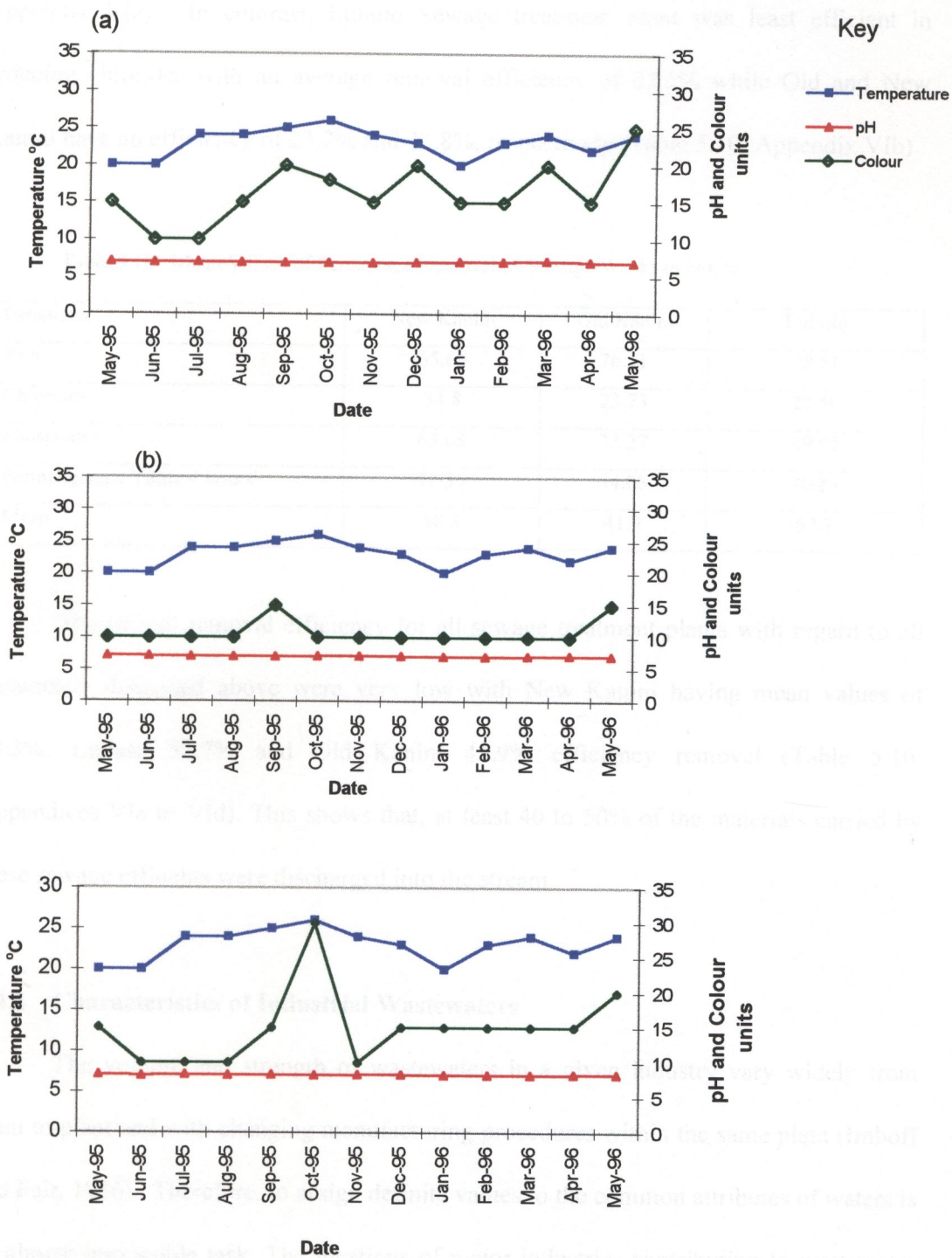


Figure 5.18 Graphs showing Temperature, colour and pH units in effluents from (a) Old Kanini (b) New Kanini (c) Lubuto Sewage Works

Appendix VIa). In contrast, Lubuto Sewage treatment plant was least efficient in reducing chlorides with an average removal efficiency of 22.5% while Old and New Kanini have an efficiency of 23.7% and 33.8%, respectively (Table 5.10; Appendix VIb).

Table 5.10: Mean Values of Percentage Removal of Sewage Works in Ndola.

Parameter	New Kanini	Old Kanini	Lubuto
TSS	65.60	76.51	78.51
Chlorides	33.8	23.73	22.50
Phosphates	63.63	33.27	39.05
Permanganate Value 4 hours	72.35	34.08	70.84
Mean	58.3	41.9	52.7

The overall removal efficiency for all sewage treatment plants with regard to all parameters discussed above were very low with New Kanini having mean values of 58.3%; Lubuto 52.7% and Old Kanini 41.9% efficiency removal (Table 5.10; Appendices VIa to VI d). This shows that, at least 40 to 50% of the materials carried by these sewage effluents were discharged into the stream.

5.4.2 Characteristics of Industrial Wastewaters

The volume and strength of wastewaters in a given industry vary widely from plant to plant and with changing manufacturing procedures within the same plant (Imhoff and Fair, 1956). Therefore, to assign definite values to the common attributes of waters is an almost impossible task. The locations of major industries contributing to wastewater discharged directly into Kafubu River through tributaries and storm drains are shown in Figure 4.1 and further described in Table 5.11. Industrial waste matters of varying kind and concentration are contained in the spent process waters of various manufacturing

Table 5.11: Listing of Major Industries in Ndola: Their Products, Potential Pollutants to Kafubu Aquatic Environment and Pre-treatment Processes.

Industry code number in Figure	Name of Industry	Location	Major products	Origin of Major Waste	Point of Discharge	Potential Pollutants	Pre-treatment Facility
1	Northern Breweries	Lowenthal Road Light industrial area	Opaque beer, Mosi beer, malt, maize, grit, sugar hops	Floor washing and other production processes	Into Council sewer line	Organic pollutants	No pre-treatment
2	Lyons Brooke Bond (Z) Ltd	Shinde street Light Industrial area	Vegetable and meat products, tea	wastes from vegetable tanning and canning	Open drain into Kafubu river	Organic pollutants	-Partial treatments -fat traps and screens of various sizes
3	Zambia Oxygen (ZAMOX) Ltd	CBD Chisokone Rd	Gas and Other by-products	Auxiliary processes, floor washing	Storm drain into Kafubu River through Hawa Dambo	Inorganic chemicals -metals	None
4	Ndola Weaving Textiles Ltd.	Kabwe road	Textile products i.e. cloth of varying types	-Auxiliary processes, dyes and flood washings	Into storm drain and into Kafubu river	-dye wastes -Liquid waste produced in weaving and spinning processes	Settling tank
5	Swamp Spinning Ltd.	Nakambala Rd Heavy industrial area	Textile products i.e. cloth of varying types	-washing floors -manufacturing operations cooling of plant	Into Kafubu through an open storm drain	Dyes, wastewater of organic and inorganic origin	Settling tanks
6	Vitrex Paints	Kabwe Rd.	Paints	Production processes and chemicals used	No discharge	Inorganic matter and trace metals	Drying beds
7	Lever Brothers (Z) Ltd	Heavy industrial area	-Detergents -oils	Soap making process	Open drain into Kafubu river	Detergent, oils	Settling pit
8	Zambezi Paper Mills Ltd	Mushili Rd Heavy industrial area	-toilet tissue -paper -Kraft variety of paper	-washing of floors -manufacturing operations	Into Mushili stream and then into Kafubu	-Organic substances paper machine back water is discharged	Through a series of settling and natural evaporation ponds
9	Colgate Palmolive (Z) Ltd	Ulenaga Rd. Light industrial area	Oral, body, fabric and household surface care products	Auxiliary processes and floor washing	Single entry at North west boundary into the Kafubu river	Inorganic chemicals and trace metals	Screens of various sizes
10	Ndola Lime Mine Area	East of Hawa Dambo	Lime, building sand	Dewatering of pits	Into Hawa Dambo through fox cut	Limestone and trace metals	Plant reservoir
11	Chilanga Cement	East of Hawa Dambo	Cement	Production processes and cooling plant	Open drain into Hawa Dambo	Cement/Limestone	none
12	Ndola Knitting Mills	Kabwe Road	Textiles	Textile wastewater, dyes and auxiliary processes	Into Council sewer line	Textile wastes and other manufacturing operation	No pre-treatment

industries and waste matters are derived in largest measure from washing, flushing, extracting and impregnating operations. Like domestic wastewaters, they contain suspended, colloidal and dissolved solids of mineral and organic origin. However, they rarely harbour viable pathogenic organisms.

Most of the industries in Ndola have pre-treatment plants within their premises. These pre-treatment plants range from simple ditches to conventional aerated plants. All the industries except Northern Breweries and Ndola Knitting Mills bypass the sewage works and discharge effluents directly into the Kafubu River. Most of these industries' pre-treatment facilities are very inefficient and have impacted on the Kafubu reservoir downstream that is the major recipient of all these wastewaters downstream. Activities and products produced by all industries in Ndola are described in Table 5.11. Operations of each of these industries are briefly summarised below.

5.4.2.1 Treatment of Industrial Wastewaters at Zambezi Paper Mills Limited

The pre-treatment facility at Zambezi Paper Mills was unable to reduce colour, conductivity, sulphites, phosphorus and lead to acceptable limits (Appendix VIIa). Effluents had colour units ranging from 10 to 30 hazen units and in most cases exceeded the maximum allowable limits of 20 hazen units (ECZ, 1993). The conductivity levels were also high (430 to 7493 $\mu\text{mhos/cm}$) and above maximum permissible levels of 4200 $\mu\text{mhos/cm}$. Although TDS concentration levels were high, averaging 813 ppm, they were still within desirable levels of below 3000 ppm. The presence of lead, a toxic trace metal in the effluents poses danger to the biological diversity of the river and to lives of people utilise the water for 'first class' purposes. Lead concentration level (2.3 ppm), though in

one sample was alarmingly high exceeding the maximum allowable limit of 0.5 ppm (Appendix I).

Nutrient loading by Zambezi Paper Mills industry was high with respect to ammonia (8 ppm), nitrates (40 ppm), nitrites (1.8 ppm) and phosphorus (26.67 ppm). Phosphorus concentration levels were grossly above maximum permissible levels of 1.0 ppm. These nutrients could have a very significant impact on the proliferation of aquatic weeds in Upper Kafubu Dam and the 'algal bloom' in the same dam which have become a nuisance to water users. There were no pathogenic organisms in these trade effluents.

5.4.2.2 Treatment of Industrial Wastewasters at Textile Mills

Textile wastes are said to vary widely with the type of fibre processed and with the number and extent of the manufacturing operations (Klein, 1966). Ndola has three textile industries namely, Swarp Spinning Mills, Ndola Weaving Mills and Ndola Knitting Mills. The effluents from Ndola Knitting Mills were discussed under municipal sewage section 5.4.1 page 85, for Ndola Knitting Mills discharges its effluents into the council sewer line.

The characteristics of effluents from Swarp and Ndola Weaving Mills were varied as indicated in Appendices VIIb and VIIc. Settling tanks were used for pre-treatment of wastewaters from these industries. At Ndola Weaving Mills, the pre-treatment facility did not adequately remove colouration from dyes such that mean value for colour of effluents was over 70 hazen units in all samples analysed (Appendix VIIb). This was three and half times above maximum allowable limit (Appendix I). The pre-treatment plant was also unable to reduce concentrations of phosphorus (1.75 ppm) and sulphides (3.0 ppm) to

acceptable limits of 1.0 ppm and 0.1 ppm, respectively. Similarly, TSS and turbidity concentration levels were sometimes above maximum permissible levels of 100 ppm and 15 NTU, respectively. The temperature of effluents from this industry was also sometimes above 40 °C, the maximum allowable limit (Appendices I and VIIb).

The organic state of the trade effluents was above the maximum recommended level of 90 ppm for COD and 50 ppm for BOD, such that mean values of 96.32 ppm and 51.66 ppm were recorded, respectively. This was an indication of serious organic matter contamination.

Trace metals such as zinc (0.45 ppm) iron (0.15 ppm) and manganese (0.05 ppm) were in detectable levels, though within acceptable limits (Appendix I). The presence of these toxic metals may be responsible for the marked decrease in the efficiency of the sludge digestion process in the pre-treatment plant, for it inhibits biological activities of bacteria.

The pre-treatment plant at Swarp Spinning Mills was able to reduce most of the constituents in their influents to concentration levels that were non-objectionable except for pH and coloration of the wastewaters (Appendix VIId). The pH levels of effluents were sometimes above maximum allowable limit of 9.0 units and averaged 9.85 units. Similarly, the mean colour unit of 21.87 was above the recommended level of 20 hazen units (Appendix I), for effluents discharge into the aquatic environment.

The presence of zinc and iron in detectable levels, though within acceptable levels, could have had a negative impact on the biological oxidation of waste materials in the pre-treatment plant for it inhibits bacteriological activity. The effluents from Swarp

Spinning and Ndola Weaving Mills had algae and coliforms virtually absent in all samples analysed.

5.4.2.3 Treatment of Industrial Wastewaters at Lever Brothers Zambia Limited

Most of the constituents found in effluents from Lever Brothers were of undesirable levels. The composition of effluents indicated that the pre-treatment plant was ineffective to remove excess waste materials from the wastewaters entering Kafubu River (Appendix VIIe). The pre-treatment plant at Lever Brothers was unable to remove suspended matter (mean of 441 ppm) from effluents and exceeded the maximum allowable levels by fourfold (Appendix I). The pH levels were also undesirable (mean of 9.38 pH units). COD and BOD concentration levels were alarmingly high that is, 813.5 ppm (COD) and 885 ppm (BOD) indicating high organic matter contamination into the receiving waters of the Kafubu River. Similarly, the nutrient loading was above recommended levels with mean values of 17.34 ppm for phosphorus, 150 ppm of organic nitrogen and nitrates and nitrites concentration levels ranging between 31.55 to 63.00 ppm and between 4.05 and 8.00, respectively.

The presence of oils (10 ppm) and total fatty matter (3724 ppm) which should be zero, is of great concern and an indication of grossly inadequate pre-treatment facilities and obsolete infrastructure. Higher amounts of sulphides (5 ppm), Iron (5 ppm), fluorides (5.6 ppm), chromium (1.3 ppm) and boron compounds (30 ppm) makes effluents from this industry extremely dangerous to living organisms in Kafubu River and harmful to downstream water users because they are toxic, persistent and bio-accumulable.

5.4.2.4 Treatment of Industrial Wastewasters at Colgate Palmolive Zambia Limited

The partial or minimal pre-treatment facility at Colgate Palmolive was not adequate to reduce concentration levels of TDS, calcium, total hardness and pH to recommended levels (Appendix VIIe). Concentration levels of TDS ranged from 2610.0 ppm (min) to 7200.0 ppm (max) with a mean of 4140.0 ppm; calcium and total hardness averaged 2599 ppm and 2590 ppm, respectively. Colour (51.0 units) of effluents also was above the maximum allowable limit of 20 hazen units by two and half times. Other undesirable concentrations were those of sulphide (45 ppm) and manganese (1.02 ppm) that exceeded maximum recommended limits of 0.1 ppm and 1.0 ppm, respectively.

Trace metals such as zinc, lead and copper were within allowable limits though their presence in detectable levels could have had far reaching implications in the biodegradation or oxidation of organic materials in the wastewaters by micro-organisms. Nutrients such as ammonia and concentration levels of phosphates and chlorides were within acceptable limits (Appendices VIIe and I). Algae and coliform organisms were virtually absent in all samples. Like other industries discussed above, Colgate Palmolive pre-treatment facilities were inadequate to reduce most inorganic constituents to recommended levels.

5.4.2.5 Treatment of Industrial Wastewasters at Zambia Oxygen Limited (ZAMOX)

Wastewaters from ZAMOX were of undesirable quality in terms of colour, taste and odour, TDS, pH, calcium, total hardness and total alkalinity (Appendix VIIIf). The coloration of effluents from this industry was always above maximum permissible levels of 20 units and averaged over 70 hazen units. Total dissolved solids (TDS) were

objectionably high with a mean value of 4140 ppm. This was the highest TDS value observed in the study. There is no indication of organic contamination (permanganate value after 4 hours was nil) in effluents from ZAMOX but lack of COD or BOD results makes this inconclusive. The presence of ammonia (1.00 ppm) and Silica (18.00 ppm) was an indication of the likely presence of nutrients. Inorganic compounds such as Iron (1.1 ppm), Copper (0.01 ppm), Zinc (0.08 ppm) and Lead (0.01) though within acceptable levels, may have had an impact on the oxidation process of organic compounds for they may have affected the biological activities of decomposition of organic matter.

The pre-treatment facilities were not efficient in removing all undesirable elements found in wastewaters from the industry that would have an adverse impact on the receiving waters.

5.4.2.6 Treatment of Industrial Wastewaters at Lyons Brooke Bond Zambia Limited

Generally, effluents from this industry were of varying composition although most of the constituents were within recommended levels (Appendix VIIg). The pre-treatment facilities at this industry were extremely insufficient to effectively remove colour (77.5 units) and turbidity (52 NTU) to acceptable levels of 20 hazen units and 15 NTU, respectively. Similarly, DO levels were very low in the effluents (1.22 ppm) compared to the minimum acceptable level of 5.0 ppm ((Appendix I). This is an indication of high amounts of organic matter in the effluent. Though COD concentration levels were high (76.13 ppm) they were within permissible levels of below 90 ppm. Nutrients like phosphorus (0.48 ppm), ammonia (2.71 ppm), Nitrates (2.25 ppm) and Silica (10.70 ppm) were within acceptable limits. The presence of inorganic compounds like arsenic (0.03

ppm), manganese (0.04 ppm), cobalt (0.05 ppm), silver (0.02 ppm), zinc (0.04 ppm) and iron (0.41 ppm) could be of harm to the fauna and flora in the Kafubu aquatic environment. Lyons Brooke Bond was the only industry where coliform organisms (40 per 100 mls) were detected in wastewaters. This was due to poor sanitary conditions within the factory premises.

5.4.2.7 Treatment of Industrial Wastewasters at Ndola Lime Mine Area

This was the only industry that had desirable physico-chemical and bacteriological quality of its effluents (Appendix VIIh). This was also in line with previous studies like that by Musonda and Simashikwe (1996) although these authors' study noticed low oxygen levels. All parameters analysed at Ndola Lime were within allowable limits an indication of an efficient pre-treatment process.

Discussion, interpretations and implications of these results are the focus of the next chapter.

CHAPTER 6: DISCUSSION, INTERPRETATION AND IMPLICATIONS

6.1. Introduction

The surveyed portion of Kafubu River between Itawa Swamps and Kafubu Dam was subjected to major variations in water flow and quality from seasonal rains. During the 1993 to 1998 hydrological years, Kafubu River at Masaiti gauging station had a mean annual discharge of $11.39 \text{ m}^3 \text{ s}^{-1}$. The mean discharge in the dry season (April to October) was found to be $3.1 \text{ m}^3 \text{ s}^{-1}$ while for the wet season (November-March) it was $24.98 \text{ m}^3 \text{ s}^{-1}$. Kafubu River was found to have a hydrological regime that had a unimodal distribution controlled by the single rainfall season experienced in the country. During field observations in the headwaters region (Itawa Swamps (ST1)), the water was clear throughout the study period with a general slow southward outflow. However, past Ndola town, river water turned to a greenish colour, more so during the dry season as the river experienced “dry season discharge”. Further downstream, the Kafubu River is joined by both sewage and industrial effluent discharge lines, which discharge municipal and trade effluents into it, and significantly alter its mineral and organic constituents. Seasonal and inter-stational variations in physico-chemical and bacteriological quality of raw and treated water were observed with major spatial and temporal variations in all the parameters under discussion.

The results thus, showed that effluents carried via Kanini sewage outflow, Mushili and Kabushi streams, and Lubuto sewage outflow and other effluent carrying storm drains greatly influenced the quality of water in Kafubu River which ultimately influence the quality of treated water at both Itawa and Kafubu water works. These, together with runoff from the CBD and dumpsites, many of which lie within the river’s catchment area,

have contributed to a large downstream increase in the concentrations of several constituents. Downstream increases in pollutants after Itawa swamps, in the river water concentration levels that included TSS, colour, pH, turbidity, COD and chlorides were most likely due to tributary inputs and runoff from the CBD.

Kafubu River water was also found to be hard and alkaline in nature. Both calcium and magnesium predominantly caused this hardness and alkalinity of water salts, which were most likely, influenced by local geology determined. For instance, TDS, conductivity, total alkalinity, total hardness, magnesium and calcium hardness and the three trace metals, zinc, lead and copper, decreased downstream from Itawa Swamps to Kafubu Dam, with lead exceeding the maximum allowable limit of river water (0.5 ppm) at all stations especially in the wet season.

Treated water at both Itawa and Kafubu water works was adversely affected by quality of river water and inadequate treatment processes. Therefore, the water was in most cases not satisfactory for drinking due to excessive colouration, taste and odour, high turbidity and occasionally high TSS, lead, zinc and copper (Tables 5.1 and 5.2). Treated water was also too hard and alkaline to be used for "first class" purposes such as drinking and laundry. Additionally, at the two water works TDS, chlorides, lead, magnesium, calcium and total hardness of treated water were found to have increased after the treatment processes. This was attributed to low dosages of treatment chemicals, addition of chlorine and obsolete infrastructure.

Overall, the river quality during the wet and dry seasons in the Upper Kafubu catchment displayed large spatial and temporal variations in concentration levels for all parameters as discussed below.

6.2 Seasonal Characteristics of River Water Quality

6.2.1 Wet Season

The wet season was characterized by both temporal and spatial variations in both physical and chemical constituents of river water (Table 5.1 and 5.2; Appendices IVa-IVd). Of the physical parameters, temperature remained fairly non-variant along the river course with Itawa Dam (ST2) having the lowest temperature (Table 5.1).

During the 1997/98 hydrological year the wet season recorded no TSS at all sampling stations except for one sample at Kanini, which recorded TSS of 8 ppm. Low TSS concentration levels could have been a result of excessive sedimentation that occurs on the riverbed due to trapping by reeds (Hippo grass) (Figure 6.1 a, b). This and other aquatic weeds in the stream channel most likely acted as filters of any TSS transported by the river, which promoted further growth of plants in the river channel. Comparatively, the concentration of TDS were higher than TSS during the wet season although they did not exceed the allowable limit of 3000 ppm at all sampling stations (Table 5.1). TDS average concentration levels decreased in the downstream direction from Itawa Swamps (ST1) (295.2 ppm) to Kafubu Dam (ST5) (2187 ppm) during the wet season. TDS decrease downstream could be attributed to the presence of aquatic weeds in the river channel in most stretches of the river that could have taken up some of the nutrients from stream flow along the way downstream. Concentration levels of conductivity also decreased in the downstream direction from between Itawa Dam (ST2) (491.88 $\mu\text{mhos/cm}$) and Kafubu Dam (ST5) (328 $\mu\text{mhos/cm}$). Itawa Dam (ST2) recorded higher conductivity levels than Itawa Swamps (ST1) and this could be attributed to high



(a)



(b)

Figure 6.1 Kafubu River at Kabwe Road Bridge, with profuse aquatic weed growth (Hippo grass) in the stream channel, (a) western side of river bank and (b) eastern side of river bank.

residence time of dam water (ST2) as compared to that of stream flow at Itawa Swamps (ST1). The same trend was observed with solutes. Electrical conductivity of water in the wet season was within desirable limits of surface waters receiving wastewaters (Appendix I).

Both colour and turbidity of water in the river during the wet season showed large inter-station differences (Table 5.1). The colour of the water was usually above the maximum permissible level of 15 hazen units at Itawa and Kafubu reservoirs but within the acceptable limit at Itawa Swamps (ST1) and Kanini (ST4) possibly due to high residence time of dam water compared to stream flow. Another possibility could be due to the presence of algae and aquatic weeds in dams, which increases water colour during decomposition. Observed water turbidity values of river water in the wet season were within recommended levels (Appendix I) and like colour of water, turbidity decreased downstream (Table 5.1).

Chemical constituents of river water during the wet season had significant inter-stational variation although pH of the water was more stable than other constituents like hardness, alkalinity and chlorides (Table 5.1). Observed pH levels ranged from a mean average 8.19 (ST2) to 8.96 (ST5) and showed a gradual downstream increase. Only Itawa Swamps had pH within acceptable range of 6.0 to 9.0 units, the other three stations sometimes recorded pH levels above maximum permissible levels. The alkaline nature (between 7 and 9) of pH levels at Itawa (ST2) and Kafubu (ST5) dams could be attributed to photosynthetic activity of algae in these reservoirs. This study, unlike previous investigations (Kasonde, 1990) revealed an increase in pH levels and also higher pH values (6.95 to 9.36) than those recorded elsewhere in Zambia (Mwiinga, 1990;

Simuunza, 1992 and Tembo *et al.*, 1997). The alkaline nature of these waters could be attributed to the underlying dolomitic limestone geology of Upper Kafubu catchment area and the influence of alkaline effluents from the sewage treatment works and industries.

Similarly, total alkalinity of river water was very high at all stations along the river with upstream stations (ST1 and ST2) having higher concentration levels than downstream stations (ST4 and ST5). The geology of the catchment, which is underlain by dolomitic limestone, partly explains the variations in pH levels. The downstream decline in total alkalinity could have resulted from humic acids from rotting vegetation. Total alkalinity levels in this catchment (Table 5.1; Appendices IVa–IVb), were similar to those found by previous studies in Upper Kafue basin (Mwiinga, 1990; Kasonde, 1990).

Kafubu River water was hard at all stations during the wet season with average total hardness ranging between 294.88 ppm Itawa Dam (ST2) to as low as 146.56 ppm at Kafubu Dam (ST5) (Table 5.1). This was mainly temporary hardness (magnesium and calcium) that, just like alkalinity, was controlled by the geology of the area. In terms of concentration levels, calcium hardness was more than twice as much as those of magnesium hardness found in water (Table 5.1). Itawa Dam (ST2) (294.9 ppm) had higher total hardness values than Itawa Swamps (ST1) (271.5 ppm). This could have been due to higher residence time for the dam water giving it a very low mixing capacity due to limited flow. The minimum mean concentration of chloride of 2.5 ppm was recorded at Itawa Swamps (ST1) and Itawa Dam (ST1). Kanini had the highest concentration level averaging 7.57 ppm that was perhaps due to its proximity to effluent discharge point at the Kanini sewage outflow. Generally, the average value show that

chloride was the least important cation during the wet season and concentrations were unobjectionable at all stations (Table 5.1; Appendix I).

Chemical Oxygen Demand (COD) was less variable from each station and was within the acceptable limit of 90 ppm (Appendix I).

Trace metal concentrations showed large inter-station differences, with lead concentration levels at all sampling stations exceeding the recommended (0.5 ppm) maximum allowable levels in raw water for subsequent production of drinking water (Appendix I). Observed average lead concentrations during the wet season ranged from 1.58 ppm at the upstream Itawa Swamps (ST1) to 0.78 ppm at the downstream Kafubu Dam station (ST5) showing a downstream decrease (Table 5.1). Most of the samples analyzed during the wet season had lead concentration levels far above maximum permissible levels of 0.5 ppm (Appendix I). These concentrations posed a great danger to fauna and flora of the river system and also to humans that depend on stream water for drinking and all other uses.

Although copper and zinc were present in detectable levels in most of the samples, they were within acceptable levels of less than 2 and 5 ppm, respectively, with upstream stations having higher concentrations compared to downstream stations (Table 5.1; Appendix I and IVa). All samples analysed at Itawa Dam (ST2) had zinc and copper present with a range of 0.45 to 1.72 ppm and 0.18 to 0.45 ppm, respectively. Itawa Dam (ST2) had the highest mean concentrations of both zinc and copper while Kafubu Dam (ST5) had the minimum average concentration of zinc and Kanini, the minimum copper concentration levels (Table 5.1; Appendix I and IVa). For the three trace metals a

general downstream decrease in concentration levels was evident throughout the wet season probably due to runoff and erosion of rocks in the catchment.

6.2.2 Dry Season

During the dry season temperature remained fairly non-variant along the river course and increased in a downstream direction from Itawa swamps (ST1) to Kafubu Dam (ST5) (Table 3). During the dry season temperature was mainly influenced by climatic conditions than inter-stational differences such that lowest temperatures for all stations were recorded in the cool months of May to mid-August and then temperatures rose during late August onwards. The influences of local factors were also evident in that upstream stations were cooler than downstream stations. This downstream warming of river water was attributed to warmer wastewaters entering the stream downstream in the urbanized reach downstream of Itawa Dam (ST2) (Appendices VIIa to VIIIh).

During the dry season, TSS was present with some concentration levels exceeding the maximum acceptable level of 100 mg/L (Table 5.2; Appendix I). The mean TSS concentrations in the dry seasons were higher at the upstream stations (ST1 and ST2) than downstream stations (ST4 and ST5) such that Itawa Dam had the highest (65.3 ppm) and Itawa Swamps 55.3 ppm. Kanini (ST4) recorded TSS averaging 48.0 ppm, while Kafubu Dam had 51.0 ppm. There was no distinct trend in TSS concentration levels, perhaps due to the reduction in cross-sectional area of the stream (i.e. excluding those areas with filters such as grasses) that allows resuspension of materials in the stream.

Mean concentration levels of TDS and conductivity of water in Kafubu River decreased downstream with distinct variations between stations (Table 5.2). This could

probably have been due to self-purification of the river and also could have been due to the presence of aquatic weeds at downstream stations that could have utilised some of the nutrients. Itawa Dam (ST2) had higher conductivity than Itawa Swamps possibly due to higher solute concentration levels in dam water than in the swamp. However, the concentrations of TDS and conductivity in river water were within recommended levels of 3000 and 4200 ppm, respectively (Appendix I).

The colour of water was very significant during the dry season and increased exponentially downstream with Kafubu Dam (ST5) having the highest colour units (Table 5.2). Itawa Swamps (ST1) and Itawa Dam (ST2) had water colour within recommended levels with a range of 5.0 to 10 and between 10 to 20 hazen units, respectively. The downstream stations, Kanini (ST4) and Kafubu Dam (ST5) recorded ranges of 10 to 30 and 15 to over 70 hazen units, respectively, with most of the samples having colouration exceeding the ECZ maximum allowable limit of 20 hazen units (Appendix I). The increased discolouration in water could have been as a result of high colour of wastewaters entering the stream from both sewage and industries. For Kafubu Dam (ST5) increased discolouration was due to the algal bloom in the dam. The presence of the blue-green algae at Kafubu Dam (ST5) in large quantities made the appearance of water (green) objectionable to most users.

Turbidity units were within the desirable limit of below 15 NTU along the stream except at Kafubu Dam (ST5) downstream where a maximum concentration of 35 NTU was recorded. This could have been due to high TSS and high colour observed in the dam water during the dry season. Therefore, only Kafubu Dam (ST5) had turbidity units exceeding the maximum allowable limit of 15 NTU (Table 5.2; Appendix I).

There were distinct interstational variations in the chemical composition of river water with parameters like pH, COD and chloride, increasing in the downstream direction while alkalinity, hardness and trace metals decreased in the downstream direction though most concentrations were within recommended limits (Table 5.2; Appendix I). pH levels of river water were quite stable at all stations. A gradual increase from Itawa Dam (ST2) to Kafubu Dam (ST5) was evident though Itawa Swamps (ST1) had a higher pH than Itawa Dam (ST2). All samples had pH levels falling within the recommended level of between 6.0 to 9.0 units (Appendix I).

River water was alkaline during the dry season with mean values ranging from 164.0 ppm (ST5) to 259.04 ppm (ST2) (Table 5.2). The downstream decline in concentration levels could have been due to neutralization of alkali by acids (cations) arising from decomposition of organic matter into the stream downstream of Itawa Dam. Similarly, total hardness of river water in the dry season decreased gradually in a downstream direction with Itawa Dam (ST2) having a mean of 188.52 ppm and Kafubu Dam (ST4) with 133.28 ppm. Calcium and magnesium salts most likely caused this hardness, with calcium still playing a major role. The total alkalinity and total hardness of water in the dry season were slightly lower than those recorded in the rain season perhaps due to limited chemical weathering of rocks taking place.

The mean COD levels at upstream Itawa Swamps (ST1) and Itawa Dam (ST2) were unobjectionable with a range of 5.3 to 82.0 and 24 to 72.0 ppm, respectively (Table 5.2). In contrast, downstream stations, Kanini (ST4) and Kafubu Dam (ST5) had COD levels exceeding the maximum allowable level of 90 ppm, with both having a range of 24 to 100 ppm. The downstream increase in COD could have been attributed to low dilution

of organic rich effluents from both domestic and industrial wastewaters entering the river. Similarly, chloride increased in a downstream direction except at Kanini station (ST4) where it was much higher than the upstream Itawa Swamps (ST1) and Itawa Dam (ST2) (Table 5.2). This could have been due to the location of Kanini station right immediately after Kanini sewage outflow that could be the major source of chloride. However, chloride values were within the desirable limit of 800 ppm at all stations (Appendix I).

During the dry season trace metals were present in detectable levels in most samples though concentration levels were low except for lead (Table 5.2). Concentrations of zinc and copper were within the allowable limits at all stations with copper ranging from 0.02 (ST4) to 0.12 ppm (ST2) and zinc from 0.03 ppm (ST2) to 0.06 ppm (ST5) (Table 5.2). Concentration levels of lead were within the desirable limit of 0.5 ppm at Itawa Swamps (ST1), Kanini (ST4) and Kafubu Dam (ST5) but concentrations occasionally exceeded the maximum allowable limit at Itawa Dam (ST2) where the value of 2.62 ppm was recorded (Table 5.2; Appendix I).

The statistical analysis showed that relationships between stream discharge and concentration levels of zinc copper and lead in Kafubu River were weak with *p* values ranging from 0.2 % (ST1) to 99% (ST4) (Table 6.1). Obtained coefficient of determination ranged from ($r^2 = 0.001$) (lead) at Kanini station (ST4) to ($r^2 = 0.603$) (copper) at Itawa Swamps station (ST1) (Table 6.1). The relationships tended to be stronger in the wet than dry seasons. This means that trace metal concentrations increase as stream discharge increases during the rain season and then decline during low flows in the dry season. Therefore, the highest risk of trace metal poisoning is during high flows. There was no dilution effect such that there was no distinct interstational variation

between the upstream Itawa Swamps station (ST1) and the downstream Kanini station (ST4). The value of statistical relationships is that the equations in Table 6.1 could be used to estimate loadings of zinc, lead and copper at Itawa Swamps Kanini stations on Kafubu River once discharge is known. However, all the above regressions are insignificant at 0.05 level of significance making all above equations not reliable. Trace metal concentrations seem to be the most significant constituents during the wet season harmful effects on living organisms found in Kafubu River.

Table 6.1 Regression equations for estimating trace metal concentrations from river discharge.

Parameter/ Station	n	Regression Equation	r ²	Standard Error of Estimate	Probability (P)
ZINC Itawa Swamps (ST1)	13	zn = 0.058Q + 0.39	0.012	0.895	0.725
Kanini (ST4)	13	zn = 1.58Q + 0.0003	0.321	0.317	0.055
LEAD Itawa Swamps (ST1)	13	Lt = 0.166Q + 0.634	0.035	1.46	0.554
Kanini (ST4)	13	Lt = 0.003Q + 0.496	0.001	0.89	0.997
COPPER Itawa Swamps (ST1)	13	Cu = 0.115Q + 0.096	0.603	0.156	0.002
Kanini (ST4)	13	Cu = 0.042Q + 0.49	0.55	0.102	0.004

r critical = 1.96

Level of Significance = 0.05

Key

n = number of samples

zn = Zinc (ppm)

Lt = Lead (ppm)

cu = Copper (ppm)

Q = Stream discharge (m³ s⁻¹)

P = Probability

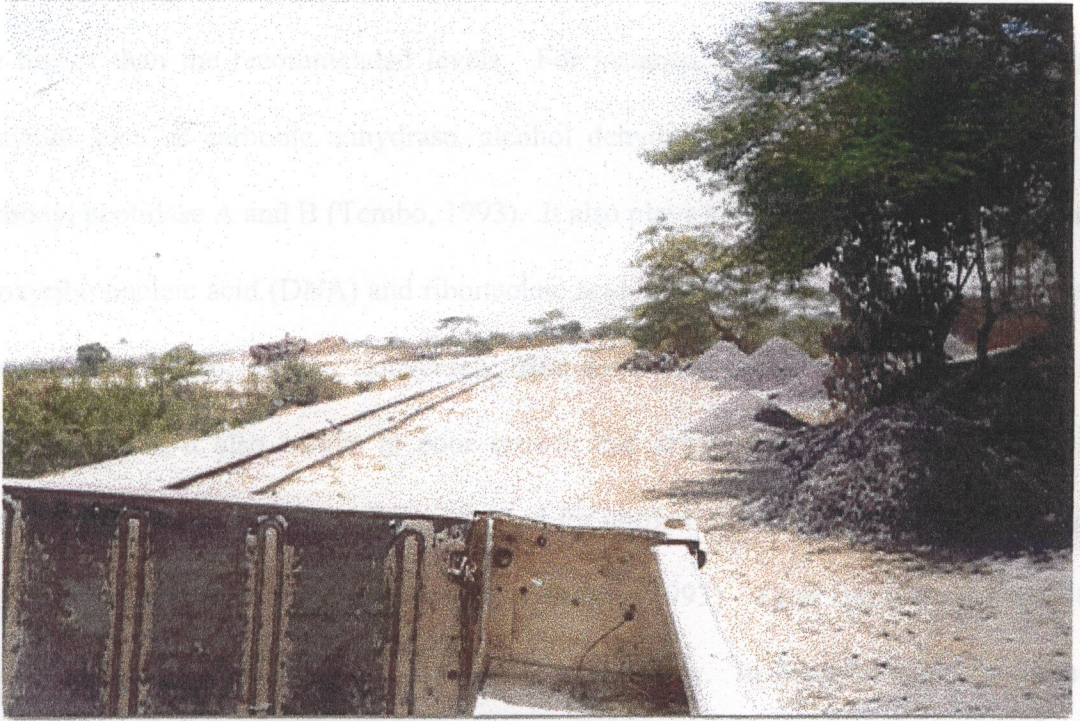
reaching influences on the concentration of other parameters and very likely to have harmful effects on living organisms found in Kafubu River.

6.2.3 Implications

Human beings were in danger of lead poisoning (concentrations above 0.5 ppm). The toxicity of lead can not be over emphasized, for it is well known for causing detrimental effects to living organism including man. High concentrations (above 0.5 ppm) are of great concern because lead poisoning results in brain damage, anemia, problems of kidney damage, tremor peripheral neuritis and permanent loss of teeth (Tembo, 1993).

Possible sources of lead in this area are not known, but lead could have come from industries like Ndola Lime Mine and Chilanga Cement. Another possibility could have been due to quarrying along Kafubu River banks, which could have lead ores like galesite (PbS), anglesite ($PbSO_4$) and cerussite ($PbCO_3$) leached into the river (Tembo, 1993) (Figure 6.2 a, b).

Kafubu River was found to have had the highest lead concentration levels compared to previous studies in Zambia (Sawula, 1985; Kasonde, 1990 and Mwiinga, 1990). In general, Kafubu River water showed low concentrations of Zinc and Copper compared to previous studies done in the Upper Kafue basin (Sawula, 1985; Mwiinga, 1990; Kasonde, 1990; Mutale, 1994 and Berglin, 1997). This could be attributed to absence of copper mining in this catchment that is a major source of these trace metals as a result of runoff from mine dumps and mine wastewaters. Zinc and copper though



(a)



(b)

Figure 6.2 Quarrying activities along Zesco - Ndola lime - Chilanga Cement road
(a) Itawa Swamps area (b) Itawa Dam west bank.

essential elements to living matter can be fatal to any living organism if concentrations are higher than the recommended levels. For instance, zinc is essential part of many enzymes such as carbonic anhydrase, alcohol dehydrogenase, alkaline phosphates and carbonyl peptidase A and B (Tembo, 1993). It also plays a key role in protein synthesis, Dioxiribo nucleic acid (DNA) and ribonucleic acid (RNA) metabolism as well as energy metabolism (Tembo, 1993). Conversely, zinc deficiency results in poor wound healing and in children it also results in poor growth and impairment of sexual development (Tembo, 1993). Similarly, copper is required for normal metabolism of all tissues in man and is a co-factor for many body enzymes (Tembo, 1993). Thus, too much or too little copper results in malfunctioning of the cells in the body. In Zambia, common diseases associated with elevated levels of copper includes malaria, sickle cell anemia, allergic reactions, central nervous system disorders, diabetes mellitus, schizophrenia and tuberculosis (Tembo, 1993).

There were no distinct inter-stational variations in trace metal concentration levels during the dry season as compared to those of the wet season, but presence of trace metals in detectable levels was a source of worry for such levels could be detrimental to living organisms in this aquatic environment. This is so because trace metals are not only toxic but also persistent and bio-accumulable. High lead concentration levels at Itawa Dam could have been detrimental to aquatic life and to humans who consume this water in its untreated form or even after treatment if the treatment plant was not effective to reduce concentration levels to the desirable limit of 0.05 ppm. In conclusion, lead seemed to have been the most undesirable constituent in raw river water in Upper Kafubu catchment

and could be detrimental to any form of life for it is not only toxic but also persistent and bio-accumulable (Tembo, 1993).

6.3 Seasonal Variations in Physico-chemical Quality of Treated Water

6.3.1 Wet Season Characteristics

Inter-seasonal changes in physico-chemical quality of treated water were evident in the wet (January to March) and dry (April to September) season with considerable variations between parameters. Tables 5.5 and 5.6 show the concentration levels of physico-chemical constituents in drinking water at Itawa (ST3) and Kafubu (ST6) water works. During the wet season, treated water temperature remained fairly constant for both Itawa (ST3) and Kafubu (ST6) water works with a mean value of 26 °C (Table 5.5). Suspended solids were completely absent in drinking water at both treatment plants. Colour units were within the recommended limit of 15 hazen units and the treatment plants at both Itawa and Kafubu were able to reduce colour units of raw river water to the desirable limit of below 15 hazen units (Appendix II). Similarly, turbidity of tap water was well within the acceptable limit of 5.0 NTU for drinking water quality.

Although TDS concentration levels were within the acceptable limit of 2500 ppm, the treated water at both Itawa (ST3) and Kafubu (ST6) water works had higher concentration levels (3 to 5 ppm) than those of raw river water found in the reservoirs. This secondary contamination was suspected in the concentration levels of chloride at both water works although the concentration levels were well within the recommended level of 800 ppm (Appendix II).

Both treatment plants produced very alkaline water that was at the same time hard, making the water less useful for drinking and other domestic purposes. COD of treated water was also objectionable, an indication of pollution in the river system (Appendix II). This was also an indication of the presence of organic matter in the treated water.

The pH of the water was also unobjectionable (6.0-9.0) and the treatment plants efficiently regulated the pH of the water works (Appendix II). Like temperature, pH was very stable at all stations during the wet season. Trace metal concentration levels were high during the wet season. Both Itawa (ST3) and Kafubu (ST6) water works recorded a range of 0.26 to 2.32 ppm and 0.01 to 2.56 ppm, respectively, which was between 1 and 51 times higher than the maximum recommended level of 0.05 ppm in drinking water (Appendix II). The high concentration level of Lead, a toxic metal, was of great significance and required further investigations. Other trace metals such as zinc and copper were detected at both water works, but were within the recommended limits of 3 ppm and 2 ppm, respectively (Appendix II). During the wet season lead was the most significant parameter in drinking water and posed great danger to human life through poisoning.

6.3 Dry Season Characteristics

The temperature of treated water was quite stable during the dry season and ranged from 20 to 24 °C and from 20 and 25 °C at Itawa and Kafubu water works, respectively. A dramatic change was evident in the concentrations of TSS, which averaged 36.44 ppm and 58 ppm at Itawa (ST3) and Kafubu (ST6) water works, respectively. TSS was occasionally above the maximum acceptable limit of 0 ppm in

drinking water (Appendix II). This was due to the presence of TSS in raw river water during the dry season, an indication that the water treatment plants were unable to reduce or remove TSS from the raw river water.

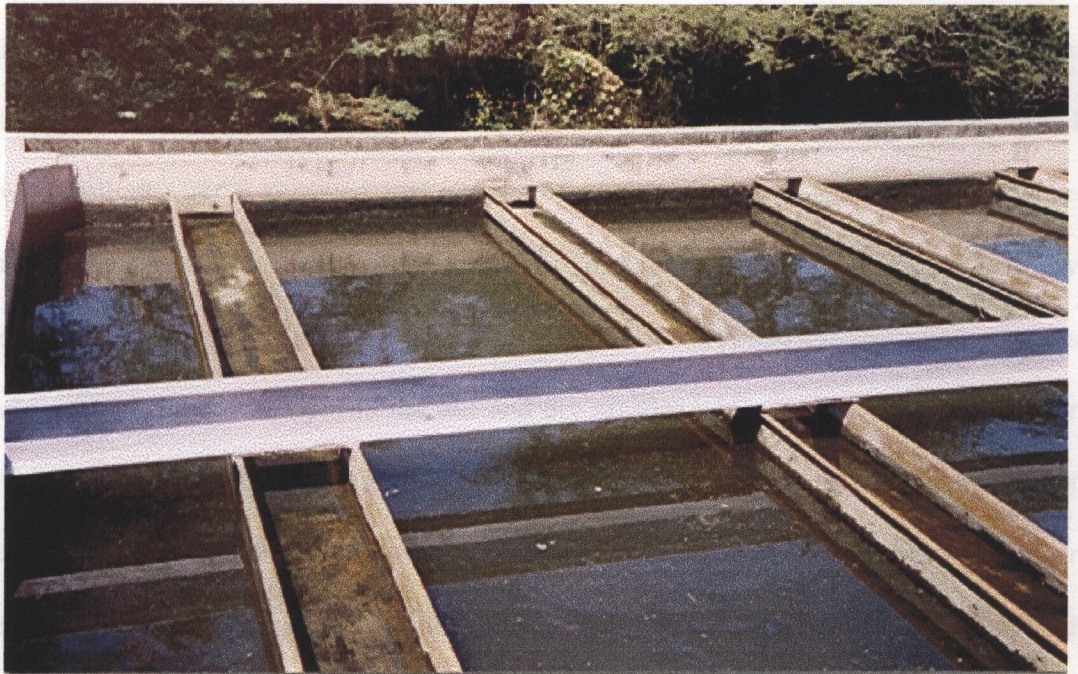
The colour of treated water at both water works was occasionally above the maximum allowable level of 15 hazen units in drinking water (Appendix II). At Itawa (ST3) colouration was between 5 and 20 units during the 1998 survey while Kafubu treated water had colouration of water ranging between 5 and 30 units. Colour units of treated water were far much lower than those of raw river water, an indication of effective removal by the treatment plants especially at Kafubu Water Works (ST6) whose raw river water was at times as high as 70 hazen units. Turbidity of treated water averaged between 1.3 NTU and 2.73 NTU at Itawa (ST3) and Kafubu water works, respectively (Table 5.5). At Kafubu Water Works (ST6) treated water maximum turbidity units reached 7.4 NTU and was above the maximum allowable (5 NTU) limit of drinking water (Appendix II). Turbidity levels at both water works were higher than those recorded in the wet season. This could be attributed to the presence of TSS and high colour units in raw river water during the dry season.

Solutes in drinking water at Itawa (ST3) and Kafubu (ST6) treatment plants were quite high and averaged between 356.39 and 263.4 ppm, respectively (Table 5.5). The mean values for treated water were slightly higher by 30.05 ppm (ST3) and by 10.24 ppm (ST6) than those of raw river water at Itawa Dam (ST2) and Kafubu Dam (ST6), respectively. Secondary contamination in the treatment plants could have been a result of poor maintenance of both Itawa and Kafubu treatment plants such that certain chemical constituents were added to the water as it passed through various treatment processes

Figure 6.3 a, b). Another source could be the corrosion of pipes and breakdown of organic matter and algae that are found in sedimentation tanks and sand filters. This situation was indeed a source of concern both to the water authority and the ultimate consumers of this water. This could also be an indication of malfunctioning of both treatment plants at certain times. During the dry season, the pH of tap water at both water works was alkaline though it was lower than the rain season results. Mean values of 8.20 and 8.06 units at Itawa (ST3) and Kafubu (ST6) water works were obtained and were unobjectionable in terms of drinking water (Table 5.5; Appendix II). pH levels of both water works were very stable throughout the study period with the downstream water works (ST6) recording the highest pH value of 8.3 units. In contrast, average total alkalinity concentration levels, varied considerably between the two water works with Itawa (ST3) recording the highest mean concentration level of 311 ppm and Kafubu (ST6) a mean concentration level of 156 ppm which was in agreement with raw river concentration levels of total alkalinity (Table 5.5). Tap water total hardness levels ranged from 160 to 208 ppm as CaCO_3 at Itawa (ST3), and from 140 and 152 ppm at Kafubu (ST6) (Table 5.5). Such concentration levels, though within the recommended limit of 500 ppm, would have had an effect on the uses water by reducing leather-forming power when washing. Magnesium and calcium hardness was the major contributor to the general 'temporal' hardness of tap water with Itawa recording the highest concentration level. Though the Itawa treatment plant managed to reduce both calcium and magnesium hardness, Kafubu treatment plant tended to have slightly increased the concentration levels resulting in the general increase in total hardness, total alkalinity and TDS in treated water. For instance, raw river water (ST2) had calcium averaging 127.06 and 127.23



(a)



(a)

Figure 6.3 Obsolete infrastructure at Kafubu Water Works and growth of algae in the water ponds (a) in primary ponds and (b) in sand filters).

ppm for dry and wet seasons respectively, whereas tap water (ST3) had calcium concentrations averaging 89.31 and 84.27 ppm for wet and dry seasons. Similarly, magnesium concentration levels were reduced from an average of 113.35 and 17.99 ppm in raw river water at Itawa Dam (ST2) in the wet and dry seasons to 87.35 and 19.03 ppm at Itawa Water Works (ST3). Conversely, Kafubu treated water (ST6) had higher concentration of 105.6 and 99.45 ppm of calcium from 117.2 and 80.36 ppm in raw river water (ST5) in the wet and dry seasons, respectively. Additionally, magnesium concentration levels averaged 37.31 and 11.28 ppm in tap (ST6) water in the wet and dry seasons whereas river water concentrations (ST5) were 41.53 and 11.25 ppm, respectively.

Chloride concentration levels were found to have been within the recommended level although their concentration increased after treatment and were sometimes higher than those recorded in the rain season. For instance, concentrations of chloride in treated water at Itawa (ST3) averaged 3.63 ppm and 4.11 ppm in the wet and dry seasons while raw (ST2) river water had an average of 2.5 ppm and 2.46 ppm in the wet and dry seasons, respectively. Similarly, Kafubu Water Works (ST6) had chloride concentrations averaging 6.4 and 8.25 ppm in the wet and dry seasons while its raw (ST5) river water had concentrations averaging 5.0 and 8.2 ppm, respectively. This showed an increase of about 0.2 to 2 times higher concentrations in treated water as compared to the raw water from the respective reservoirs. The increase in treated water chloride concentrations could more likely be reaction between added chlorine and calcium carbonate and magnesium carbonate to form calcium chloride and magnesium chloride.

6.3.3 Implications

Drinking water quality is of great importance for protection of public health. Therefore, reduction to a minimum level for parameters that are known to be hazardous to health and well being of the community is of utmost importance. Therefore, the presence of lead, a toxic metal in large quantities especially in the wet season posed a risk to health, while objectionable colour in water and high COD concentration levels was not directly related to health, but was important in ensuring the wholesomeness of water (WHO, 1984). Although only lead and COD were objectionable during the wet season, the recontamination of treated water at both water works was of great concern as indicated by the evaluation the efficiency of the treatability of river water. Even if the pH values for the treated water were within the recommended limit of 6.5 to 8.5 for aesthetic quality of drinking water, the pH exceeding 8.0 units may have lead to a progressive decrease in the efficiency of the chlorine disinfection (WHO, 1971). The water was found to be hard (135 to 245 ppm) during both seasons such that, depending on the interaction of other factors such as pH and alkalinity, soap consumption could have been higher and ‘scum formation’ could have also occurred during domestic use of water.

6.3.4 Evaluation of Water Treatment Efficiency for Physico-chemical Constituents in River Water

Evaluating the adequacy of water treatment plant, procedures employed at both Itawa and Kafubu water works involved monitoring of tap water quality at Itawa (ST3) and Kafubu (ST6) that were taps located within the water treatment plants. The quality characteristics were compared to those of raw river water in reservoirs Itawa (ST2) and

Kafubu (ST5) Dams. Detailed results from the monitoring studies between 1991 and 1998 are shown quantitatively using t-test raw data used is given in Appendices IVa-IVb). The main assumption was that there was no significant difference between means of raw river (reservoir) water and the treated (tap) water at both Itawa and Kafubu water works.

Tables 6.2 shows the statistical analysis between several parameters (pollutant concentration levels) and the outcome after treatment (tap water) at 0.05 level of significance. The treatment plants had little or no significant effect on the removal of certain constituents such that only TSS, colour and turbidity were significantly reduced at Itawa Water Works and only colour and turbidity were reduced at Kafubu Water Works. Therefore, the null hypothesis is accepted. Several parameters such as TDS, alkalinity, hardness, TSS, and chlorides either remained the same as that of raw river water or they increased after treatment processes in the plants due to low chemical additive dosages and obsolete infrastructure.

Average pH of the raw water at Itawa was 7.70 units and increased to an average of 8.21 after treatment. At Kafubu Water Works (ST6), average pH of raw river water was 8.7 units and only reduced to an average of 8.3 units after treatment. Similarly, temperature of raw water had an average of 21.5 °C (ST2) and 23.85 °C (ST5) and increased to an average of 23.5 °C (ST2) and 23.82 °C (ST6) after treatment. Colour of water and turbidity were reduced significantly after the treatment. For instance, colour of water as high as 70 hazen units at Kafubu Dam (ST5) was reduced to 30 units after the treatment process. Similarly, turbidity in raw river water, which was 34 NTU, was reduced to 12 NTU after treatment. However, both colour and turbidity concentration levels in tap water usually exceeded the maximum allowable limits of 15 and 5 units, respectively.

Table 6.2 Results of t-test on the Effectiveness of Itawa and Kafubu Water Treatment plants.

Parameter	n	T calculated	t-critical	Level of Significance
A. ITAWA WATER WORKS				
Conductivity $\mu\text{mhos/cm}$	42	0.81*	1.99	0.05
TSS (ppm)	42	0.00*	2.00	0.05
TDS (ppm)	42	0.34*	1.99	0.05
Total hardness (ppm)	42	0.31*	1.99	
				0.05
Colour units	42	0.01*	1.99	0.05
Total alkalinity (ppm)	37	0.54*	1.99	0.05
Turbidity (ppm)	42	0.02*	2.00	0.05
Chloride (ppm)	42	0.49*	1.99	
B. KAFUBU WATER WORKS				
Conductivity ($\mu\text{mhos/cm}$)	38	0.05*	2.00	0.05
TSS (ppm)	38	0.77*	1.99	0.05
TDS (ppm)	38	0.35*	2.00	0.05
Total - hardness (ppm)	38	0.91*	1.99	0.05
Colour (units)	38	0.00*	2.00	0.05
Total alkalinity (ppm)	38	0.53*	1.99	0.05
Turbidity (ppm)	38	0.00*	2.02	0.05
Chloride (ppm)	38	0.27*	1.99	0.05

Key:

n = number of samples

* = not significant

resulted into increased conductance of treated water. The Kafubu treatment plant was not able to remove or reduce conductance of water such that there was very minimal increase and occasional decrease in conductance of water during the study period. This was also evident in total hardness, which exhibited a similar trend as that of conductivity at the two water works.

Chloride concentration had increased to almost twice as much at Itawa water works (ST3) and by 0.5% to 30 % at Kafubu water works during the treatment processes (Tables 5.1, 5.2, 5.4 and 5.5). This increase in chloride concentration levels could mean that there was serious secondary contamination in the plant whose source could be harmful. The amount of chlorides found in potable waters varies so much that no conclusive remarks could be made as to their source without other corroborative evidence. If additional concentrations of chloride were derived from sewage this could only be proved if nutrients like nitrates were also analysed for they would both increase and decrease together (Taylor, 1958). But this excess concentration could also be derived from chemical reactions occurring due to varying industrial and sewage effluents entering the treatment plants.

6. 4 The Bacteriological Characteristics of Treated (Tap) Water

Bacteriologically, treated water at both water works failed to meet the recommended guidelines for drinking water by having coliform organisms and at times *E. coli* in detectable levels in tap water (Appendix II). The values obtained during this study, that is, 27 % of water samples at Itawa Water Works (ST3) and 40 % of water samples at Kafubu Water Works (ST6), seemed to have been lower compared to those obtained by previous studies. For instance, Nsomi (1991) observed that 100% of all samples from Itawa Water Works (ST3) had faecal bacteria and 80% of the water samples at Kafubu Water Works (ST6) had *E. coli* and 60% had faecal streptococci and clostridia detected (Nsomi, 1991). Similarly, Kasonde (1990) observed higher bacteriological concentrations compared to the present study though the general trend shows that Kafubu Water Works (ST6) was more contaminated than Itawa Water Works (ST3).

The presence of pathogenic organisms in drinking water at Kafubu Water Works (ST6) and its distribution system could be a direct result of sewage contamination from the three sewage treatment plants. In contrast, the contamination of Itawa Water Works (ST3) that is upstream of the sewage discharge points was an indication that there were indirect sources of contamination. These could have been from runoff during the rain season and also possibly from infiltration of underground water from unsewered areas that use pit latrines. For instance, Nkwazi and Chipulukusu squatter compounds were possible sources of pathogenic organisms into the river since they were not just located upstream of the uptake point of water at Itawa Dam (ST2), but located in a jointed and fissured dolomite area that could have allowed quick underground water infiltration into the river system. Therefore, drinking water at both water works did not meet the recommended levels of no *E. coli* or coliform organisms in treated water (Appendix II) implying that the civic authorities in Ndola failed to guarantee their consumers water supply that was microbiologically safe. Thus, adequate residual chlorine dosages are vital for a waste-receiving stream like Kafubu. Concentrations of residual chlorine at both water works varied considerably and in most cases were below recommended dosages of 2 ppm in reservoirs and a minimum of 0.1 ppm in the distribution systems to help keep the water bacteriologically safe. The recommended residual chlorine of 2.0 ppm for the water works was necessary to maintain residual chlorine in the distribution network between 0.2 and 0.5 ppm. This wasn't the case at both treatment plants and in most cases high coliform organisms prevailed when there was no chlorine or when the dosages were very low. Therefore, correct residual chlorine dosages increased the potability of drinking water in the distribution system. In fact, there was an inverse relationship between residual chlorine concentrations and the distance from the water works such that areas at the

far end of the distribution system were more vulnerable to pathogenic contamination than those close to the water works (Table 5.10). The concentration of residual chlorine declined further away from the treatment plant showing that there was a lot of biological activity in the distribution system resulting into secondary contamination. But a dosage of 2.0 ppm of chlorine at the water works demonstrated that it could effectively reach the last point of the distribution system. These dosages should be increased during certain seasons that were more vulnerable to faecal contamination like rain seasons when outbreaks of pandemic diseases like cholera were prevalent.

6.5 Conclusion

The water quality in the 20 km portion of Kafubu River between Itawa Swamps (ST1) and Kafubu Dam (ST5) was deteriorating as a result of sewage and trade effluents discharged into the river mostly with minimal pretreatment. Therefore, based on colour, total hardness, total alkalinity, conductivity, lead, taste and odour the water in this portion of the river should not be consumed in its untreated form. Although most of the physico-chemical parameters were within the WHO and ECZ quality standards for water sources, Kafubu River water was found to be highly mineralised and mineralization was higher than known published data for small streams in Zambia. This was evident in the high concentration levels of TDS, conductivity, total alkalinity and hardness, and the high trace metal concentrations in the whole study reach. It is hoped that comprehensive water pollution prevention scheme for the Kafubu River in Ndola will be formulated to prevent further environmental degradation. Most of the objectives of the study have been achieved. The hydrological regime of Kafubu River, a perennial stream, was characterised and it

was found to have a unimodal distribution with peak discharge occurring in the month of February. The characterization of raw river and treated water in terms of physico-chemical regime was successfully done and showed that Upper Kafubu catchment was greatly polluted by discharged wastewaters from sewage and industrial plants in Ndola town. Some parameters in river water such as trace metals, TDS, conductivity, alkalinity and pH increased in the wet season while TSS, colour of water, turbidity and COD were high in the dry season. Little information was sought on the bacteriology of Upper Kafubu River water in particular that of treated water due to lack of laboratory facilities. This means that the objective of characterising river water in terms of physical, chemical and bacteriological regimes has only been partially achieved. Similarly, this study could not analyze discharge and sediment concentration data (1991-1999) to examine both suspended sediment and total dissolved sediment transport rates and their relationship to effective discharge based on daily discharge duration curves. This was due to inadequate data obtained during the study for Itawa Swamps (ST1) and Kanini (ST4) station such that determination of sediment-rating curves was not possible.

The chapter following concludes the findings of the study and offers recommendations to the current situation in Upper Kafubu River basin.

CHAPTER 7: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study found that the hydrological regime of Kafubu River a perennial stream has a unimodal distribution controlled by the single rainfall season experienced in the country. The mean discharge in the wet season (November-March) was $24.98 \text{ m}^3 \text{ s}^{-1}$ while for dry season (April to October) was $3.1 \text{ m}^3 \text{ s}^{-1}$ in the 1993 to 1999 period. The quality of water in the Upper Kafubu River in the period of study, had been altered by the introduction of three sewage treatment plants and the existence of various industries which discharged raw or minimally treated effluents into the river. Both organic and inorganic constituents contaminated the urbanised reach of the Upper Kafubu River, with some parameters occasionally exceeding the ECZ maximum allowable limits for water and wastewater discharged into surface waters. The findings are summarised below under different subheadings.

7.1.1 Physico-chemical Characteristics

The Upper Kafubu River was found to have been characterised by pH, colour, taste and odour and sometimes total hardness, TSS and turbidity exceeding the recommended ECZ maximum allowable levels in raw water used subsequently for production of drinking water. TDS, conductivity, calcium and magnesium hardness, total alkalinity, and chloride were relatively high although within the recommended ECZ standards for water and wastewater discharge into aquatic environments (Appendix I and II). But it is important to monitor these on a regular basis so that when dangerous levels are reached they can be controlled. Detailed analysis showed that the Upper Kafubu River water, in the surveyed portion, was heavily polluted by organic matter (COD, 0 to

100 ppm) and was highly mineralized as indicated by average values of TDS (350 ppm) and conductivity (450 ppm). The water temperatures were well within the normal subtropical range (18 to 32 °C) for surface waters. The pH of the water was only satisfactory at the upstream station that is Itawa Swamps (ST1) but occasionally exceeded the maximum allowable limit of 6.0 to 9.0 units at all downstream stations starting from Itawa Dam (ST2) to Kafubu Dam (ST5) during wet and dry seasons. For the production of drinking water, raw river water contributed to the excessive colouration, smell and taste. Most physico-chemical parameters analysed displayed heavy contamination by municipal and trade effluents. High COD concentration levels at all stations indicated the presence of highly oxidizable matter in the river water. The river water was also highly mineralised in the whole surveyed stretch such that observations were the highest ever recorded in the Upper Kafue basin in terms of conductivity (328.0 µmhos/cm (ST5) to 491.88 µmhos/cm (ST2)) and TDS (218.7 ppm (ST5) to 326.4 ppm (ST4)) concentrations, when compared to previous studies (Sawula, 1985; Kasonde, 1990 and Mwiinga, 1990). River water colour together with taste and smell were the most undesirable parameters at all sampling stations, during the dry season, making treated water especially at Kafubu Water Works the most unpalatable to its consumers. The non-continuous aluminium sulphate additive dosage and low chlorine dosage levels, were believed to have contributed to the excessive treated water colour (up to over 20 hazen units), turbidity (10 NTU), pH (up to 9.3 units) and alkalinity and hardness up to 250 and 400 ppm, respectively, all which exceeded the recommended WHO maximum allowable limits for drinking water.

7.1.2 Trace Metal Contamination

There was strong evidence of trace metal contaminants in Kafubu River water and its treated water to such an extent that the whole surveyed river portion may reach a degeneration stage with regard to Lead and sometimes Copper and Zinc contamination posing serious health dangers to consumers. High concentrations of lead, zinc, and copper in raw river water which, in a majority of cases, exceeded the maximum allowable limits for drinking water contributed to low quality of treated water supplied to the consumers. In order to improve the quality, both water treatment plants (Itawa and Kafubu) require more extensive treatment by efficient and effective coagulation, sedimentation and filtration to remove excessive concentration levels of lead that is present. The chemical additive dosage levels (chlorine) which were usually below 2 ppm in reservoirs and less than 0.1 ppm in distribution systems were insufficient for effective treatment of water.

7.1.3 Bacteriological Contamination of Treated Water

The microbiology of drinking water at both water works showed that, “indicator” bacteria such as total coliforms and *E. coli* contaminated raw river water. The presence of “indicator” bacteria in most samples of treated water revealed that the water was liable to contamination by pathogens that could cause diseases such as cholera, typhoid fever, bacillary dysentery, etc. These findings were indicative of perhaps obsolete infrastructure (clogged sand filters) and none or low HTH granular additive dosages at both water treatment plants, making treated water not satisfactory to its consumers in Ndola. Additionally, low chlorine dosage levels were insufficient for maximum disinfection and protection of the water in the distribution system against subsequent contamination,

though based on insufficient data, made the microbiological quality of treated water very unsatisfactory (with coliform bacteria up to 18 per 100 mls) at both treatment plants.

7.1.4 Characteristics of Wastewaters from Municipal and Industrial Activities

The quality of river water deteriorated significantly in the 15 km portion of Kafubu River between Itawa and Kafubu Dams, a result of the sewage effluents from Kanini and Lubuto Sewage Works and wastewater discharges from the Light and Heavy industrial areas. Discharged municipal and trade effluents from Ndola town adversely affected the quality of water in the surveyed portion of upper Kafubu catchment, 20 km upstream of Kafubu Dam. Similarly, runoff from the CBD during the rain season and tributary inputs from Kansenshi, Mushili and Kabushi streams, and open storm drains from several industries are believed to have adversely affected raw river water in terms of organic and inorganic constituents.

7.2 Conclusions

The water quality in the 20 km portion of Kafubu River between Itawa Swamps and Kafubu Dam was found to deteriorate in downstream direction as a result of sewage and trade effluents discharged into the river mostly with minimal pretreatment. Therefore, based on colour, total hardness, total alkalinity, conductivity, lead, taste and odour the water in this portion of the river should not be consumed in its untreated form. Although most of the physico-chemical parameters were within the WHO and ECZ quality standards for water sources, Kafubu River water was found to be highly mineralised and some concentrations higher than known published data for small streams in Zambia. This was evident in the high concentration levels of TDS, conductivity, total alkalinity and hardness, and the high trace metal concentrations in the whole study reach.

Sewage and industrial effluents discharged in the river and possibly the rainfall runoffs from dumpsites and quarrying were the sources of pollution in Upper Kafubu River. Thus, due to the proximity of these discharge points, Kafubu River did not undergo self-purification before the abstraction points at Itawa and Kafubu dams. Therefore, river water required more extensive treatment for production of drinking water by efficient and effective coagulation, sedimentation and filtration to remove excessive levels of lead, copper, zinc and other cations, and hence reduce colour, turbidity, TDS, TSS, and total hardness of treated water. The presence of pathogens in treated water at Itawa and Kafubu water treatment plants such as coliforms and *E. Coli* indicated inadequate water treatment systems being used by the Ndola City Council and thus, posing a health hazard to the consumers. Similarly, lead concentrations in some tap water samples were found to be above the recommended limit of 0.05 ppm by WHO standards of drinking water.

It is hoped that comprehensive water pollution prevention measures for the Kafubu River in Ndola will be formulated to prevent further environmental degradation for the benefit of residents.

This study may have raised more questions than answers in the investigation of complex water quality aspects of a medium sized urbanised tropical catchment. It is concluded that a combination of temporal, spatial, anthropogenic factors, hydrological and climatological factors are believed to control water quality in a complex fashion. Therefore, multivariate analysis of these factors in future could greatly improve prediction of quality characteristics of water in Upper Kafubu River basin. Environmental degradation and the associated water quality problems discussed herein, though based on limited data resulted in gained knowledge. The gained knowledge and appreciation of environmental issues in Ndola related to water supply should be useful to

city planners and environmental protection agencies. Complaints from consumers on sources of water and its quality should not be viewed as frivolous, responsible officers in water undertakings should deal with them conscientiously.

7.3 Recommendations

River water requires more extensive treatment for production of drinking water by efficient and effective coagulation, sedimentation and filtration to remove the excessive levels of cations and hence reduce colour, turbidity, taste and odour, and hardness of treated water. Results of this study therefore have indicated that organic and inorganic pollution in Kafubu River portion, upstream of Kafubu Dam is high and poses a major threat to the quality of treated water offered to its consumers in Ndola. It is therefore recommended that:

- (i) The sewage works and industries in Ndola should monitor and control the quantity and quality of effluents discharged via small streams and storm drains into the Kafubu River so that permissible levels are not exceeded.

- (ii) Water works personnel should occasionally monitor the quality of river water at points between Itawa Swamps and Kafubu Dam for observation of discharged sewage and industrial effluents in order to determine chemical additive dosage levels for day to day control purposes. This should be done together with general examination of water works, reservoir filters and plant and main distribution lines.

- (iii) Water treatment processes at Itawa and Kafubu water works should be improved so that adequate chlorination is applied for the disinfection and sand filters should be well maintained to avoid clogging.
- (iv) Kafubu River upstream of Kafubu Dam should be constantly dredged if it has to survive as a medium-sized stream in the next two decades.
- (v) Future directions of research in Upper Kafubu River basin should focus on intensive pollution monitoring and assessment in relation to weed blooms and their control, as well conservation of small life forms (animals and plants) found in water. Sources of toxic metals like lead in Kafubu River should be thoroughly investigated.
- (vi) Future research should also emphasize identification of possible point and non point sources of pollutants in a more careful manner like locating where waste from the industries/sewage enters the river. Then pollutants at sample stations can be related to these sources.

8: REFERENCES

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9: APPENDICES

Appendix I: **Zambian standards (limits) for effluents and waste water**

Parameter	Limits for effluents and waste water
<i>A. PHYSICAL</i>	
1. Temperature (Thermometer)	40°C at the point of entry
2. Colour (Hazen units)	20 Hazen units
3. Odour and taste (Threshold Odour number)	must not cause any deteriorating in taste or odour as compared with the natural taste
4. Turbidity (NTU Scale)	15 Nephelometer turbidity
5. Total Suspended Solids (gravimetric method)	100 mg/L. must not cause formation of sludge receiving water
6. Settleable matter (sedimentation in 2 hours. Imhoff funnel)	0.5 mg/L in two hours. Must not cause formation of sludge or scum in receiving water.
7. Total dissolved solids (evaporating at 105°C and gravimetric method)	3000 mg/L. The TDS of the wastewater must not adversely affect surface water.
8. Conductivity (electrometric method)	4300 US/cm
<i>B. BACTERIOLOGICAL</i>	
9. Total coliform/100 ml (membrane filtration method)	25000
10. Faecal coliform/100 ml (membrane filtration method)	5000
11. Algae/100 ml	1000 cells
<i>C. CHEMICAL</i>	
12. pH (0 - 14 scale, electrometric method)	6.0 – 9.0
13. Dissolved oxygen. mg O ₂ /L (modified Winkler method and membrane method)	5mg/L after compete mixing, oxygen content must not be less. Extreme temperature may result in lower values.
14. Chemical oxygen demand (COD) (Dichromat method)	COD based on the limiting values for organic carbon 90mg O ₂ /L average for 24 hours

Parameter	Limits for effluents and waste water
15. Biochemical oxygen demand (BOD) (modified Winkler method and membrane electrode method)	50 mg O ₂ /L (mean value over 24 hours period). According to circumstances in relation to the self cleaning capacity of the water
16. Nitrates (NO ₃ as nitrogen) (spectrometric method and electrometric method)	The nitrate burden must be reduced as far as possible watercourses 50mg/L.
lakes 20mg/L according to circumstances:	
17. Nitrite (NO ₂ as nitrogen/l) (spectrophotometric sulphanimide)	2.0 mg NO ₂ as N/L
18. Organic nitrogen (N-Kjeldahl)	5.0 mg/L mean * (* the % of nutrient elements for degradation of BOD should be 0.4-1% for phosphorous, different for processes using algae)
19. Ammonia and ammonium (total) (NH ₃ as N/l) (Nesslerization method and electrometric)	The burden of ammonia salts must be reduced to 10 mg/L (depending upon temperature, pH and salinity)
20. Cyanides (spectrophotometric)	0.2 mg/L
21. Phosphorous, total (PO ₄ as P/l)(colorimetric)	treatment installation located in the catchment area of lakes: 1.0 mg/L located outside catchment area: reduce the load of P as low as possible (PO ₄ = 6 mg/L)
22. Sulphates (turbidimetric method)	the sulphate burden must be reduced to 1500 mg/L
23. Sulphite (iodometric method)	1.0 mg/L (presence of oxygen changes SO ₃ to SO ₄)
24. Sulphide (iodometric and electrometric method)	0.1 mg/L (depending on temperature, pH and dissolved O ₂)
25. Chlorides Cl/l (Silver nitrates and mercuric nitrates)	
26. Active chloride Cl ₂ /l (iodometric method)	0.5 mg/L
27. Active bromine (Br ₂ /l)	0.1 mg/L
28. Fluorides F/l (electrometric and colorimetric Chlorides levels must be 800 mg/L method with distillation)	2.0 mg/L

D. METALS

Appendix I: continued

Parameter	Limits for effluents and waste water
29. Aluminium compounds (atomic absorption)	2.5 mg/ L
30. Antimony (ppm) 0.5 mg/L	0.05 mg/L
31. Arsenic compounds (ppm)	0.5 mg/L
32. Barium compounds (water soluble concentration, (ppm)	
33. Beryllium salts and compounds (ppm) 0.5 mg/L	
34. Boron compounds 0.5 mg/ (spectrophotometric method-curcumin method)	
35. Cadmium compounds (ppm)	0.5 mg/L
36. Chromium hexavalent, trivalent (ppm)	0.1 mg/L
37. Cobalt compounds (ppm)	1.0 mg/L
38. Copper compounds (PPM)	1.5 mg/L
39. Iron compounds (ppm)	2.0 mg/L
40. Lead compounds (ppm)	0.5 mg/L
41. Magnesium (ppm) and flame photometric method.	500 mg/L
42. Manganese (ppm)	1.0 mg/L
43. Mercury (ppm)	0.002 mg/L
44. Molybdenum (ppm)	5.0 mg/L
45. Nickel (PPM)	0.5 mg/L
46. Selenium (ppm)	0.02 mg/L
47. Silver (ppm)	0.1 mg/L
48. Thallium (ppm)	0.5 mg/L
49. Tin compounds (ppm)	2.0 mg/L
50. Vanadium compounds (ppm)	1.0 mg/L
51. Zinc compounds (ppm)	10.0 mg/L

E. ORGANICS

52. Total hydrocarbons

10.0 mg/L

Appendix I: concluded

Parameter	Limits for effluents and waste water
(chromatographic method)	
53. Oils (mineral and crude)	5.0 mg/L
(chromatographic and gravimetric method)	
54. Phenols, steam distillable	0.2 mg/L
non-steam distilled (colorimetric method)	
55. Fats and saponifiable oils	0.05 mg/l
(gravimetric and chromatographic method)	
56. Detergents (atomic) (AAS)	20.0 mg/L
57. Pesticides an PCB's (total) (chromatographic method)	2.0 mg/L (detergents should contain at least biodegradable compounds)
58. Trihaloforms (chromatographic method)	0.5 mg/L
<i>F. RADIOACTIVE MATERIALS</i>	
59. Radioactive materials as specified by international atomic energy agency	discharge not permitted/accepted

Source: ECZ,1993

Appendix II: Some Water Quality Guidelines for Drinking Water

Parameter	Permissible Limits (mg/L)	Desirable Limit (mg/L)	Comments and/or undesirable effects
<i>A. PHYSICAL</i>			
1. Temperature	None	None	None
2. Colour (units)	15	5	Aesthetic consideration
3. TSS	0	0	
4. TDS	1500	500	Aesthetic consideration
5. Conductivity	0.7	3.0	
6. Turbidity (NTU)	10	5	Aesthetic, filterability and disinfection
7. Odour and Taste	Nil	Nil	Should be acceptable
8. COD	10	10	Taste problem
<i>B. CHEMICAL</i>			
9. pH	6.5 – 9.0	7.0 – 8.5	Taste and corrosion
10. Chlorides	600	200	Taste problem
11. Total Alkalinity	400	30 – 250	Taste and scale formation
12. Total Hardness	500	250	Scale formation and soap consumption
13. Calcium Hardness	200	75	Contributes to hardness
14. Magnesium Hardness	150	50	Contributes to hardness
<i>C. METALS</i>			
15. Zinc (Zn)	15	5	Above 5 taste may be noticeable
16. Copper (Cu)	1.5	1.0	Acceptability may depend on concentration of other heavy metals
17. Lead (Pb)	0.05	0.01	Toxic
<i>D. BACTERIOLOGICAL</i>			
17. Coliform Organisms/100 mls	0	0	No Coliform organisms in treated or untreated water entering the distribution system and none in any two in 98% of the yearly samples. Water in the distribution system should only have three Coliform organisms in any 1 sample, none in two consecutive samples and nil in 95% of the yearly samples and 10 in uniped supplies.
18. Faecal Coliforms/100 mls	0	0	None for treated, untreated and in water entering the distribution system and nil even in uniped supplies.

Source: WHO, 1971; JICA, 1996: International Programme on Chemical safety (IPCS), 1997.

Appendix III: Variations in Mean Monthly Stream Discharge, Water Levels at Masaiti Gauging Station and Rainfall at Ndola Airport in Kafubu River Basin

Date	Average Rainfall (mm)	Mean Discharge ($m^3 s^{-1}$)	Water Level (m)
Oct-93	1.40	1.40	1.53
Nov-93	194.30	4.56	1.61
Dec-93	302.90	5.85	1.74
Jan-94	244.20	18.32	2.48
Feb-94	214.50	34.8	3.19
Mar-94	102.60	24.74	2.78
Apr-94	0.00	8.8	1.97
May-94	0.00	5.34	1.69
Sep-94	5.90	3.59	1.51
Oct-94	92.50	3.51	1.5
Dec-94	119.30	3.48	1.5
Jan-95	159.00	6.57	1.8
Feb-95	356.90	19.34	2.53
Mar-95	148.80	20.87	2.61
Apr-95	1.40	8.27	1.91
Apr-96	39.70	16.47	2.42
May-96	18.90	10.67	2.1
Jun-96	0.00	8.05	1.92
Jul-96	0.00	6.48	1.79
Aug-96	0.00	5.42	1.7
Sep-96	0.10	4.3	1.59
Oct-96	0.20	3.77	1.53
Nov-96	39.70	3.88	1.54
Dec-96	167.80	5.82	1.7
Jan-97	381.40	24.91	2.73
Feb-97	199.00	43.74	3.47
Mar-97	149.00	25.48	2.79
Apr-97	46.70	12.66	2.22
May-97	7.20	8.06	1.92
Jun-97	0.00	6.75	1.82
Jul-97	0.00	5.95	1.75
Aug-97	0.00	4.79	1.64
Sep-97	9.80	4.01	1.56
Oct-97	4.80	3.69	1.52
Nov-97	154.90	14.82	2.17
Dec-97	358.10	16.96	2.44
Jan-98	231.20	35.2*	3.2
Feb-98	157.00	15.01*	2.31
Mar-98	222.40	30.95*	3
Apr-98	0.00	12.45*	2.2
May-98	0.00	7.33	1.36
Jun-98	0.00	6.26	1.77
Jul-98	0.00	5.22	1.68
Aug-98	0.00	4.53	1.61

17.93* = measured discharge by author
4.53 = Estimated discharge from water levels

Appendix IVa: Physico-chemical Characteristics of Raw River Water at Itawa Swamps (ST1)

Date	PH Units	Colour Units	Conductivity (µmhos/cm)	TDS (ppm)	TSS (ppm)	Total Hardness (ppm)	COD (ppm)	Chloride (ppm)	Turbidity (ppm)	Alkalinity (ppm)	Calcium Hardness (ppm)	Magnesium Hardness (ppm)	Zinc (ppm)	Lead (ppm)	Copper (ppm)
14-Jan-98	8.22	50.00	530.00	353.30	0.00	243.20	80.00	3.00	0.90	250.00	136.00	107.20	1.15	0.73	0.68
20-Jan-98	7.61	20.00	450.00	300.00	0.00	401.60	78.00	2.00	0.60	218.00	214.40	167.20	0.98	0.27	0.53
03-Feb-98	8.36	20.00	510.00	340.00	0.00	385.60	79.00	4.00	2.10	240.00	231.60	64.00	0.00	4.55	0.182
11-Feb-98	8.34	5.00	320.00	213.30	0.00	376.00	79.00	1.00	0.50	238.00	84.80	71.05	0.72	2.68	0.45
24-Feb-98	8.36	10.00	480.00	320.00	0.00	184.00	77.00	2.00	0.60	225.00	44.00	31.16	2.68	2.82	0.16
04-Mar-98	8.97	5.00	390.00	260.00	0.00	179.20	0.00	2.00	0.50	214.00	97.60	19.90	0.02	0.00	0.00
10-Mar-98	8.80	5.00	420.00	280.00	0.00	152.00	0.00	1.00	0.30	225.00	81.00	1.90	0.01	0.00	0.00
24-Mar-98	7.46	5.00	430.00	286.60	0.00	184.00	0.00	3.00	0.50	225.00	152.00	1.60	0.03	0.32	0.02
01-Apr-98	8.56	5.00	470.00	313.30	0.00	164.80	0.00	1.00	0.60	218.00	130.00	8.49	0.07	0.35	0.02
05-May-98	8.50	5.00	470.00	315.60	0.00	170.00	24.00	3.00	0.60	217.00	130.00	34.20	0.05	0.33	0.00
27-Jul-98	7.30	10.00	470.00	387.00	260.00	185.00	48.00	3.00	0.70	214.00	44.50	34.20	0.04	0.07	0.11
19-Aug-98	7.40	5.00	480.00	390.00	34.00	177.60	48.00	3.00	4.40	230.00	155.20	5.40	0.04	0.06	0.01
29-Sep-98	7.10	10.00	400.00	380.00	38.00	203.00	24.00	3.00	2.50	269.00	152.00	12.40	0.04	0.02	0.01

Appendix IVb: Physico-chemical Characteristics of Raw River Water at Itawa Dam (ST2)

Date	PH units	Colour units	Conductivity (umhos/cm)	TDS (ppm)	TSS (ppm)	Total Hardness (ppm)	COD (ppm)	Chloride (ppm)	Turbidity units	Total Alkalinity (ppm)	Calcium Hardness (ppm)	Magnesium Hardness (ppm)
15-Jul-92	6.98	5	30	408	0	250	ND	8.00	2.00	50	36.0	ND
17-Aug-92	7.68	10	45	260	0	230	ND	6.00	1.60	52	38.2	ND
27-Aug-93	7.60	5	40	280	0	185	ND	7.00	1.90	247	40.8	ND
27-Sep-93	8.20	10	60	80	210	150	ND	3.00	2.00	276	28.8	ND
02-Nov-93	7.70	10	60	144	0	340	ND	7.00	1.90	276	28.8	ND
09-Nov-94	7.81	20	600	476	.0	380	ND	10.00	12.00	340	100	ND
28-Mar-95	7.31	10	480	372	0	260	ND	7.00	2.50	273	180	ND
28-Apr-95	8.24	15	500	268	0	220	ND	5.00	2.30	320	180	ND
26-May-95	8.01	5	500	500	0	340	ND	4.00	3.50	345	127	ND
06-Jun-95	7.06	5	500	330	0	365	ND	3.00	2.50	360	148	ND
08-Aug-95	7.50	5	550	366	0	312	ND	3.00	2.00	360	208	ND
12-Sep-95	7.98	5	600	400	0	291	ND	3.00	9.00	364	163	ND
31-Oct-95	8.08	30	600	400	0	340	ND	5.00	25.00	360	140	ND
14-Nov-95	7.10	50	500	334	0	320	ND	12.00	9.00	380	100	220
04-Jan-96	7.26	10	530	353	0	236	ND	1.00	0.55	248	140	96
06-Feb-96	7.83	20	450	225	0	245	ND	8.00	1.00	265	140	86.4
17-Apr-96	7.48	0.4	480	320	0	238	2.00	6.00	1.00	340	192	81.8
02-Dec-96	7.96	10	600	400	0	313	2.50	13.00	2.00	480	153	86.4
10-Jan-97	7.70	5	540	360	0	256	5.00	4.00	2.00	265	227	38.6
11-Feb-97	7.71	5	490	327	0	240	5.00	8.00	0.55	240	197	92.8
10-Mar-97	7.44	5	520	347	0	244	3.40	3.00	0.60	ND	147	23.4
02-Apr-97	7.65	10	500	333	0	244	1.50	3.00	1.20	ND	148	28.1
09-Jun-97	7.75	10	586	587	0	272	2.00	3.00	1.50	ND	129	48.4
11-Jul-97	7.94	10	500	333	0	267	2.30	6.00	0.70	ND	73	48.4
03-Nov-97	8.01	20	530	353	0	288	5.20	9.00	2.80	ND	164	36.6
14-Jan-98	8.22	30	510	340	0	226	82.00	2.00	0.60	315	137	73.6
20-Jan-98	7.65	20	460	307	0	373	80.00	2.00	0.90	240	152	340.8

Appendix IVb: concluded

11-Feb-98	8.25	15	510	340	0	426	80.00	3.00	1.00	170	145	72.0
19-Feb-98	7.26	15	490	227	0	346	5.30	3.00	1.50	240	81.5	20.3
24-Feb-98	8.50	15	530	3530	0	175	78.00	3.00	1.10	250	92	35.5
04-Mar-98	8.09	20	470	313	0	208	72.00	2.00	0.90	252	67	10.54
10-Mar-98	9.10	20	475	317	0	120	48.00	2.00	0.70	253	96	13.27
10-Mar-98	8.83	10	470	313	0	206	24.00	3.00	8.50	165	54	10.75
24-Mar-98	8.77	15	420	280	0	180	48.00	2.00	10.00	250	147	16.00
01-Apr-98	8.63	20	500	333	0	200	72.00	3.00	1.00	248	120	10.74
14-Apr-98	8.65	15	500	313	0	200	72.00	2.00	1.50	253	120	15.00
05-May-98	6.99	15	520	280	0	195	24.00	2.00	0.90	250	110	20.30
29-Jun-98	6.95	15	527	253	0	208	24.00	3.00	3.60	245	130	21.30
08-Jul-98	6.97	15	546	264	0	184	24.00	3.00	1.00	301	120	20.23
27-Jul-98	7.80	15	530	468	304	174	24.00	3.00	1.00	310	120	20.50
19-Aug-98	7.90	15	510	460	36	219	24.00	3.00	4.50	304	110	25.50
29-Sep-98	7.40	10	500	440	40	252	48.00	3.00	2.00	334	152	24.40

NID = not detected

Appendix IV: Physico-chemical Characteristics of Raw River Water at Kanini (ST4)

Time	pH	Colour	Conductivity	TDS	TSS	Total Hardness	COD	Chloride	Turbidity	Total Alkalinity	Calcium Hardness	Magnesium Hardness	Zinc	Lead	Copper
14-Jan-98	8.33	10.00	510.00	340.00	0.00	199.20	81.00	10.00	8.50	170.00	104.00	24	0.88	0.21	0.44
20-Jan-98	7.88	10.00	390.00	260.00	0.00	275.20	82.00	8.00	3.60	173.00	171.20	104	0.77	0.16	0.35
03-Feb-98	8.33	20.00	480.00	320.00	0.00	371.20	78.00	2.00	0.90	240.00	337.60	33.6	0.77	1.74	0.18
11-Feb-98	8.39	20.00	475.00	318.00	0.00	368.00	78.00	8.00	1.05	230.00	337.60	23.00	0.75	1.80	0.18
24-Feb-98	8.53	10.00	470.00	313.30	0.00	120.00	78.00	8.00	6.50	220.00	40.00	19.53	0.65	2.90	0.19
04-Mar-98	8.27	15.00	360.00	240.00	0.00	131.20	24.00	12.00	10.40	164.00	115.20	3.90	0.05	0.00	0.08
10-Mar-98	9.21	15.00	400.00	266.60	0.00	84.80	24.00	5.00	7.50	165.00	64.00	6.80	0.01	0.26	0.00
24-Mar-98	7.4	10.00	430.00	286.60	0.00	144.00	100.00	8.00	5.50	190.00	104.00	4.20	0.03	0.43	0.00
01-Apr-98	7.86	10.00	430.00	286.60	0.00	120.20	48.00	10.00	5.80	180.00	86.00	8.29	0.02	0.25	0.02
05-May-98	7.86	10.00	430.00	286.9	0.00	120.00	48.00	10.00	6.00	190.00	70.00	19.50	0.04	0.17	0.00
27-Jul-98	7.20	10.00	480.00	373.00	220.00	120.00	24.00	13.00	6.30	208.00	40.00	19.50	0.04	0.17	0.09
19-Aug-98	7.30	30.00	440.00	365.00	32.00	180.80	24.00	14.00	7.40	215.00	94.40	21.00	0.04	0.11	0.01
29-Sep-98	7.00	15.00	400.00	360.00	36.00	184.00	24.00	12.00	4.00	250.00	89.60	23.00	0.04	0.03	0.01

Appendix IVd: Physico-chemical Characteristics of Raw River Water at Kafubu Dam (ST5)

Time	pH	Colour	Conductivity	TDS	TSS	Total Hardness	COD	Chloride	Turbidity	Alkalinity	Calcium Hardness	Magnesium Hardness
05-May-92	7.28	30	60	160.0	0.0	120.0	ND	12	6.7	36.0	34.4	ND
10-Sep-93	8.50	40	770	690.0	0.0	169.0	ND	10	0.4	137.0	68.8	ND
13-Oct-93	8.90	60	770	280.0	0.0	130.0	ND	10	10.0	170.0	54.4	ND
05-Nov-93	9.30	60	770	143.0	43.0	150.0	ND	10	30.0	193.0	65.4	ND
31-Aug-94	7.96	60	320	243.0	24.0	220.0	ND	15	26.0	196.0	128.0	ND
30-Mar-95	8.58	15	350	80.00	26.0	180.0	ND	7	9.0	181.0	140.0	ND
26-Apr-95	8.13	20	340	324.0	0.0	180.0	ND	8	10.0	185.0	100.0	ND
17-May-95	8.21	10	350	372.0	0.0	180.0	ND	10	5.5	195.0	100.0	ND
16-Jun-95	7.81	25	300	200.0	0.0	180.0	ND	7	16.0	174.0	81.6	ND
05-Sep-95	9.38	70	380	254.0	0.0	174.0	ND	10	20.0	205.0	96.0	ND
04-Jan-96	6.98	15	280	186.6	0.0	137.6	ND	4	33.0	125.0	86.0	51.6
13-Feb-96	8.07	10	450	300.0	0.0	232.4	ND	8	10.0	190.	140.0	92.4
21-May-96	8.02	30	300	200.0	0.0	152.0	2.00	8	10.0	225.0	96.0	56.0
18-Jun-96	7.85	50	390	200.0	0.0	160.0	4.50	10	10.0	230.0	50.0	50.0
17-Jul-96	7.15	15	365	260.0	0.0	160.0	2.48	9	8.5	230.	69.0	48.0
20-Nov-96	8.72	60	390	260.0	0.0	268.0	2.50	8	30.0	330.0	156.0	112.0
04-Dec-96	8.31	10	385	256.7	10.0	169.6	2.50	15	10.0	260.0	104.0	65.6
10-Jan-97	7.98	5	410	275.3	25.0	163.2	3.50	14	30.0	152.0	96.0	16.3
18-Feb-97	8.24	10	320	213.3	0.0	155.2	1.70	19	3.5	167.0	91.2	64.0
27-Mar-97	7.28	15	370	246.7	0.0	164.6	6.80	5	10.0	181.0	104.0	15.8
13-May-97	7.58	10	385	256.6	0.0	156.8	3.70	8	6.0	160.0	107.0	49.6
04-Jun-97	8.24	59	385	256.7	0.0	155.2	3.50	13	6.9	178.0	72.0	20.3
14-Jul-97	8.03	60	345	230.0	0.0	156.8	2.80	8	6.5	165.0	83.2	20.0
16-Sep-97	7.85	40	350	233.30	0.0	68.40	2.20	8	7.0	165.0	80.0	19.1
22-Oct-97	8.96	60	380	233.3	0.0	166.4	2.50	14	22.0	190.0	96.0	70.4
05-Nov-97	8.75	70	400	166.7	0.0	145.6	3.50	14	15.0	180.0	83.2	15.2
17-Dec-97	8.27	30	380	253.3	20.0	176.0	1.00	8	9.0	255.0	92.8	20.3
14-Jan-98	9.31	10	330	220.0	0.0	132.8	80.00	7	4.5	148.0	104.0	28.8
20-Jan-98	8.13	15	330	220.0	0.0	256.0	80.00	5	5.0	148.0	187.0	88.0
24-Feb-98	9.36	30	330	220.2	0.0	118.4	80.00	5	1.1	154.0	102.0	28.0
04-Mar-98	8.69	30	320	213.3	0.0	129.6	48.00	4	1.0	158.0	112.0	58.9
10-Mar-98	9.32	25	330	220.0	0.0	96.00	0.00	4	5.5	153.0	80.0	3.90
24-Mar-98	8.95	15	310	206.8	0.0	129.6	100.0	3	9.0	155.0	83.2	10.3
01-Apr-98	8.90	15	360	240.0	0.00	128.0	24.00	5	9.5	160.0	91.2	8.97
27-Jul-98	7.80	30	350	269.0	208.0	118.0	48.00	9	1.2	152.0	103.0	3.40
19-Aug-98	8.70	30	380	270.0	23.0	148.8	48.00	14	10.0	155.0	83.2	16.0
29-Sep-98	7.50	70	280	280	24.0	142.0	24.00	10	35.0	198.0	70.4	17.4

ND =Not detected

Appendix IVe: Physico-chemical Characteristics of Treated Water at Itawa Water Works (ST3)

Date	PH units	Colour units	Conductivity (desirable) ($\mu\text{mhos/cm}$)	TDS (ppm)	TSS (ppm)	Total hardness (ppm)	COD (ppm)	Chloride (ppm)	Turbidity units	Total alkalinity (ppm)	Calcium hardness (ppm)	Magnesium hardness (ppm)
15-Jul-92	6.98	5	30	408.0	0	250	ND	8.00	2.00	50.00	36.00	ND
17-Aug-92	7.68	10	45	260.0	0	230	ND	6.00	1.60	52.00	38.20	ND
27-Aug-93	7.60	5	40	280.0	0	185	ND	7.00	1.90	247.00	40.80	ND
27-Sep-93	8.20	10	60	80.00	210	150	ND	3.00	2.00	276.00	28.80	ND
02-Nov-93	7.70	10	60	144.0	0	340	ND	7.00	1.90	276.00	28.80	ND
09-Nov-94	7.81	20	600	476.0	0	380	ND	10.00	12.00	340.00	100.00	ND
28-Mar-95	7.31	10	480	372.0	0	260	ND	7.00	2.50	273.00	180.00	ND
28-Apr-95	8.24	15	500	268.0	0	220	ND	5.00	2.30	320.00	180.00	ND
26-May-95	8.01	5	500	500.0	0	340	ND	4.00	3.50	345.00	127.20	ND
06-Jun-95	7.06	5	500	330.0	0	365	ND	3.00	2.50	360.00	148.00	ND
08-Aug-95	7.50	5	550	366.0	0	312	ND	3.00	2.00	360.00	208.00	ND
12-Sep-95	7.98	5	600	400.0	0	291	ND	3.00	9.00	364.00	163.20	ND
31-Oct-95	8.08	30	600	400.0	0	340	ND	5.00	25.00	360.00	140.00	ND
14-Nov-95	7.10	50	500	334.0	0	320	ND	12.00	9.00	380.00	100.00	220.00
04-Jan-96	7.26	10	530	353.0	0	236	ND	1.00	0.55	248.00	140.00	96.00
06-Feb-96	7.83	20	450	225.0	0	245	ND	8.00	1.00	265.00	140.00	86.40
17-Apr-96	7.48	10	480	320.0	0	238	2.00	6.00	1.00	340.00	92.80	81.80
02-Dec-96	7.96	10	600	400.0	0	313.6	2.50	13.00	2.00	480.00	153.60	86.40
10-Jan-97	7.70	5	540	360.0	0	256	5.00	4.00	2.00	265.00	227.20	38.60
11-Feb-97	7.71	5	490	326.6	0	240	5.00	8.00	0.55	240.00	97.60	92.80
10-Mar-97	7.44	5	520	346.6	0	244.8	3.40	3.00	0.60	ND	147.20	23.40
02-Apr-97	7.65	10	500	333.3	0	244.8	1.50	3.00	1.20	ND	148.80	28.10
09-Jun-97	7.75	10	586	586.7	0	272	2.00	3.00	1.50	ND	129.60	48.40
11-Jul-97	7.94	10	500	333.3	0	267	2.30	6.00	0.70	ND	73.60	48.40
03-Nov-97	8.01	20	530	353.3	0	288	5.20	9.00	2.80	ND	164.80	36.60
14-Jan-98	8.22	30	510	340.0	0	225.6	82.00	2.00	0.60	315.	137.60	73.60
20-Jan-98	7.65	20	460	306.6	0	372.8	80	2.00	0.90	240	152.00	340.80
03-Feb-98	8.43	25	490	326.6	8	486	80	2.00	1.00	218	32.00	340.80
11-Feb-98	8.25	15	510	340.0	0	425.6	80	3.00	1.00	170	145.60	72.00
19-Feb-98	7.26	15	490	226.6	0	345.6	53	3.00	1.50	240	81.50	20.30
24-Feb-98	8.50	15	530	353.3	0	175	78	3.00	1.10	250	92.00	35.50
04-Mar-98	8.09	20	470	313.3	0	208	72	2.00	0.90	252	67.20	10.54
10-Mar-98	9.10	20	475	316.6	0	120	48	2.00	0.70	253	96.00	13.27
10-Mar-98	8.83	10	470	313.3	0	206	24	3.00	8.50	165	54.60	10.75
24-Mar-98	8.77	15	420	280.0	0	180	48	2.00	10.00	250	147.20	16.00
01-Apr-98	8.63	20	500	333.3	0	200	72	3.00	1.00	248	120.00	10.74
14-Apr-98	8.65	15	500	313.0	0	200	72	2.00	1.50	253	120.00	15.00
05-May-98	6.99	15	520	280.0	0	195	24	2.00	0.90	250	110.00	20.30
29-Jun-98	6.95	15	527	253.0	0	208	24	3.00	3.60	245	130.00	21.30
08-Jul-98	6.97	15	546	264.0	0	184	24	3.00	1.00	301	120.00	20.23
27-Jul-98	7.80	15	530	468.0	304	174	24	3.00	1.00	310	120.50	20.50
19-Aug-98	7.90	15	510	460.0	36	219	24	3.00	4.50	304	110.40	25.50
29-Sep-98	7.40	10	500	440.0	40	252	48	3.00	2.00	334	152.00	24.40

ND = Not detected

Appendix IVf: Physico-chemical Characteristics of Tap Water at Kafubu Water Works (ST6)

Date	pH	Colour	Conductivity	TDS	TSS	Total Hardness	COD	Chloride	Turbidity	Total Alkalinity	Calcium Hardness	Magnesium Hardness	Residual Chlorine
05-May-92	7.08	5	50	144	0	124	ND	8	2.5	34	34.4	ND	ND
11-Jun-92	7	5	52	160	0	16	ND	8	2	33	30.5	ND	ND
10-Sep-93	7.5	50	40	116	0	90	ND	10	1.5	143.8	38	ND	ND
13-Oct-93	7.8	60	60	90	0	130	ND	8	4	165	36.8	ND	ND
05-Nov-93	9.3	60	60	104	37	220	ND	10	6.5	190.3	33	ND	ND
31-Aug-94	7.68	60	315	238	0.18	180	ND	13	6.8	189	34	ND	1.6
30-Mar-95	7.4	10	360	68	0	180	ND	5	4	170	140	ND	1.2
26-Apr-95	7.94	5	340	276	0	180	ND	8	5.5	185	100	ND	1.6
17-May-95	7.6	5	350	320	0	180	ND	6	1	190	100	ND	1.5
16-Jun-95	7.87	15	320	213	0	180	ND	6	4	164	80.8	ND	1.5
05-Sep-95	8.85	30	395	263	0	174	ND	8	5	200	98	ND	ND
04-Jan-96	7.33	10	285	190	0	138	ND	5	11	143	87.27	52.8	ND
13-Feb-96	8.16	5	460	308	0	232	ND	6	0.3	185	140	92	ND
21-May-96	7.94	30	290	193.3	0	152	1.9	8	4	225	102	50	ND
18-Jun-96	7.47	10	295	193.3	0	160	2	13	9	225	112	48	0.4
17-Jul-96	7.95	5	380	263.3	0	158	1.96	9	3.2	232	68	44	ND
20-Nov-96	8.02	20	420	280	0	264	1	6	6.5	225	156	108	ND
04-Dec-96	8.1	5	390	260	0	166.4	2	8	1.5	250	102	64	2.5
10-Jan-97	7.65	5	420	280	0	163	3.2	14	2.5	150	96	16.3	0.4
18-Feb-98	8.31	10	320	213.3	0	155.2	1.5	19	1.5	167	92	64	ND
27-Mar-97	7.31	5	385	256	0	164	3.3	5	1.5	172	102.4	15.8	1
13-May-97	7.64	5	385	256.6	0	153.6	1.6	8	1.8	150	104	49.6	ND
04-Jun-97	7.71	10	390	260	0	154	1.7	8	6	160	71.8	20	ND
14-Jul-97	7.57	10	350	233.3	0	153.6	1.5	8	3	160	81.6	19.1	ND
16-Sep-97	7.76	15	355	236.7	0	157.6	1	6	6.5	158	79.2	19	ND
22-Oct-97	8.2	10	400	273.3	0	163.2	1.2	14	10	187	92	71.2	ND

Appendix IVf: concluded

05-Nov-97	8.65	29.8	410	273.3	0	142.4	1.9	13	7	175	81.6	14.7 ND
17-Dec-97	7.87	10	390	260	0	174	0.5	5	4	260	91.2	20.3 ND
14-01-98	8.38	10	330	220	0	121.6	80	7	3	155	89.6	32 ND
20-Jan-98	7.92	10	340	226.6	0	267.2	80	5	3.1	146	152	115.2 ND
24-Feb-98	8.88	10	350	233.3	0	140	80	5	0.5	150	121.6	4 ND
04-Mar-98	8.03	10	320	213.3	0	45.6	0	7	2.5	155	88	29.1 ND
10-Mar-98	8.92	10	340	226.6	0	102.4	0	8	2.2	150	76.8	6.24 ND
24-Mar-98	8.02	5	350	233.3	0	142.4	0	6	2	160	104	8.61 ND
01-Apr-98	8.03	10	350	233.3	0	152	0	5	1	156	88	15.6 ND
27-Jul-98	7.9	10	330	297	208	140	48	13	0.5	143	122.6	4.2 ND
19-Aug-98	8.3	20	350	290	24	152	48	9	7.4	165	83.2	16.7 ND
29-Sep-98	7.6	15	290	270	30	156	48	6	6.6	176	70.4	20.8 ND

ND = not detected

Appendix Va: Concentration levels of Residual chlorine at Itawa Water Works and its Distribution system in relation to Coliform organisms and *E. coli* per 100 mls.

Sampling point	Date	Total coliforms / 100mls	<i>E.coli</i> / 100mls	Residual chlorine (ppm)
Itawa Water Works	19/9/91	9	+ve	0.0
	19/5/92	0	0	0.2
	27/7/92	1	+ve	0.0
	17/8/92	0	0	0.4
	4/3/93	18	+ve	0.0
	20/5/94	0	0	0.7
	24/8/94	0	0	0.8
	25/8/94	0	0	2.0
	10/10/94	0	0	2.0
	3/4/95	16	+ve	0.0
	11/4/95	0	0	0.0
	12/6/95	0	0	3.0
	28/7/95	0	0	1.5
	14/01/98	0	0	0.6
	23/3/98	0	0	0.6
CBD	20/5 /94	0	0	0.0
	20/7/94	0	0	1.5
	7/11/94	9	0	0.0
Northrise	19/9/91	0	0	0.0
	27/7/92	0	0	0.0
	17/8/92	0	0	0.3
	14/3/93	18	+ve	0.0
	13/4/94	0	0	0.3
	10/10/94	0	0+	0.5
	3/4/95	18	0	0.0
Kansenshi	4/3/93	18	+ve	0
	13/4/94	0	0	0
	19/5/92	0	0	0.4
Kanini	19/5/92	0	0	0.4
	10/10/94	0	0	0.4
	28/7/95	0	0	0.2
CHifibu	19/5/92	0	0	0
	27/7/92	1	0	0
	13/4/94	0	0	0
Zambia Railways	19/5/92	0	0	0.6
	20/5/94	0	0	0.7
	10/10/94	0	0	0.6
Civic Centre	19/9/91	9	+ve	0
	19/5/92	2	+ve	0
	4/3/93	18	+ve	0
	24/8/94	0	0	0.5
Henry Makulu Hostels	20/5/94	18	+ve	0
	13/4/95	1	+ve	0
Pine Flats	3/4/95	18	+ve	0
	28/7/95	0	0	1.5
Light Industrial Area	17/8/92	0	0	0.3
	28/7/92	0	0	0.2
Twapia	10/4/94	0	0	0
	28/8/94	16	+ve	0
	7/11/94	0	0	0

+ve = *E. coli* detected

Appendix Vb: Concentration levels of Residual chlorine at Kafubu Water Works and its Distribution system in relation to Coliform organisms and *E. coli* per 100 mls.

Sampling point	Date	Total coliform organisms/ 100mls	E.coli / 100mls	Residual chlorine (ppm)
Kafubu Water Works	20/9/91	5	+ve	0
	10/2/92	18	+ve	0
	10/3/92	0	0	2.0
	26/1/93	0	0	1.0
	24/11/93	3	-ve	0.7
	31/8/94	0	0	1.6
	30/3/95	0	0	1.2
	16/6/95	0	0	1.5
	21/5/96	18	+ve	0
	18/6/96	0	0	0.4
	4/12/96	0	0	2.5
	10/1/97	9	+ve	0.4
	27/3/97	0	0	1.0
	14/7/97	9	+ve	0
	20/10/98	0	0	0
Kabushi	20/9/91	0	0	0.2
	10/2/92	18	+ve	0
	10/3/92	0	0	0.3
	26/1/93	0	0	0.1
	16/6/95	16	-ve	0.2
	11/9/95	9	-ve	0.2
	31/8/95	0	0	0.1
	16/11/95	2	-ve	0
Masala	20/9/91	5	+ve	0
	10/3/92	0	0	0.3
	16/6/95	0	0	0.3
	11/9/95	6	-ve	0.1
	15/11/95	0	0	0
	20/10/98	0	0	0.2
Mushili	10/2/92	18	+ve	0
	10/3/92	0	0	0.4
	31/8/95	18	-ve	0.1
Lubuto	20/9/91	18	+ve	0
	10/2/92	18	+ve	0
	15/11/95	0	0	0
	31/8/95	0	0	0.1
	10/3/92	0	0	0.6
	26/11/93	0	0	0.1
	16/6/95	18	-ve	0.2
	11/9/95	6	0	0.2
	20/10/98	0	0	0.2
Mine Masala	10/2/92	18	+ve	0
	20/01/93	0	0	0.1
Ndeke	10/3/92	0	0	0.2
	26/11/93	0	0	0.1
Itawa	20/10/98	0	0	0.2

+ve = *E. coli* detected

Appendix VIa: Relative efficiencies of sewage treatment plants operations on Total Suspended Sediments (Removal efficiency)

Date	New Kanini (%)	Old Kanini (%)	Lubuto (%)
30 May 1994	43.33	65.79	90.24
30 Jun 1994	43.40	66.67	91.65
29 Jul 1994	79.27	76.00	91.65
31 Aug 1994	44.74	81.71	52.00
30 Sept 1994	78.13	82.19	77.90
28 Oct 1994	79.49	84.01	68.00
30 Dec 1994	88.00	84.8	85.28
31 Jan 1995	82.35	91.75	82.13
28 Feb 1995	81.25	83.06	83.33
31 Mar 1995	78.34	82.83	91.06
Mean %	65.40	76.51	78.51

Appendix VIb: Treatment performance of various sewage works for Chlorides (Removal efficiency)

Date	New Kanini (%)	Old Kanini (%)	Lubuto (%)
30 May 1994	48.00	32.55	22.33
30 Jun 1994	36.81	32.04	43.71
29 Jul 1994	52.00	17.65	7.84
31 Aug 1994	6.25	41.76	48.03
30 Sept 1994	38.46	33.33	32.69
28 Oct 1994	50.00	23.45	19.05
30 Dec 1994	12.5	10.00	10.71
31 Jan 1995	11.77	27.00	16.66
28 Feb 1995	9.09	12.50	15.79
31 Mar 1995	43.48	30.77	6.66
30 Apr 1995	22.22	7.1	20.83
30 May 1995	76.00	16.66	13.65
Mean %	33.80	23.73	22.50

Appendix VIc: Treatment performance for various sewage works for Phosphates (Removal efficiency)

Date	New Kanini (%)	Old Kanini (%)	Lubuto (%)
30 May 1994	60.75	39.32	46.73
30 Jun 1994	68.00	37.5	58.33
29 Jul 1994	65.00	46.57	57.64
31 Aug 1994	65.67	4.89	19.40
30 Sept 1994	50.00	23.45	19.04
28 Oct 1994	55.45	12.5	57.54
30 Dec 1994	69.75	61.79	73.45
31 Jan 1995	73.30	33.04	37.97
28 Feb 1995	77.30	53.59	34.40
31 Mar 1995	67.70	47.25	25.00
30 Apr 1995	47.51	6.10	21.18
30 May 1995	47.51	6.10	21.18
Mean	63.63	33.27	39.05

Appendix VIId: Treatment performance (%) of various sewage works for Permanganate Value 4 hours (organic matter)

Date	New Kanini (%)	Old Kanini (%)	Lubuto (%)
30 May 1994	75.86	33.98	64.52
30 Jun 1994	15.39	1.80	72.48
29 Jul 1994	88.64	-2.5	91.16
31 Aug 1994	76.21	63.97	59.12
30 Sept 1994	84.75	55.32	151.09
28 Oct 1994	87.26	72.81	75.00
30 Dec 1994	74.89	55.00	53.75
31 Jan 1995	52.41	75.00	52.13
28 Feb 1995	60.00	73.54	77.44
31 Mar 1995	96.98	87.50	15.67
30 Apr 1995	83.45	78.40	66.85
30 May 1995	83.45	78.40	66.85
Mean	72.35	54.08	70.84

**Appendix VIIa: Physico-chemical and Bacteriological characteristics of effluents
From Zambezi paper Mills Limited into the Kafubu aquatic environment (1993-98)**

Parameter	Number of samples	Average
Temperature °c	10	26.90
pH units	12	6.90
Colour units	11	19.09 (up to 30)*
Conductivity (umhos/cm)	11	656 (up to 7493)*
TDS	10	813
TSS	11	32.36
Total Hardness	7	213.71
COD	11	35.14
Total Solids	10	779.80
Settleable matter	11	0.30
Calcium	9	79.73
Magnesium	8	21.88
Chloride	11	13.82
Turbidity units	13	12.08
Total Alkalinity	9	177.00
Residual chloride	2	Nil
Algae	11	Nil
Total Coliforms	11	Nil
Sulphates	3	75.00
Sulphites	2	9.05 *
Phosphorous	3	26.67 *
Ammonia	1	8.00
Nitrite	1	1.80
Nitrates	1	40.00
Do	1	5.00
Manganese	1	0.28
Lead	1	2.30*
Iron	1	nil
Sodium	1	60.00

Source: ECZ (unpublished)

* Above maximum permissible levels

Appendix VIIIb: Physico-chemical and Bacteriological characteristics of effluents from Swarp Spinning Mills into the Kafubu aquatic environment, (1993-98)

Parameter	Number of samples	Average Observed Value
Temperature ° c	6	27.65
pH units	16	9.85*
Colour units	14	21.87*
Conductivity µmhos/cm	10	1906.81
TSS	17	26.07
TDS	16	913.90
Total hardness	15	186.64
Total alkalinity	15	181.47
Calcium	12	84.00
Magnesium	3	45.67
Permanganate value 4hours	5	13.72
COD	6	12.14
Turbidity units	16	8.31
Chloride	15	17.60
Settleable matter	6	0.32
Iron	2	0.25
Zinc	2	0.03
Algae	16	nil
Total Coliforms	16	nil
Residual chlorine	6	nil

Source: ECZ unpublished).

Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour and conductivity.

Appendix VIIc: Physico-chemical and Bacteriological characteristics of effluents from Ndola Weaving Mills into the Kafubu aquatic environment (1993-98)

Parameters	Number of samples	Average Observed Value
Temperature ° c	9	37.47(up to 50)*
pH units	12	7.98
Colour units	8	70.00 *
Conductivity µmhos/cm	12	856
TSS	10	19.13 (up to 218)*
TDS	12	1659.64
Total Hardness	8	43.75
Total alkalinity	5	243.00
Magnesium	5	20.00
Turbidity units	12	20.45*
DO	1	5.00
COD	6	96.32*
BOD	1	51.60*
Permanganate Value 4 hours	1	1092.80*
Free ammonia	2	1.92
Chlorides	10	23.70
Phosphorous	3	1.75*
Sulphates	2	67.54
Sodium	6	255.00
Potassium	5	98.75
Sulphide	1	3.00*
Copper	5	Nil
Iron	4	0.15
Zinc	2	0.45
Lead	3	Nil
Manganese	1	0.05
Coliforms	5	Nil
Algae	5	Nil

Source: ECZ (unpublished).

Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour, turbidity and conductivity.

Appendix VIId: Physico-chemical and Bacteriological characteristics of Effluents from Lever Brothers Zambia Limited into the Kafubu aquatic environment (1993-98)

Parameter	Number of samples	Average Observed Value
Temperature ° c	4	36.00
Colour units	4	Clear
TSS	4	441.00*
Settleable Matter	1	0.70*
TDS	4	702.00
Conductivity µmhos/cm	1	1524.00
pH units	4	9.38*
DO	4	5.55
COD	3	813.5*
BOD	2	885.00*
Nitrates	2	47.28*
Nitrites	2	6.03*
Ammonia	1	47.25*
Organic Nitrogen	1	150.00*
Organic Matter	1	125.00
Cyanides	3	0.003
Phosphorous	3	17.34*
Sulphates	2	61.00
Sulphides	1	5.00*
Active Chlorides	1	0.01
Iron	1	5.00*
Florides	1	5.60*
Chromium	1	1.30*
Boron compounds	1	30.00*
Oils	1	10.00*
Total fatty matter	1	3724.00*

Source: ECZ (unpublished).

*Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour and conductivity.

Appendix VIle: Physico-chemical and Bacteriological characteristics of effluents from Colgate Palmolive Zambia Limited into the Kafubu aquatic environment (1993-98)

Parameter	Number of samples	Average Observed Value
Temperature ° c	1	30.00
pH units	3	9.30
Colour units	1	51.00*
Turbidity units	1	5.00
TSS	1	60.00
TDS	3	4140.00*
Conductivity µmhos/cm	1	2000.00
Total Hardness	1	2590.00
Phosphates	1	23.76
Chlorides	1	7.70
Sulphate	1	8.52
Sulphite	1	45.00*
Calcium	1	2599.00*
Ammonia	1	1.00
Manganese	1	1.02*
Iron	1	1.10
Copper	1	0.01
Lead	1	0.01
Zinc	1	0.08
Silica	1	18.00
Algae	2	nil
Coliforms	2	nil

Source: ECZ (unpublished).

*Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour and conductivity.

Appendix VIII: Physico-chemical and Bacteriological characteristics of effluents from Zamox into the Kafubu aquatic environment (1993-98)

Parameter	Number of samples	Average Observed Value
Temperature ° c	2	27.00
Colour units	3	>70.00*
Odour and taste	2	Positive
TSS	2	60.00
TDS	3	4140.00*
Conductivity umhos/cm	1	1800.00
pH units	3	9.93.00*
Sulphides	2	45.00*
Calcium	1	2599.00*
total hardness	1	2590.00*
Chlorides	1	7.20
Ammonia	1	1.00
Phosphate	1	23.76
Sulphate	1	8.52
permanganate Value 4 hours	1	nil
P/alkalinity	1	1755.00*
M/alkalinity	1	2650.00*
Oil	1	nil
Silica	1	18.00
Lead	1	0.01
Iron	1	1.10
Copper	1	0.01
Zinc	1	0.08

Source: ECZ (unpublished).

*Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour ,turbidity and conductivity.

Appendix VIIh: Physico-chemical characteristics of Effluents from Ndola Lime Mine Limited into the Kafubu Aquatic Environment (1993-98)

Parameter	Number of samples	Average Observed Value
Appearance	2	Clear
pH	2	7.62
Colour	2	5.00
Conductivity	2	295.00
TDS	2	196.60
TSS	2	nil
Total hardness	2	134.40
COD	2	0.08
Calcium	2	84.00
Magnesium	2	3.00
Chloride	2	1.90
Turbidity	2	5.00
Total alkalinity	2	135.00

Source : ECZ (unpublished).

* Above maximum permissible levels.

All parameters are shown in parts per million except for pH, colour, turbidity and conductivity.