ASSESSMENT OF PHYSICAL AND BIOCHEMICAL PARAMETERS OF POLLUTION IN FRESHWATER RESERVOIRS IN KERICHO TEA ESTATES, KENYA

BY

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DECLARATION

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

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To the glory of God the Almighty; for His amazing grace; and to my dear parents- **Mr. and Mrs. Andrea Akunga Nyamari** for their inspirational upbringing.

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LIST OF ACRONYMS

ANOVA-	Analysis of Variance.
APHA-	American Public Health Association
BOD-	Bio-chemical Oxygen Demand
Chll-a-	Chlorophyll-a
Cfu -	Colony forming units
DMRP-	Dissolved molybdate reactive phosphorus
DNA-	Deoxyribonucleic acid
DO-	Dissolved oxygen
EPA-	Environmental Protection Agency
FC-	Faecal Coliforms
GEMS-	Global Environmental Monitoring Systems
GOK-	Government of Kenya
H.E.P-	Hydro-Electric Power
$KgNha^{-1}a^{-1}$	Kilograms of Nitrogen per hectare per annum
$KgPha^{-1}a^{-1}$	Kilograms of Phosphorus per hectare per annum
KTDA-	Kenya Tea Development Agency
KTGA-	Kenya Tea Growers Association
LVEMP-	Lake Victoria Environmental Management Project
mgl^{-1}	Milligrams per litre
mgm^{-3}	Milligrams per cubic metre
MOWD-	Ministry of Water Development
N-	Nitrogen
NEMCA-	National Environmental Management and Coordination Act
NO_3^-	Nitrate
NPKs	Compound fertilizer containing Nitrogen, Phosphorus and Potassium
NPs-	Non-point source pollution
NRC-	National Resource center
OECD-	Organization for Economic Co-operation and Development.
P-	Phosphorus

PCBs-	Polychlorinated Biphenyls
PO_4^+	Orthophosphate (SRP)
RNA-	Ribonucleic acid
SRP-	Soluble Reactive Phosphorus
TC-	Total Coliforms
TN-	Total Nitrogen
TON-	Total Oxidized Nitrogen
TP-	Total Phosphorus
TSS-	Total Suspended Solids
TVC-	Total Viable Bacterial Counts
UNDP-	United Nations Development Programme
UNEP-	United Nations Environment Programme
UNESCO-	United Nations Educational, Scientific and Cultural Organization
USEPA-	United States Environmental Protection Agency
WHO-	World Health Organization
WMO-	World Meteorological Organization

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ABSTRACT

The physical, biological and biochemical characteristics in four small private man-made reservoirs in the central part of Kericho district, Kenya were studied between November 2001 and March 2002. The main aim of the study was to relate the land management in tea estates and water quality. This is important because the Kericho area forms a catchment for many rivers flowing to Lake Victoria.

Over the study period, forty depth integrated water samples were collected from each of the four dams. A total of 25 parameters were investigated over the study period to provide the baseline data for future reference in these water bodies. In the field, temperature, pH, electrical conductivity, and dissolved oxygen were determined at every site using a multiple electrochemistry analyzer meter while transparency was determined using a Secchi disc. During sampling, 3-litre water samples were collected for chlorophyll-a analyses while 250ml water samples were collected for both chemical and bacteriological quality assessment.

In the laboratory, the water samples were analyzed for heavy metals; cadmium, lead, copper, silver, iron, manganese, magnesium and zinc by spectroscopic methods. Water samples for total nitrogen and nitrates were digested by steam distillation method and measured calorimetrically, while the photometric method was used for orthophosphorus and total phosphorus determination. The presence of total coliforms and faecal coliforms were determined by the multiple tube fermentation techniques while plate count method was employed in the determination of total viable counts. Chlorophyll-**a** was extracted by methanol and measured spectrophotometrically. Total suspended solids were estimated by filtering 500ml sample using pre-weighed oven dried 0.45μm Millipore filter papers. For 250ml water, samples in biochemical oxygen demand (BOD_5) were incubated for five days and the remaining dissolved oxygen measured by the multiple electrochemistry analyzer meter above.

The overall mean measurements for temperature was 18.11^{0}C, Secchi depth 27.84cm, pH 6.72 units, electrical conductivity 39.95μS, percent dissolved oxygen 73.14%, BOD 28.55mg/l and suspended solid 126.97mg/l. It was observed that Kerenga dam recorded the highest mean levels in iron (6.379mg/l), magnesium (1.479mg/l), zinc (2.472mg/l), copper (0.065mg/l), nitrates (5.47mg/l), orthophosphates (0.017mg/l), total nitrogen (14.84), total phosphorus (0.098), chlorophyll-a levels (0.055mg/l) and BOD (31.15mg/l) while Jamji recorded highest mean levels in silver (0.191mg/l) and suspended solids (174mg/l). Sambret dam, which was our control reservoir, recorded the lowest levels of nutrients, chlorophyll-a and highest levels of manganese (1.172mg/l). Total coliform bacteria were more prevalent in Kerenga and Jamji; faecal coliforms 99MPN/100ml, total coliforms (349MPN/100ml) and total viable counts (4.6x10^{5}cfu/ml) followed by Sambret and Chagaik in that order.

The results show that the levels of metals (except manganese and iron) and nitrates are below the maximum permissible levels set by WHO in drinking water. However, as regards microbial analyses, the dams were observed to be highly polluted by faecal and total coliforms and therefore not safe for domestic purposes before treatment. In addition, three of the four dams were found to be highly eutrophic regardless of the criteria used for their classification. Agricultural run-offs, domestic effluents, geo-chemical sources, municipal and urban run-off as well as leaching of nutrients were some of the possible contamination sources to the reservoirs. It was therefore proposed that nutrient containment, especially phosphorus, be given special attention. For Kerenga dam, this might require corporate action between the Brooke Bond tea company and the Municipal council to develop stabilization ponds. There is need therefore for an extended study to model the water quality of these dams and to be able to recommend the appropriate treatment process that suits these water bodies.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

Water covers 71% of the earth's surface and constitutes a key component in all ecosystems. The economic value provided by aquatic ecosystems is estimated at three quarter of the total value of the biosphere making these habitats most important to human livelihood and welbeing (GIWA, 2003a). Sadly, these resources are exceedingly getting polluted from agriculture, industry, commercial, and other human activities (Abiya, 1996). There is an increasing awareness of non-point source pollution of freshwaters from agricultural chemicals through underground seepage and run-off (Kauppi, 1990; OECD, 1986). Intensive use of agrochemicals has been reported to lead to high nutrient concentrations in freshwater bodies (Ansa-Asare and Ansong, 1996), resulting in algal blooms in tropical freshwater bodies. In Kenya, increased use of agrochemicals for crop production has also been witnessed in many areas (GOK, 2000; Abiya, 1996). The intensive use of chemical fertilizers in Kericho tea estates is a case in point. Since the small private reservoirs in Kericho tea estates were constructed with the purpose of water storage for hydroelectric generation and domestic supply, runoff in the tea estates might brings high concentrations of nitrogen and phosphorous in these watercourses. This may contribute to cultural eutrophication and undesirable growth of aquatic plants and weeds (OECD, 1988). This reduces water quality due to the increased growth of algae and aquatic weeds in addition to oxygen shortages caused by the decomposition of organic substances.

The dramatic structural change that may result from nutrient loadings causes species differentiation and/or succession of aquatic plant communities (Kemp *et. al.,* 1983; Moss, 1988). However, the direction of change can vary depending on the nature and quantity of the nutrients as well as the original structure of the aquatic plants. Thus, in some cases, relatively small concentrations of nutrient enrichment may result in an increase in the bio-mass of submerged macrophytes (Brown, *et. al.,* 1988); whereas higher nutrient concentrations may result in the dominance of phytoplankton (Moss, 1980; Granelli and Solander, 1988), filamentous algae (Lapointe & O'Connell, 1989) or floating mats

(Hough *et. al.*, 1989) followed by a decline in submerged macrophytes. This study was designed to investigate the reservoirs' trophic level, heavy metal concentration as well as the bacteriological density in reservoirs with emphasis placed on the population dynamics of algae. Although these aspects are known in other reservoirs, no work had been done in the Kericho area. This study would help in identifying the likely causes of eutrophication, metal pollution and water-borne coliforms and thus contributing to the on-going Lake Victoria basin management and conservation campaign.

1.2 STATEMENT OF THE PROBLEM

Tea estates in Kericho use between 150-400kgNha^{-1}a^{-1} and 90-120 kgPha^{-1}a^{-1} (KTGA, 2000). These nutrients may find their way to watercourses in the estates through surface runoff, soil erosion and underground seepage thus resulting in changes of the physical, chemical and biological conditions of the water bodies. Significant ecological effects will occur on receiving water bodies especially reservoirs in the area due to the proliferation of algal blooms.

Most of the reservoirs in the district are shallow with little fluctuation in water levels (GOK, 1997). At the same time, the reservoirs in the study area provide a stable environment for colonization by submerged aquatic plants due to permanence of feeding streams. Such an environment may encourage growth of emergent weeds such as *Pragmites australis*, *Echinochloa* spp., *Polygonum* spp., *Typha* spp., *Cyperus* spp., *Eichhornia crassipes* and *Salvinia molesta* (Abiya, 1996), which cause considerable problems. Some of the most troublesome species may include: *Potamogeton pectinalus, P.crispus, P. nodosus* and *Ceratophyllum demersum (*Meybeck *et al*, 1998). Filamentous algae such as *Cladophora* can become associated with these weed beds and increase the resistance to the flow of water (Abiya, 1996). Emergent plants such as *Typha domingensis*, *Echinochloa stagnina* and *Pragmites* (Harper, 1992) can colonize the reservoir banks. This is because there will be species differentiation as the nutrient load increases or decreases. The diversity of the phytoplankton for example decreases with increase in nutrient load (Abiya, 1996). This may also leads to the emergence of dominant species such as those of the Cyanobacteria group.

The stimulation of algae blooms and other aquatic plants will in turn adversely affect water for the different uses. Some of the effects include water loss through plant evapotransipiration, deterioration of water quality, displacement of native species and the consequent loss of biodiversity in these reservoirs, public health risk, obstruction of channels and intake to hydroelectric plants and increased sedimentation with subsequent shortening of the useful life of these water bodies (Eric *et al.*, 1994; Meybeck *et al.*, 1998; William, 2000).

1.3 OBJECTIVES OF THE STUDY

The main objective of the study was to assess the physico-biochemical quality of reservoir water in selected tea estates in Kericho district with emphasis on nutrient loadings and the associated trophic level of these dams. The specific objectives of the study include to:

1) Determine the concentration of phosphorous and nitrogen in selected reservoirs in Kericho tea estates.

2) Evaluate the effect of different levels of nutrient loadings on the density of algal blooms in the selected reservoirs in the tea estates of Kericho district.

3) Assess the chemical suitability of the water in the selected reservoirs in Kericho tea estates for portability.

4) Estimate the density and/or source of bacterial contamination in the selected reservoirs within the tea estates in Kericho district.

1.4 JUSTIFICATION OF THE STUDY

The small private reservoirs in Kericho tea estates were constructed with the purpose of water storage for hydroelectric generation and domestic supply. The investigation of ecological, limnological, economical and social impacts associated with their construction is not documented. It follows that an E.I.A was no carried out before their construction. With the enactment of the Environmental Management and Coordination Act, 1999 (Wamukoya and Sifuna, 2000), all existing and future development activities in Kenya will need to be aligned to sustainable resource utilization. This research has therefore provided an opportunity of providing baseline limnological data in these reservoirs in relation to their physico-chemical and biological characteristics. The approach of comparative analysis adopted has provided a useful framework for indicating the present status or future developments in the tea farming and may form a database for modelling reservoir-predicting processes.

1.5 SIGNIFICANCE OF THE STUDY

Kericho district is endowed with many natural resources- both terrestrial and aquatic. In an endeavour to utilize the natural resources in the district catchment area, sustainable approaches need to be employed. The tea crop yield in the plantation estates is mainly determined by the economic decisions of the company management with little considerations of the effects upon the waters receiving runoff. Tea farming forms the backbone of the Kericho economy and immensely contributes the overall Kenyan economy and thus human well-being. Long-term catchment's management practices for control of diffuse sources nutrients in the drainage basin need to be developed and implemented. The study thus aimed at relating the land management systems in Kericho tea estates to water quality. This is important because the Kericho area forms a catchment for some rivers e.g Sondu and Nyando draining into Lake Victoria.

So far, information on how land-use of tea estates in Kericho district and associated fertilizer application affect the physico-chemical conditions of water bodies and flora that result had not been studied or documented. This lack of information makes prediction of the dynamics of microbial aspects in aquatic systems and possible negative impacts difficult. It has therefore become imperative to aim at identifying the various sources of contaminants, assess the quality of the reservoir water by quantifying the physico-chemical and microbial differences among the waters of the Kericho reservoirs in order to provide the scientific basis for finding appropriate remedies to the contamination problems that confront the reservoirs and their inherent impacts on the population. Biological monitoring of microbial densities in the aquatic environment of tea estate catchment area of Kericho district was thus used to indicate the ecological effect of changes in nutrient and other physico-chemical aspects. Thus, this study connected nutrient and physico-chemical characteristics of the study reservoirs to biological aspects.

1.6 STUDY AREA

1.6.1 Location

This study was conducted in Kericho district within the large tea estates owned by Brooke Bond (Fig 1.1). Kericho is one of the 18 districts of the Rift Valley Province, Kenya. It lies between longitude 35° 02' and 35° 40' east and between the equator and latitude 023' south. Uasin Gishu borders the district to the north, Baringo and Nandi to the northeast, Nakuru to the east, and Bomet to the south. It is also bordered to the southwest by Nyamira and Rachuonyo districts and to the west by Kisumu (GOK, 1997). It covers an area of about 2515km^2 85% of which is arable.

1.6.2 Topography and climate

The major part of the district exhibits undulating to rolling topography that gives way to flatter terrain in the south (Jaetzold and Schmidt, 1983). The district slopes to the west with altitudes ranging from 1500m to 2450m above the sea level and consequently rivers flow in that direction. Within the district, a hilly shelf is formed between the Mau escarpment and the lowlands of Kisumu district. To the northeast are found Tinderet hills and Mau escarpment and between them is the gently rolling land from the Londian division. The central part of the district rises eastwards towards 3000m above the sea level on the Mau ridge. The Kericho plateau forms the central part of the district and slopes gently from 2500m to about 1800m above the sea level (GOK, 1997).

The district has high altitude tropical climate with moderate temperatures ranging from 16°C to 24°C and total rainfall range of 1200mm-2200mm (GOK, 1997). Temperature variation in the district is primarily caused by altitude (Jaetzold and Schmidt, 1983). It receives conventional type of rainfall, which is influenced by altitude. Rainfall is well distributed except for the short dry season in January and part of February. Indeed there is no real break between short and long rains in the whole district (GOK, 1997). The first rains normally start end of February while second rains start indistinctively around end of

July (G.O.K, 1997). Low evaporation rates and high rainfall characterize the lower highland areas whereas high temperatures, high evaporation rates and low rainfall characterize the upper highland areas.

1.6.3 Geology and Soils

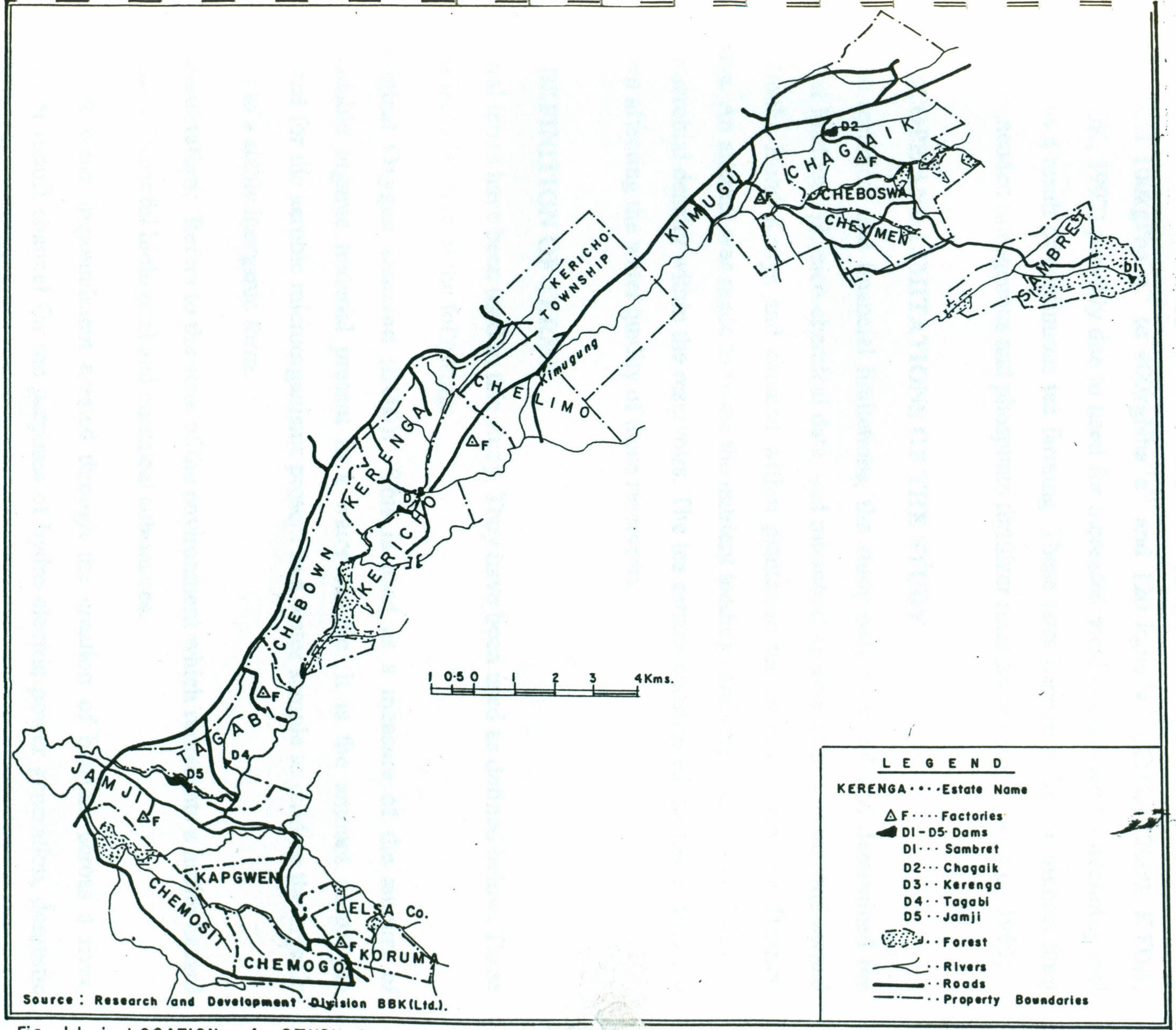
Intermediate and basic volcanic rocks (phonolites) underlie most of the area, while undifferentiated basement system rocks (mainly granite) outcrop in the south. The central part of the district, where all study dams were located, is occupied by volcanic footridge landscape. Here, soil units of moderate to high fertility are found (Jaetzold and Schmidt, 1983). Soils are developed on Tertiary basic igneous rocks (basalt, nepheline phonolites and basic tuffs included) (Jaetzold and Schmidt, 1983). Humic Nitisols and Ando- Humic Nitisols characterize the interfluves. These soils are associations of well-drained, extremely deep dark reddish brown friable clay, with humic topsoil. On the valley sides, the soils are partly lithic phase of the humic cambisols (Jaetzold and Schmidt, 1983).

1.6.4 Location of study dams

Kerenga dam is located in Kiptetan location, Belgut division in Kericho district. The dam was constructed in 1930's along river Kimugu, which has its source at Mau forest located to the east of the dam and is a tributary of river Sondu that drains into Lake victoria. The dam has a capacity of 132,000m^3 of water and drains an area of 6.6 hectares. It is 6m deep at the weir and 4m towards the upper end. Over the years, the dam has accumulated a silt load of about 45,000m^3 thus slowing down the water flow and causing the hydro-electric power plant output to drop at a rate of 3% fortnightly (Owiti, 2001a). Kerenga dam is surrounded by natural forest to the south; tea plantation to the northeast and a quarry, 0.45 hectares, to the northwest with Kerenga Engineering Department situated about 500m north of the dam (Fig 1.1). Apart from hydroelectric power generation, the dam provides water for domestic consumption, supplying Kerenga and Chebown estates as well the engineering department.

Situated about four kilometres downstream of Kerenga dam is Jamji dam. The dam was constructed in 1927 along river Kimugu, with a capacity of 106,000m^3 and drains an area of 5.4 hectares (Owiti, 2001b). It is 4m deep at the weir and has accumulated silt for over a period of 70years. The dam provides water for domestic consumption to Jamji estate residents, Jamji tea factory, lower Tagabi estate as well as Kitoi estate. The riparian reserve is well vegetated with some sections overgrown by natural grass mainly used for grazing purposes. Downstream the river passes near Premier Dairy and then converges to river Itare.

Chagaik dam is located about 5km east of Kericho town as one drives to Nakuru town (Fig 1.1). This dam is situated around 500metres away from the main road in the Chagaik tea estate. It drains an area of about 6.6ha and provides water for domestic and industrial use. Chagaik factory is situated about 1km south of the dam on a topography facing the dam. During storms, pollutants may be washed to the dam through surface runoff. A single stream (Kimugu river) that seems to originate in East Mau Forest feeds the dam. This river also feeds Kerenga and Jamji dams downstream. Sambret dam is situated 4km east of Tea Research Foundation of Kenya and about 12km southeast of Kericho town, the dam is located in Mau forest. It covers an approximate area of 0.25ha and receives its water through forest overland flow and a small stream.



Source : Research and Development Division BBK(Ltd.).

Fig. 1·1 : LOCATION of STUDY DAMS RELATIVE TO BROOKE BOND TEA ESTATES

1.6.5 PLANTATION TEA ESTATES

Large tea estates in Kericho district cover approximately 15,559.61 hectares of land (KTGA, 2000). NPK (20:10:10) fertilizer is used by tea farmers (GOK, 1997). Large-scale tea estates fertilizer application has, over the years, increased from the rate of 150kg $Nha^{-1}a^{-1}$and $100kgPha^{-1}a^{-1}$ to $400kgNha^{-1}a^{-1}$ and 120 $kgha^{-1}a^{-1}$ (KTGA, 2000; KTDA, 2000; GOK, 1997) possibly due to need for increased yield occasioned by declining soil fertility as a result of continuous tea farming. These rates happen to be the highest limit of recommended nitrogenous and phosphate fertilizer rates for tea crops (Wilson, 1999).

1.7 SCOPE AND LIMITATIONS OF THE STUDY

Due to technical and financial limitations, the study only assessed and determined the nutrient loadings, physico-chemical data, and microbial aspects of four reservoirs owned by Brooke Bond Kenya and situated within plantation tea estates in Kericho District, Kenya. An attempt was made to relate the nutrient loadings and physico-chemical data to the microbial density within the reservoirs. The tea estates constituted the major land use system affecting the water quality of these reservoirs.

1.8 DEFINITION OF TERMS

Several terms have been used in this study. They have been used as defined below. These terms include some of the following:

Biological Oxygen Demand (BOD): This is used as a measure of the amount of degradable organic material present in a water sample. It is the amount of oxygen required for the aerobic microorganisms present in a water sample to oxidize the organic matter to a stable inorganic form.

Contamination: Refers to the state of the environment which represents a health hazard because of harmful biological and chemical substances.

Dam: A water impoundment created through the creation of barriers across a river, stream or runoff channel for the purposes of hydro-electric power generation, domestic water supply or irrigation.

Eutrophication: It is a condition in a water body due to abundant growth of aquatic plants, particularly algae, as a result of nutrient enrichment in the water.

Depth-integrated water sample: Water sample collected from the reservoir sampling station by vertically sending the sampler to the bottom of the reservoir and as it is being lifted, the sampler fills through to the surface.

Water Quality: The physical, chemical and biological condition of water related to beneficial use.

Water Pollution: The discharge of organisms or substances into water, which limits its use as a natural resource.

Reservoir: A water impoundment established through the construction of dams, barriers or excavations across a river, stream or runoff channels. Their construction involves the super-imposition of a riverine ecosystem into a terrestrial ecosystem.

CHAPTER TWO: LITERATURE REVIEW

2.0 INTRODUCTION

This chapter deals with the literature associated with surface water pollution under the following sub-headings: water quality deterioration, eutrophication, nutrient losses from catchment areas focusing on nitrogen and phosphorus, effect of physico-chemical water quality changes on the aquatic ecology, heavy metal concentration and microbial aspects of water bodies.

2.1 WATER QUALITY DETERIORATION IN CATCHMENTS

2.2.1 Global water quality deterioration

It is estimated that 450 billion cubic metres of wastewater currently enter world water bodies each year through point pollution sources (Shiklomanov, 1997). Non-point source pollution (NPs), which brings in pollutants of diverse constituents and from diverse sources, has, over the years, provided a challenge to researchers and planners.

In the United States for example, 50-70 % of impaired or threatened surface waters are affected by non-point source (NPs) pollution from agricultural activities (USEPA, 1991). In the state of Wisconsin, some form of NPs pollution degrades 40 % of streams and 95 % of lakes, reservoirs and ponds. Clarke *et.al.,* (1985) estimated that NPs pollutants primarily from agriculture account for 73 % of Biochemical oxygen demand (BOD), 83% of bacterial loads and 92% of the suspended sediments in the waterways in the United States (USEPA, 1991). Moreover, EPA (1987) estimated that 57% of the lake area, 64% of the river miles and 19% of the estuarine areas are adversely affected by discharge from agricultural lands.

In Britain, plantation forest has been perceived as a widespread example of a catchment's land-use effect on river ecology (Mills, 1986). Plantation involving predominantly softwoods have caused river acidification through the increased scavenging of air pollutants, altered hydrology, enhanced erosion and sedimentation; alteration in stream habitat structure and alteration in energy inputs from heat, light and tree products.

In Africa, aquatic habitat destruction hotspots are scattered over the continent. In Morocco for example, some fresh water sources contain more than the recommended nitrate levels necessitating a research programme to identify the origin of the nitrate and to assess the rate of increase (Kronvang *et al.*, 1995). Elsewhere, lake Victoria ecosystem is in a precarious situation as a result of many contributing factors including eutrophication, invasive species and overexploitation (GIWA, 2003b). Recent research findings under the Industrial and Municipal Waste Management Component of the LVEMP reveals that of the estimated total pollution loads being discharged into lake Victoria after passing through wetlands, river systems and other natural purification systems, urban centers account for 77% and fishing villages account for 15% while industries account for 8% (LVEMP, 2003). One factory, the Uganda Breweries was found to account for about 80% of BOD load, 85% of COD load, 93% of the suspended solid load, 60% of the nitrogen load and 82% of the phosphorus load discharged by factories into the lake (LVEMP, 2003).

In Kenya, a study by Kithia and Musingi (1995) revealed that water in most Nairobi - river sub catchments was highly polluted. Major pollutants identified include heavy metals, pesticides, organic materials and suspended solids. Occurrence of the solids was attributed to land use activities up-stream mainly agricultural, industrial, commercial activities and urban run-off. The study however, did not separate and quantify the exact contribution of each land-use type. On river Gatharaini Ndaruga (1998) states that the river is highly polluted with major pollutants particularly fertilizers, pesticides and particulate suspended solids resulting from the intensive agricultural land use. An increase of electrical conductivity and total dissolved solids was associated with discharges of wastewater from coffee factories into the river. Ngetich (1996), reported nitrite concentrations range of 0.05-0.3mg/l, Nitrate-Nitrogen (NO_3-N) concentration range of 12-25mg/l while that of phosphate phosphorus measured as orthophosphate was in the range of less than 0.01mgl^{-1}- 0.3 mgl^{-1} in river Kipsonoi in Sotik district.

2.2.2 Water quality deterioration in Lake Victoria basin

Lake Victoria is the world's second largest freshwater lake and the largest in Africa with a surface area of 68,800 Km^2. It has a volume of 2,760Km^3 and an average depth of 40m (Okungu *et al., 2003)*. The major rivers flowing into the lake from Kenya include Nzoia, Sio, Yala, Kibos, Nyando, Sondu-Miriu, Kuja, Migori, Riaria and Mawa and drain a catchment area of approximately 47,700Km^2 (Otieno, 1995). The lake is used as a source of food, energy, drinking and irrigation water, and transport and as a repository for human, agricultural and industrial waste (LVEMP, 2003; LVEMP, 2002b; Leo; 2002; Okungu and Opango, 2003).

The problem of water quality deterioration in lake Victoria basin has been known for a long time but has not been adequately addressed. Urban development activities, industrial waste, discharge of nutrients and growth of population have caused changes in the lake ecosystem (LVEMP, 1999; Leo; 2002). Massive blooms of algae have developed, water borne diseases have increased in frequency and water hyacinth started choking important waterways and landings as well as water supply intakes (LVEMP, 1995). Three case studies of 3 rivers: Nzoia, Nyando and Kerio, all in western region of Kenya (MOWD *et.al.,* 1976) reported the chemical characteristics of the water shortly before the establishment of factories along their courses. River Nzoia drains into Lake Victoria and carries effluents discharged from Pan Paper Mills in Webuye and Mumias Sugar factory. River Nyando also drains into lake Victoria and carries effluent from sugar factories of Muhoroni and Chemelil (LVEMP, 2002a; LVEMP, 2002b; LVEMP, 2001; Machiwa, 2003).

Studies in the L. Victoria Catchment Rivers have revealed that human activities are the major causes of pollution in these rivers principally through agricultural and urban runoff, industrial effluents and domestic sewage (LVEMP, 2003; Otieno, 1995; LVEMP, 1995; Okungu *et al,* 2003). These studies have shown that nutrient influx into lake Victoria has had significant impact in the physical chemistry and ecology of the lake Victoria as a whole. However, the amounts of nitrogen and phosphorus concentrations do not seem to follow a similar pattern (Okungu *et al,* 2003). Loadings of nutrients and suspended solids have generally been related to individual river discharge as well as the kind of human activities along its course. For example, Ogendi (2003) has reported that total river discharge in the watersheds of the lake basin is influenced by the catchment size as the rainfall distribution in the catchment seems to be uniform and these rivers come from the highland areas with similar pattern of rainfall.

Nutrient concentrations in the rivers draining Kisii highlands are high indicating more degradation of the environment ((LVEMP, 1995). In this area the predominant crop is maize so the soil remains bare before next crops are planted and grow to adequately cover the soil. Meybeck (1998) has observed that total nitrogen from tributaries draining areas predominantly cultivated with wheat and maize are higher than for perennial crops like tea and sugar. Total suspended solids from these rivers are also high. Most of the nitrogen is possibly from the farmlands and may be in the form of nitrates washed with the sediments into the river. Clarke *et al* (2000) showed that annual nitrate levels in rivers closely follow annual levels of fertilizer application within the catchment. Ngetich (1996), studying river Kipsonoi in Sotik district – a tributary of river Sondu which drains into lake Victoria- also records nitrite concentrations range of 0.05-0.3mg/l, Nitrate-Nitrogen (NO_3-N) concentration range of 12-25mg/l while that of phosphate phosphorus measured as orthophosphate was in the range of less than 0.01mgl^{-1}- 0.3 mgl^{-1}.

Lamb (1999) reported that some of the fertilizers applied to agricultural lands is transported into streams by run off and sometimes represent up to about 80% of the total fertilizer applied. The loss of phosphates by leaching from agricultural lands is very small, so that the input to rivers is largely by soil erosion. Slope and rainfall are the dominant factors that largely explain the variation in soil erosion. Okungu *et al* (2003) have shown that Sio river contributes very low suspended sediment loads compared to the other rivers even during its high flow possibly as a result of its passing through areas with clay soil that normally do not release a lot of suspended solids. Catchments of *Awach Kibuon*, *Awach Tende* seem to have undergone the worst destruction and have a lot of soil lass into the rivers. Catchments of Nzoia, Kuja and Nyando have also suffered degradation. River Nyando has, over the years, given the highest phosphorus value possibly due to high effluent loads, both domestic and industrial as well as from agricultural runoff (LVEMP, 2003b).

From the foregoing literature it is clear that quantitative studies on the contribution of tea farming systems in Kericho district to nutrient enrichment of surface waters draining this catchment into lake Victoria together with associated algal proliferation have either not been undertaken or are not documented. This study was therefore designed to assess the contribution of tea plantation estates to the nutrient enrichment and associated algal proliferation of reservoirs in the catchment area. This will help in providing useful information on to what extent has tea farming, as an economic activity, contributed to the nutrient load in lake Victoria.

2.3 EUTROPHICATION

Eutrophication is a natural stage in a lake's life as it is gradually filled in with sediments eroded from its catchment and with organic matter from its own metabolism. Starting with the ultra-oligotrophic stage that has low productivity, aging then proceeds through oligotrophic to eutrophic and on to hypertrophic (Ellis, 1989). The divisions between these categories can best be defined in terms of the average annual mean concentrations of the phosphorous in a water reservoir and/or the seasonal average mean of the concentration of chlorophyll-a (Kalff, 1983; GIWA, 2003b; Table 2.1).

Table 2.1 Concentration of TP and chlorophyll-a in different lakes

Reservoir type	Annual mean level of TP in mgM^{-3}	Annual mean concentration chlorophyll-a in mgM^{-3}
Oligotrophic	4.5	1.0
Eutrophic	48	8
Hypertrophic	150	22

Source: Ellis, (1989)

The Global International Water Assessment (GIWA) experts have assessed eutrophication and suspended solids as severe in many world regions (GIWA, 2003b).

Eutrophication is largely caused by the inflow of excess nutrients (principally phosphorus and nitrogen) from land-based activities. Agriculture, deforestation and untreated municipal sewage are some of the main sources of these nutrients (Machiwa, 2003).

The supply of nutrients is an important factor in determining the species and quantity of plant material in lakes (reservoirs), which in-turn control the oxygen concentrations and the animal species. The growth of algae in reservoirs is limited by the availability of one or more key nutrients; an increase in the supply of these nutrients by human activity is likely to change many of the characteristics of the reservoir (William, 2000). The direct biological effects occur when organisms, usually phytoplankton algae, and other aquatic plants are released from nutrient limited growth (Harper, 1992; Lamb, 1999). The usual environmental resources that limit production are light and nutrient supply. Whichever falls below the minimum level to sustain growth will regulate the population of the species. This is often called the law of the minimum and is an important ecological concept (Hutchinson, 1973).

Although phytoplankton, attached algae and macrophytes require 20 or more elements for synthesis of protoplasm, the growth rate of a given species population at a particular time will be either unresponsive or responsive to the addition of nutrients (William, 2000). Growth rate increases and may be such that the population then comes into competition for one or more other resources with neighboring species (Mwaura, *et al.,* 2002). One consequence of this may be the replacement of lesser competitor by another, which is more efficient in the use of the resources (Abiya, 1996). Thus with increase in nutrient supply (phosphorus and nitrogen or any that may be limiting) to the reservoir, algal biomass may change (Abiya, 1996). Both epiphytic (attached) and plankton algae take up these nutrients. This results in an increase in mean biomass productivity (Lamb, 1999) and changes in their seasonal patterns. Species change occurs, leading for example in the plankton to fewer species overall and dominance by species of *Diatoms*, Cyanobacteria and unicellular green algae (Brook, 1964; GIWA, 2003a). Submerged macrophyte may also increase in biomass (Harper, 1986) particularly in calcareous water but more often macrophyte biomass is reduced with increased enrichment as a result of competition for light with phytoplankton or epiphytes (Jupp and Spence 1977; Phillips, *et al* 1978). There is also a decline in diversity as species intolerant of low light, higher dissolved solids or competition disappear (Seddon, 1972; Spence 1964).

The sequence of changes occurring in reservoirs (lakes), subject to cultural eutrophication, is both a direct and indirect consequence of an increase in concentration of nutrients flowing through each component of the pond ecosystem (Harper, 1992). While phosphorus is widely considered to be the dominant limiting nutrient for reservoirs in temperate latitudes (Welch, 1992), available information suggests that nitrogen limitations is more important at tropical latitudes (Talling and Lamoalle 1998). Although it has not been demonstrated, tropical inland waters lose a much larger proportion of their total inorganic nitrogen to denitrification than do temperate reservoirs (William, 2000).

Under natural conditions, the ability of a lake to sustain primary production is determined by the recycling mechanisms under nutrient limiting conditions (William, 2000). Such effects can be intensified by human activities such as industrial development, discharge of sewerage from urban centres and the use of agro-chemicals (fertilizers, pesticides and herbicides) in the agricultural sector. The increase in concentration of plant nutrients primarily phosphorous and nitrogen leads to enhanced plant growth (both algal and macrophyte) that result in visible algal blooms, floating algae and submerged macrophyte agglomerations (Meybeck, 1998; Harper, 1992).

Intensification of agricultural land use results in greater nutrient losses (Harper, 1992). For example an increased use of chemical fertilisers in the former Soviet Union has been observed to lead to increased supply of phosphorous and nitrogen to standing water bodies thus causing a higher total biomass turnover in the water bodies (Meybeck *et al.*, 1998). The precise quantities lost depended on various factors; chief amongst which are soil types, soil drainage, rainfall, nature and extent of vegetation cover, and nature and amount of fertilizer (Talling and Lemoalle, 1998) As such, nutrient run-off and sedimentation as a result of intensification of agricultural land use and settlements may be associated with tea estates in Kericho district. The precise concentrations of quantities lost to the reservoirs through runoff, soil erosion and underground seepage are not known. This makes the prediction of their effects on the reservoir water ecology difficult. This study therefore sought to assess the phosphorus and nitrogen concentration in the study reservoirs with a view of determining their influence on algal densities of the waters.

2.4 NITROGEN LOSSES FROM CATCHMENT AREAS

2.4.1 Forms of nitrogen in the soil

Nitrogen in the soil occurs as organic and inorganic N with 95% or more of total N in surface soils present as organic N (Brady, 1992). The inorganic forms of soil N include ammonium (NH_4^+), Nitrite (NO_2^-), Nitrate (NO_3^-), nitrous oxide (N_2O), Nitric oxide (NO) and elemental N (N_2), which is inert except for its utilization by Rhizobia and other N-fixing microorganisms (Tisdale *et al.*, 1993). Organic soil N occurs as proteins, amino acids, amino sugars and other complex N-compounds. The proportion of total N in these various fractions is as follows: bound amino acids 20%-40%; amino sugars 5%-10% and purine and pyrimidine derivatives, 1% or less. Very little is known about the chemical nature of the 50% or so of the organic N not found in these fractions (Tisdale *et al.*, 1993).

Plants absorb N as both NH_4^+ and NO_3^- whose availability to plants depend largely on the amount applied as N fertilizers and that mineralized from organic soil N. The amounts released from organic N and to some extent the soil after the addition of NH_4^+ or NO_3^- depend on many factors affecting mineralization and immobilization of N and loss from the soil (Brady, 1992; Tisdale *et al.*, 1993). In well-aerated warm soils, microbial activity will rapidly oxidize NH_4^+ to NO_3^-. Consequently, soil conditions and time interval between fertilizer application and the first precipitation event are important in the determining of N converted to NH_4^+ and NO_3^-. This means that forms of N transported in surface run-off is soluble and once in contact with moist surface is rapidly hydrolyzed to NH_4^+ which can be chemisorbed by micaceous clay minerals present in many soils (Ellis, 1989).

2.4.2 Forms of nitrogen in water

Nitrogen can exist in three distinct forms in natural waters: as combined organic nitrogen, as the ammoniacal nitrogen or as total oxidized nitrogen (Ellis, 1989). The proportion of the different forms of nitrogen in a water body is determined by the forms introduced and the balance between assimilation (plant uptake), mineralization (bacterial decomposition of organic matter with ammonia being a by product), nitrification (fungal and bacterial oxidation of ammonia to nitrates), denitrification (anaerobic biological reduction of nitrates into reduced gaseous forms) and nitrogen fixation (gaseous nitrogen reduction to ammonia by bacteria and algae).

Organic nitrogen exist either as an integral part of protein molecules, essential in all living organisms or in the partial breakdown products of these molecules (Tisdale *et al.*, 1993). Total oxidized nitrogen (TON) exists in two forms; nitrite (NO_2^-) and nitrate (NO_3^-) (Brady, 1992). It is unusual to find nitrite (NO_2^-) in appreciable concentrations in water since oxidation of the ammonia to nitrate is the rate limiting in bacteriological oxidation of ammonia, (Mannion, 1995). High concentrations of nitrate together with phosphates in water bodies lead to the proliferation of algal blooms (Ansa-Ansare and Ansong, 1999).

2.4.3 Sources of nitrogen in water bodies

Nitrification is the major source of nitrate in the environment and the most common nitrifying bacteria in fresh water are *Nitrosomonas* and *Nitrosococcos*, which are ammonia oxidizers while *Nitrobacter,* among others, is a nitrite oxidizer (Brady, 1992; Tisdale *et al.*, 1993). Erosion and surface run-off are sources of nitrogen from terrestrial to aquatic ecosystems. Although soil erosion and run-off provide a natural source of nitrogen to fresh waters, their effect is enhanced by agricultural activity and in particular the use of chemical fertilizers (Parsons *et al.*, 1995). Fertilizers were estimated to be the largest single anthropogenic input of nitrogen into freshwaters of USA (NRC, 1978) and also accounted for the largest source of fixed nitrogen to the environment (Clarke *et al.*, 1985). The freshwater inputs originate from fertilizer nitrogen that is not taken up by crops as indicated in the nitrogen budget for a typical cultivated field (Table 2.2).

Table 2.2 **The annual Nitrogen budget for a typical cultivated field**

Nitrogen inputs		**Nitrogen outputs**	
Source	Nitrogen (kg/ha/a)	Output	Nitrogen (kg/ha/a)
Rain			
a. Ammonium	8	Plant production	111
b. Nitrate	8	Nitrate lost to groundwater	80
Fertilisers			
a. Ammonium	40	Denitrification	30
b. Ammonia	50	Evaporation of ammonia	38
c. Nitrate	40	Combustion	5
Manure	108		

Source: Adapted from Meybeck *et al* (1990)

The formation of inorganic forms of nitrogen from the breakdown of organic materials is *mainly* influenced by bacterial action (Brady, 1992; Tisdale *et al.*, 1993). The amount of nitrogen that is leached out of the soil and into the water is related to the amount of rainfall in the catchment area of the water body (Parsons *et al.*, 1995). The nutrient concentration in the soil is therefore severely reduced by flushing out into rivers and lakes (reservoirs) at the onset of the rains. The management implications for nutrient limitations dominated by nitrogen are more complex than one might expect (William, 2000). A high likelihood of nitrogen limitations for tropical reservoirs suggest that human disposal or mobilization of inorganic nitrogen is more perilous in the tropics than it is at the temperate latitudes (Talling and Lemoalle, 1998). Because tropical lakes are especially prone to eutrophication and loss of hypolimnetic oxygen, nutrient containment has an even higher priority than it does at temperate latitudes (William, 2000).

The increases in nitrogen fertilizer applied in Kericho district tea estates is expected to be reflected in the mean concentration of NO_3^- in water bodies within the district as was observed for the Lough Neagh catchment area in Northern Ireland (Smith, 1977). Growth in the use of nitrogen fertilizers has increased two to threefold in the study area since the development of the plantations (KTGA, 2000). This increase is expected to lead in turn to an increase in nitrate leaching from the tea plantations to water bodies. Whether the availability of the leached nitrogen in surfaceand/or ground waters of Kericho is a cause of ecological and environmental health concern is not known hence the study.

2.4.4 Nitrogen loss into water bodies

Nitrogen entering aquatic systems arise from a variety of sources that include point and nonpoint source pollution, biological fixation of gaseous nitrogen and the deposition of nitrogen oxides and ammonium salts (Kotut, 1998). In general, deposition under natural conditions has a limited impact on the nitrogen levels. Several studies have reported an increased transport of N in surface run-off following fertilizer N applications in cropped watersheds (Schuman *et al.*, 1973; Klausner *et al.*, 1974; Kudeyarov, *et al.*, 1995; Parson *et al.*, 1995). The magnitude of non-point source of nitrogen loadings has been shown to vary considerably depending on the proportion of agricultural land in the catchment and on run-off, soil type and geology as well as type of farming system (Taylor *et al.*, 1986; Neill, 1989; Dillon and Kirschener 1975; Rast and Lee, 1983).

Modern agricultural practices, particularly the use of mineral, commercial and organic animal fertilisers, have strongly been linked with elevated nutrient loads in the aquatic environment (Neill 1989; Wright *et al.*, 1991). Studies carried out in Denmark indicated that agriculture was responsible for 65-83% of yearly riverine nitrogen transport to Danish coastal waters (Kronvang *et al.*, 1995). However, agriculture has been reported to be responsible for only about 50% of riverine nitrogen loading in the former West Germany (Anon, 1983) and about 25 % in Sweden (Lofgrens and Olsson, 1990).

Nitrogen loss increases with the intensity in land use and to artificial additions of fertilizers more so than phosphorous losses, because of the greater mobility of soluble nitrogen compound (Mannion, 1995). In lysimeter studies at Rothamstead, with fallow soil and no fertilizer additions, the equivalent of $23 kgNha^{-1}a^{-1}$ was lost; lysimeters in Aberdeen, northeast Scotland with around 250 $kgNha^{-1}a^{-1}$ added in fertilizer lost up to 52 $kgNha^{-1}a^{-1}$ (Cooke and Williams, 1973). Some lysimeter studies have recorded average annual losses of up to 200kgNha $^{-1}$a $^{-1}$ on unfertilized sandstone soils, rising to 300kgNha $^{-1}$a $^{-1}$ after fertilization (Anon, 1983).

Organic N has also been associated with large losses of N (Kemppainen, 1995). Parsons (1995) has also suggested that holding other factors constant, an addition of one kilogram of nitrogenous fertilizers applied from commercial inorganic fertilizers is associated with 0.16kg of nitrogen losses. Assuming this result to be true, then the application of between 150-400kg Nha $^{-1}$a $^{-1}$ in Kericho tea estates will potentially lead to losses of between 24-64kg Nha $^{-1}$a $^{-1}$ some of which may end up in the water bodies (under Parson's conditions). Nevertheles, these can be regarded as upper extremes, since tea crops are perennial crops with the soil surface covered by vegetation for most of the year. Also plant root uptake reduces nutrient losses.

A large research programme in the United Kingdom carried out between 1975 and the late 80s on sources, movement and fate of N in freshwater reports nitrate content tending to rise in many streams and arable lands (Anon, 1983). In Morocco some fresh water sources contain more than the recommended nitrate levels and a research programme instituted to identify the origin of the nitrate and to assess the rate of increase (Kronvang *et al.*, 1995). In Kenya such work has not been done and information regarding the same is lacking. This study therefore intends estimate the loss of nitrogen from tea crops to surface water bodies.

2.5 PHOSPHORUS LOSSES TO WATER BODIES

2.5.1 Forms of phosphorus in the soil

Most inorganic phosphorus compounds in soils fall into three groups: those containing calcium, iron and aluminium (Brady, 1992). The nature and extent of inorganic P fixation or retention reactions depend most importantly on soil pH (Tisdale *et al.*, 1993). In acid soils, inorganic P precipitates as Fe/Al-P secondary minerals and/or is adsorbed to surfaces of Fe/Al oxides and clay minerals (Brady, 1992; Tisdale *et al.*, 1993). In neutral and calcareous soils, inorganic P precipitate as calcium-P secondary minerals and/or is absorbed to surfaces of clay minerals and calcium carbonate ($CACO_3$) (Brady, 1992;

Tisdale *et al.*, 1993). Table 2.3 shows common P minerals found in acid, neutral and calcareous soils.

Table 2.3 Phosphorus minerals in acid, neutral and calcareous soils

Compound	Formula
Acid Soils	
1) Variscite	$AlPO_4 . 2H_20$
2) Strengite	$FePO_4 . 2H_2O$
Neutral and Calcareous Soils	
1) Dicalcium phosphate diaphyhidrate (DCPD)	$CaHPO_4 .2H_2O$
2) Dicalcium phosphate (DCP)	$CaHPO_4$
3) Octacalcium phosphate (OCP)	$Ca_4H(PO_4)_3 .2.5H_2O$
4) B-tricalcium phosphate (BTCP)	$Ca_3H(PO_4)_2$
5) Hydroxyapatite (HA)	$Ca_5(PO_4)_3OH$
6) Flourapatite (FA)	$Ca_5(PO_4)_3F$

Source: Tisdale *et al*, (1993)

Organic P represents about 50% of the total P in soils and typically varies between 20% and 50% in most soils (Brady, 1992; Tisdale *et al.*, 1993). The quantity of organic P in soils generally increases with increasing organic carbon and/or nitrogen but many organic P compounds in soils have not been characterized (Brady, 1992). Most organic P compounds are esters of orthophosphatic acid ($H_2PO_4^-$) and have been identified primarily as inositol phosphates, phospholipids and nucleic acids (Tisdale *et al.*, 1993).

Inositol phosphates are the most abundant of the known organic phosphorus compounds making up to 10-50% of the total (Brady 1992; Tisdale *et al.*, 1993). They are thought to be of microbial origin. Inositol phosphates tend to be quite stable in acid and alkaline conditions and interact with higher molecular weight humic compounds (Brady 1992; Tisdale *et al.*, 1993). These properties may account for their relative abundance in soils.

Nucleic acid, exemplified by ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) are phosphorus-containing compounds in soils (Tisdale *et al.*, 1993). These are known to contain more than 1.5% soil organic phosphorus (Brady, 1992). The third known form of organic phosphorus is phospholipids- fat-like compound of microbial origin. They make up only about 0.2-2.5% of the organic phosphorus (Brady 1992; Tisdale *et al.*, 1993).

2.5.2 Forms of phosphorus in water

Relatively high concentrations of phosphates may be in surface waters either in solution or as sediment bound as a result of discharge of wastewater effluents, sewage effluents and agricultural run-off. P is essential to life and in many situations it may be the growth-limiting element in the waters. Phosphorus in surface water will overwhelmingly be present either as orthophosphates and/or polyphosphates (Ellis, 1989). Orthophosphoric acid is tri-basic, so as a result, three types of salt can be available: the di-hydrogen, the mono-hydrogen, and the normal phosphate. Common examples of these are di-hydrogen sodium phosphate (NaH_2PO_4), mono-hydrogen sodium phosphate (Na_2HPO_4) and sodium phosphate (Na_3PO_4) (Harper, 1986). Polyphosphates exist as hexametaphosphates ($Na_3(PO_3)$), tripolyphosphates ($Na_5P_3O_{10}$), and Pyrophosphate ($Na_4P_2O_7$). All polyphosphates in water will revert in time to orthophosphates (Ellis, 1989) a change, which is accelerated by heat, particularly near the boiling point, and by acidic conditions.

There is general agreement that phosphorus (P) is the key nutrient limiting or accelerating eutrophication (Lee 1973; Schindler, 1977) particularly in temperate freshwater bodies. This is because phosphorus is often present in natural water in concentrations that result from man's activities other than natural sources (Kalff, 1983). The forms and availability of P in surface run-off is complicated by the complex chemistry and surface reactions of P (Meybeck *et al.*, 1998). The dissolved P fraction most often reported is that which reacts with ammonium molybdate and potassium antimonyl tartarate in an acid medium. This fraction has been termed orthophosphate soluble reactive P (SRP) and dissolved molybdate reactive P (DMRP) (Ellis, 1989).

Sediments contain organic and inorganic P, the latter being normally associated with iron, aluminium or calcium compounds. Sediment P is not immediately available as DMPRP levels are depleted. Li *et al.*, (1972) and Wildung and Schmidt (1973), have reported that surface bound absorbed iron, aluminium and calcium P are the most chemically mobile and are most likely to play an important part in sediment P available to algae. Huettl *et al.* (1979) has estimated that 20% to 40% of sediment inorganic P is potentially available. The exact availability depends on a number of interactions between biological and physico-chemical processes occurring in the sediment water system (Li *et al.*, 1972). Sawyer (1942) after studying several Wisconsin lakes found that concentrations exceeding 0.01 mg/l of soluble P (DMRP) caused excessive weed growth. O'Shaughnesty *et al.*, (1973) who estimated limiting nutrients in natural streams in Pennyslivania reported similar findings. Studies carried out in Denmark indicated that agriculture was responsible for 10-36% of yearly riverine total phosphate transport to Danish coastal waters (Kronvang *et al.*, 1995).

2.5.3 Phosphorus loss into water bodies

Most soil bound P is attached to soil particles and run-off from arable lands contains high concentrations of these soil particles. Albert *et al.* (1978), in a 12-year study, has illustrated that although loadings of P are very high DMRP is low over an arable land. The research reported loadings of 0.17 and 1.76 $kgha^{-1}$ of solution DMRP and soil particle bound P respectively from a 30 hectare conventionally tilled watershed. Thus the greatest potential biological impact from these run-offs arises from surface soil particle bound P rather than DMRP (Albert *et al.*, 1978).

Studies have suggested that organic coatings of phosphate fertilizers may modify the sorption properties of the mineral particles causing P mobilization (Clarke *et al.*, 2000). However Phosphorus losses from intensely farmed crops remain comparatively low unless there is soil erosion or water logging. A mean loss calculated for arable soils in Netherlands was 250g $Pha^{-1}a^{-1}$ (Kohlenbrander, 1972) whilst lysimetrer losses in the U.K ranged between 70 to 250g $Pha^{-1}a^{-1}$ (Cooke and Williams, 1973). In some catchments in Missouri USA, annual losses recorded were up to 1.9$kgPha^{-1}$ of which 1.8

kgPha $^{-1}$ was particulate, associated with sediment erosion, and only the remaining 100g being soluble phosphate (Clarke *et al.*, 2000).

Change of slope causes relatively more phosphorous to be lost than nitrogen because it increases particulate run-off. A slope change from 8° to 20° increased phosphorous losses by 360% but only doubled nitrogen losses (Goldman and Horne, 1983). Erosion on steep uncultivated land or exposed arable land has been estimated to result to topsoil losses containing as much as 6-12kgPha^{-1}a^{-1} and in extreme cases of wind erosion up to 150kg Pha $^{-1}$a $^{-1}$ and ten times as much nitrogen (Cooke and Williams, 1970).

Losses of phosphorous are seasonal, depending upon rainfall patterns and the cycle of crop planting and harvesting. Alberts *et al.* (1978) showed that out of 1.9kgP lost annually from a catchment, 1.3kgP losses occurred during the period of fertilizing. Studies, which have focused upon the nutrient losses from monoculture farming systems, are less common than studies of whole catchments under mixed agriculture. Nevertheless, the pattern of mixed agriculture catchment loss revealed by measurements at the point of exit of the catchment is broadly similar to those revealed by the single crop studies. A catchment of mixed pasture with 71% grassland and 29% arable lost 200g Pha $^{-1}$a $^{-1}$ (Smith, 1974; Holden, 1975). The tea scenario on Brooke Bond Kenya farms has adopted conservation tillage by leaving prunings *in situ* as well as the permanent tea canopy cover. Rumkens *et al.* (1973) compared five contoured tillage practices and reported significantly less sediment bound P losses than from conventional ploughing.

These studies are important if sustainable agricultural practices have to be maintained. The development and sustainability of tea farming in Kericho and Kenya in general will need to assess how much P is lost into the water bodies from the farmlands. However, such assessments require that the baseline P concentration in the reservoirs are known. This study was therefore an endeavour to determine the baseline P concentrations from which future assessment can build.

2.6 PHYSICO-CHEMICAL ASPECTS OF RESERVOIR WATERS

2.6.1 Colour and total suspended solids (TSS)

Suspended solids are the undissolved fine particles in suspension due to water movement (Harper, 1992). They usually include the coarser particles that settle on calm waters as well as those that remain in suspension (Ellis, 1989). They may either be organic or inorganic and may result from erosion, waste discharge or algal blooms (US Water Resource Research, 1973). Increase in suspended solids comes about as a result of discharge of organic and inorganic enrichment of water and also from discharge of suspended materials such as silt from agricultural land (Ryan, 1991).

Total suspended solids cause a reduction in light penetration thereby suppressing primary production by algae and macrophytes (Quinn *et al.*, 1992). This in turn affects the aquatic invertebrates that depend directly or indirectly on plants for food. These invertebrate populations are therefore suppressed or eliminated in severe conditions (Meybeck *et al.*, 1998).

2.6.2 Temperature

Water bodies undergo temperature variations along with normal climatic fluctuations. Lakes and reservoirs may exhibit vertical stratification of temperatures within the water column (UNESCO, 1992). The temperature of surface water may normally range from 0°C to 30°C, with minima occurring during wet periods and maxima in dry periods (William, 2000). Ecological effect of increased temperatures on aquatic biota communities is complex. An increase in temperature alters the physical environment in terms of both reductions in density of water and in oxygen concentrations (Masons, 1994). Warming also tends to increase water turbidity, macrophyte growth and algal bloom (UNESCO, 1992).

Most biochemical reactions within a cell are temperature dependent, showing an exponential increase with temperature up to a maximum, which varies for each reaction, usually between 25°C to 40°C (Harper, 1986). Maximal photosynthetic rates for the whole phytoplankton communities show temperature dependence over a seasonal time course particularly in temperate waters (Harper, 1992). Temperature may also have a more far-reaching effect on photosynthesis and growth and thus affecting the outcome of competition between species (Ngetich, 1996).

It has been known for many years that phytoplankton growth in most water reservoirs and lakes follow a broadly predictable pattern. Tillman *et al.* (1986) found that diatoms dominated cultures at lower temperatures if phosphorus but not silica was limiting, green algae dominated at higher temperatures with moderate or low N: P and Si: P ratios, whilst Cyanobacteria came to dominate at the highest temperatures (over 24°C) and at low N: P ratios. Metabolic processes that are dependent on temperature tend to be steadier and of a higher rate in the upper mixed layers of tropical reservoirs (Talling and Lemoalle, 1998). The temperature of the epilimnion (upper mixed layer) in a tropical reservoir is only as low as the seasonal minimum air temperature. Such high temperatures sustain high rates of microbial metabolism. Consequently, microbes will cause rapid inorganic nutrient recycling and regeneration in the upper zones of the tropical reservoir. Hence, nutrients are likely to be regenerated rapidly and completely and oxygen is removed rapidly (William, 2000).

2.6.3 pH

The pH is a measure of the concentration of hydrogen ions of a solution at a given temperature (Nemerow, 1991). The pH indicates the acidity or alkalinity of water (Meybeck *et al.*, 1998). In most natural waters the pH is principally controlled by the balance between carbon dioxide, carbon and bicarbonate ions and is slightly alkaline (pH>7) (Eric *et al.*, 1994). Evidence for species succession changes with pH has been presented (King 1970; Shapiro 1973). This is because, pH plays a central role in aquatic chemistry and thus affects uptake of nutrients in ways not fully understood. For example, high pH decreases the solubility of phosphorus (Harper, 1992). However, at high pH the upper 5cm sediment P may become soluble due to ligand exchange mechanism (Stauffer and Armstrong 1986). Increase in acidity causes a reduction of numbers of several phytoplankton algae especially the green algae i.e *Chlorophyceae* (Mulholland *et al.*, 1986). Acidification also leads to a marked decrease in the number of invertebrate species in water bodies (Fryer, 1987).

2.6.4 Dissolved oxygen

Three main processes use dissolved oxygen in aquatic habitats: microbial decomposition of dead organisms, respiration of living organisms and the chemical oxidation of sediments (William, 2000). Throughout the growing season, any unconsumed biomass dies and sinks so that decay of accumulated debris can deplete the dissolved oxygen of bottom waters. Large numbers of fishes that require colder waters in the bottom of the reservoir cannot live without sufficient dissolved oxygen (Ellis, 1989). Summer kills of cold-water fishes are typical of reservoirs that have received excessive nutrients from mismanagement of the reservoirs' drainage area. If littoral scavengers (such as crayfish or crabs) do not consume the dead fish they are washed up on beaches or sink to the bottom waters and lead to further deoxygenation (Gleick, 1993)

Warm tropical waters are susceptible to oxygen depletion due to reduced solubility in warm waters coupled with higher rates of microbial metabolism (Hutchinson, 1973). In contrast, the low solubility of oxygen in warm waters and higher productivity of phytoplankton in tropical waters would be expected to favour oxygen super saturation (Townsend, 1999). Large fluctuations in oxygen concentrations are probably more common in tropical water bodies than in their temperate counterpart. Reservoir oxygen dynamics vary with their trophic state. Phytoplankton concentrations tend to increase with eutrophy of a water body, which in-turn reflects the potential for the photosynthetic production of oxygen. On the other hand the concentration of detritus (heterotrophy) is an indication of oxygen consumption (Meybeck *et al.*, 1998).

Oxygen in the tropical waters is critical for their protection and management. Three factors work against the retention of oxygen in the deep waters of tropical reservoirs: the long duration of stratification, poor ability of water to hold oxygen at high temperatures and higher rates of microbial metabolism at higher temperatures (William, 2000). Together these three factors magnify the influence of any organic enrichment of waters.

Therefore undesirable effects associated with anoxia caused by eutrophication or direct organic enrichment of waters will be more serious and more quickly realized in tropical water bodies (Townsend, 1999).

2.6.5 Heavy metal concentration

Heavy metals belong to a group of elements whose hydrogeochemical cycles have greatly been accelerated by man. Anthropogenic emissions to the atmosphere of metals such as lead (Pb), zinc (Zn), cadmium (Cd), mercury (Hg), and copper (Cu) are one to three orders of magnitude higher than natural fluxes (Schindler, 1991). Similarly, direct anthropogenic inputs into the hydrosphere by waste disposal or by corrosion of zinc coated tubings have increased. As a consequence these elements are expected to become increasingly accumulated in natural reservoirs.

The sources of heavy metals in surface water may be diverse although generally associated with industrial discharges. As suggested by Agg and Zabel (1987) 75% of all lead entering rivers does so from diffuse sources, these being particularly road run-offs, aerial deposition, and leachate from dump sewage sludge. The toxicity of various compounds in a reservoir will be strongly affected by the quality of the water, especially by such factors as dissolved oxygen concentration, water hardness, the temperature and the pH (Ellis, 1989). On the whole toxicity normally increases with decreasing dissolved oxygen and with decreasing pH and declines with increasing hardness. The toxicity of zinc, copper and cadmium are all increased by decreasing water hardness and by reduced levels of dissolved oxygen (Alabaster and Lloyd, 1980).

Decontamination of sites polluted by heavy metals is often difficult and expensive. For example, once the sediment of a reservoir has been contaminated by mercury, even without further additions, it might take two to three decades for the system to recover as the heavy metal is continually recycled through different trophic levels and back into the sediment (Welch, 1980).

2.7 BIO- INDICATORS OF POLLUTION IN RESERVOIRS

The number of free-living aerobic heterotrophic bacteria in freshwater environments is directly proportionate to the degree of organic pollution (Kumar, 1992). Bacteriological quality of water has traditionally been assessed by measuring the levels of heterotrophic bacteria (HT), total coliforms and faecal coliforms and/or *Escherichia coli* (Meybeck *et al.*, 1998). The growth of microorganisms from extraneous sources in aquatic systems mainly depends on the amount of available nutrients. Besides, the factors involved in the survival of bacteria in aquatic systems are temperature, light, bacterial consumers, and various chemical and physicochemical factors (Kumar, 1992). The principle risk is the presence of pathogenic and non-pathogenic bacteria in faeces, which cause enteric diseases.

Pathogenic microorganisms present in surface waters vary both in variety and numbers depending on the general state of health of the community, the geographical region and the extent of any sewage treatment available. The pathogenic bacteria may include the genera *Vibrio, Leptospira, Brucella, Mycobacterium, Salmonella* and *Shigella* (Ellis, 1989). The three usual indicator bacteria are the fecal coliforms the fecal streptococci and *Clostridium perfringens* (Feachem *et al.*, 1983; Agg *et al.*, 1978). Excremental pollution of freshwater mostly is derived from discharged sewage. In Kericho tea estate reservoirs, this could come from Kericho urban stormwater runoff and/or runoff from agricultural lands (including settlements).

The coliforms belong to the large family Enterobacteriaceae, which includes pathogenic bacteria such as the typhoid bacillus (*Salmonella typhii), Escherichia coli* and the dysentery bacilli (*Shigella* spp.) and includes non-coliform bacteria. Others include *Enterococci* and *Aeromonad.* The Enterobacteriaceae are facultative anaerobes, Gram-negative, non-spore forming, bile tolerant rods capable of fermenting lactose with the production of both acid and gas within 48h at 37°C (Agg *et al.*, 1978). The presence of bacterial indicators of faecal pollution in surface waters provides useful information concerning the degree of pollution by both human and animal feaces and gives a strong indication of the public health hazard associated with such waters (Ellis, 1989). *E. coli* is generally regarded as the *sine qua non* of faecal pollution and there is no doubt its presence in reservoir water in tropical waters is confirmation of faecal pollution (Ampofo, 1997). In UK, waters known to be affected by nearby sewerage discharge, faecal coliform counts of 0 and 10000 $100ml^{-1}$ were obtained (Rollins and Colwell, 1986). It is however recognised that there can be considerable variation in counts caused by weather conditions and other factors.

The importance of the presence of of faecal indicator organisms is that they imply the possible presence of pathogens. Faecally excreted organisms are not natural inhabitants of freshwater bodies and are thus subject to environmental stress. Factors such as temperature, pressure, oxygen, pH, sunlight, predation, the effect of toxins and competition by other organisms for nutrients combine to result in their decay (Ogbondeminu *et al.*, 1994). Experimental studies on the survival of faecal indicator organisms and pathogens have shown that the effect of light on microbial decay in water is important with the survival of *E. coli* being about half that of faecal *Streptococci* and very much shorter than *Salmonella typhii* and *S. anatum* (Rollins and Colwell, 1986). However, the survival of *E.coli* was similar to that of *Shigella sonnei* (Dadswell, 1993). The presence of *E. coli* in water samples may therefore be an indication of recent pollution.

Microbes in freshwater indicative of faecal or sewage origin have received much attention in environmental health related research. These include coliforms, *Pseudomonas aeruginosa, Bifidobacteria, Enterovirus, Rotaviruses, Coliphages* and *Bacteriodes* and certain yeasts some of which are also pathogens (Dadswell, 1993). In Kenya, disease outbreaks have occurred due to the consumption of untreated or poorly treated drinking water. This has been so because information on the bacterial status of surface water is rarely considered. Since the hygiene status of a surface water source is a major public health priority especially in developing countries, the incidence and occurrence of indicator organisms and pathogenic *E. coli* need to be determined hence the study.

CHAPTER THREE: MATERIALS AND METHODS

3.0 INTRODUCTION

In this chapter, the methods used in data collection are discussed under the following subheadings: Criterion for reservoir selection, sampling techniques, chemical and microbial analysis of the water samples, and data analysis procedures. In the chemical water analysis, attention is given to physico-chemical parameters and nutrient loadings while microbial analysis focuses on total viable bacterial counts, total coliforms, faecal coliforms, and chlorophyll-a analyses.

3.1 CRITERIA FOR RESERVOIR SELECTION

A reconnaissance survey was carried out to determine the total number of reservoirs within the study area. Tea plantation farms were the major land use type thought to influence the water quality as defined by nutrient load that causes eutrophication. However, housing units, municipal wastes and industrial effluents do contribute nutrient loads to the reservoirs although their contribution is thought to be relatively small. Fieldwork was undertaken at four private reservoirs for five consecutive months starting from November 2001 to March 2002. The main criteria for selection were the nature of the watershade landscape, land cover and land utilization (Mwaura, et al, 2002). The reservoirs include Sambret, Chagaik, Kerenga and Jamji dams, whose location have been described elsewhere (section 1.6). Chagaik, Kerenga and Jamji dams are fed by Kimugu River that drains Kapkorech Tea Estate, Chagaik Tea Estate, Kimugu Tea Estate, Kericho town, Kericho Tea Estate, Kerenga Tea Estate, Chebown Tea Estate, and part of Jamji Tea Estate.

For each reservoir, sampling stations (points) were located along transect lines (Kalff, 1983) established in the dams. Depth integrated samples were collected between 0800 and 1100hrs in sterile 250-ml sampling bottles. This is because during this time chemical changes of water are minimal (Nemerow, 1991). The samples were preserved by using concentrated nitric acid and placed in ice chest cooler boxes (GEMS, 1992) and transported to the laboratory for analysis using standard methods as outlined in the commonly recommended manuals (APHA, 1985; AOAC, 1984).

3.2 SAMPLING TECHNIQUES

The water sampling strategy was based on longitudinal, heterogeneous, biophysical zonation common to most reservoirs. This strategy minimizes the clustering effect of simple random sampling. This involved fixed area multi-transect random area-sampling technique (Tarus, 1990; Tundisi, 1993; Mwaura *et al.,* 2002). Preliminary sampling of water samples at different depths in the reservoirs was undertaken to establish if stratification did occur. The parameters investigated at this stage were temperature, dissolved oxygen, electrical conductivity, nutrients and chlorophyll-**a**. The temperature probes of a reversed thermometer were dipped into the reservoirs at different depths to test for thermal stratification in the reservoirs. The preliminary results showed that the reservoirs mixed daily and no thermal stratification existed and the decision of using integrated depth samples was subsequently taken.

The study involved monthly sampling at each station for five months (GEMS, 1992). Periods of high stream discharge and low stream discharge were considered so as to reflect the dilution and/or runoff effect (Harper, 1992). Field measurement of other physical-chemical parameters was conducted (dissolved oxygen, pH, conductivity, and temperature).Water chemistry (heavy metals, nitrogen and phosphorus) and bacteriological quality (total viable counts, total coliforms and faecal coliforms) were tested at the same time as the chlorophyll-**a** analysis (GEMS, 1992).

3.3 CHEMICAL ANALYSIS OF THE WATER SAMPLES

3.3.1 Calibration and washing of laboratory equipments

Field equipments used in the study were a reversed thermometer for recording depth temperatures, a Jenway multiple electrochemical analyzer meter (Model 3420-UK) was used to measure pH, dissolved oxygen, electrical conductivity and surface temperature. For pH measurements, instrument calibration entailed the use of commercially prepared standard solutions with pH values of 4.00, 7.00 and 8.5 units. The dissolved oxygen meter was calibrated using the Azide modification of the Winkler method as specified in APHA (1985). For conductivity, the manufacturer's specifications were used.

Laboratory instruments mainly used were the SP9 series atomic absorption spectrophotometer (AAS) by Pye Unicam Ltd Cambridge England (Model: Philips, 1982), PERKIN ELMER UV/VIS spectrophotometer (Model: Lambda 3B) and the Kjedhal distillation system for nitrogen analysis. Six standard solutions of analytical grade reagents with different concentrations of the various metals were prepared with an inclusion of a blank. These were then used to standardize the AAS. Phosphorus standards were also prepared and were used for analysis to enable the plotting of calibration curves from which concentrations of samples were read. The chemical analyses for all the parameters were replicated twice to guard against errors. Table 3.1 below shows the instrumental operational conditions of the AAS equipment.

Table 3.1 AAS Instrumental conditions

Operating Parameters	Cd	Cu	Pb	Mn	Mg	Fe	Zn	Ag
Wavelength (nm)	228.8	324.7	217.0	279.5	285.2	248.3	313.0	328.1
Slit width (nm)	0.2	0.2	0.3	0.2	0.4	0.2	0.2	0.2
Lamp current (mA)	3.0	5.0	4.0	5.0	4	15	4.0	4
Flame	Air/ Acetylene							
Sensitivity (ppm)	0.02	0.04	0.015	0.04	0.003	0.06	0.01	0.03
Detection limit (ppm)	0.015	0.005	0.02	0.005	0.2	0.1	0.003	0.2

3.3.2 Dissolved Oxygen and Biochemical Oxygen Demand

Samples were collected in narrow-mouthed Biochemical Oxygen Demand (BOD_5) bottles that have beveled glass stoppers to avoid entrapment of air in the samples (GEMS, 1992). Two millitres of Manganese sulphate were added into the collected water to arrest any dissolved oxygen in the water. Two identical samples of the water so far sampled were placed in 250-ml BOD polythene bottles. The dissolved oxygen concentration of one was measured immediately the samples arrived in the laboratory while the other was placed in an incubator at 20°C for five days in the dark (APHA, 1985). At the end of the five-day period, the second bottle was removed from the incubator and its remaining DO concentration measured. The 5-day BOD of the sample was the difference between the two measurements of DO. For measurement, an electrochemical analyzer meter etched to read at an accuracy of 0.001 was used (Ellis, 1989).

3.3.3 pH measurements

This was measured in the field using a battery Jenway 3420 multiple electrochemical analyzer meter. An electrode at the end of a long chord was dipped into the reservoir and the pH then read (GEMS, 1992).

3.3.4 Electrical conductivity (EC)

Electrical conductivity of reservoir water was measured in the field using a Jenway 3420 multiple electrochemical analyzer meter etched to read with a resolution of 0.001 at the 200 microsiemens (µs) range (GEMS, 1992).

3.3.5 Temperature

Determination of temperature was at the field using mercury filled Celsius thermometer etched to read with a resolution of at least 0.1°C (APHA, 1985).

3.3.6 Total suspended solids

The determination of total suspended solids was done using ultra cellulose membrane filter papers (millipore-0.45µm) in a Buckner funnel, a filter flask and a filler pump to estimate the total suspended matter (Choubey, 1994). Two qualitative filter papers were oven dried at 121^0C for 10 minutes and pre-weighed, and 500ml of untreated water sample shaken vigorously and filtered through. The papers were then carefully oven dried at 121^0C for 10 minutes and re-weighed. The increase gave the total suspended solids in 500ml of the sample water and average values were calculated. This was done for each station samples and then expressed as concentrations in mgl^{-1}.

3.3.7 Transparency

The Secchi disc was found to be suitable for measuring the water clarity. This is an aluminium disc of 20cm diameter with additional iron pallets attached to make it heavy and steady in the water column during measurements. The disc was painted black and white at alternate quadrants (Choubey, 1994). The Secchi disc was used to measure the extinction depth (the depth at which the markings on the secchi disc become indistinct or invisible in water). The average of two readings for the depth at which the disc disappears during descending and reappears during lifting was adopted (Tarus, 1990). Secchi depth observations were made in all the sampling sites.

3.3.8 Heavy metal analysis

Samples were digested according to procedures described by Kartz and Jenniss, (1983). A hundred millitres of the acidified water samples were placed in 250 ml beakers and 3ml redistilled concentrated nitric acid added. This was evaporated to near dryness. An additional 3ml redistilled concentrated nitric acid was added and the beakers covered with a watch glass. The contents were heated gently to complete digestion after which 2ml of 1:1v/v hydrochloric acid was added followed by further heating to dissolve the insoluble material (AOAC, 1984). The Atomic Absorption Spectrophotometer (AAS) instrument was used to measure the concentrations of the samples. The metals analyzed were, zinc (Zn), copper (Cu), manganese (Mn), magnesium (Mg), lead (Pb), cadmium (Cd), iron (Fe) and silver (Ag).

3.3.9 Phosphates

The forms of phosphorus determined were orthophosphate phosphorus and total phosphorus using the photometric method through the ascorbic acid reduction procedures. For orthophosphate phosphorus determination, filtration of the samples was first carried out with the aid of pre-washed glass fiber filter papers (GF/C) with a diameter of 4.5mm. For total phosphorus determination all forms of phosphorus in unfiltered samples were first oxidized to orthophosphate phosphorus. This was achieved through autoclaving a 50ml water sample at 140°C, 15-pound pressure (psi) for forty minutes in the presence of ammonium persulphate oxidizing agent (APHA, 1985). The concentration of P was measured using the PERKIN ELMER UV/VIS spectrophotometer (Model: Lambda 3B) at 880 wavelength (AOAC, 1984).

3.3.10 Total Nitrogen

Samples were collected in 250ml polythene bottles that had been rinsed with distilled water and chromic acid (GEMS, 1992). The samples were transported at 4°C and were preserved by the addition of 2ml of concentrated H_2SO_4 per litre. These samples were analyzed within 24hrs of sampling to avoid conversion of organic nitrogen to ammonia (GEMS, 1992). NO_3^- and NO_2^- was reduced to NH_3 by Devarda's alloy under strongly alkaline conditions and then determined as NH_3. Then Ammonia was determined calorimetrically as described by APHA (1985). This fraction formed the inorganic form of nitrogen.

Total organic nitrogen was determined as NH_3 in an oxidation mixture of 200ml H_2SO_4 added cautiously with stirring to a solution of 1g Ag_2SO_4 in 100ml $K_2Cr_2O_7$. The digest was partially neutralized with half 10M NaOH (Golterman *et al.*, 1978). The mixture was then transferred to the distillation apparatus and then neutralized completely with NaOH. NH_3 was distilled off and then determined as described by AOAC (1984).

3.4 MICROBIAL ANALYSIS OF WATER SAMPLES

3.4.1 Sample collection and preparation

Sampling bottles were sterilized overnight in an oven at 170°C while closed and wrapped in aluminium foils. On the day of sample collection, the bottles were carried aseptically while closed and still wrapped to the sampling site. The sampling bottles remained closed until the time they were being filled (APHA, 1985). Eight samples were collected from each dam. The bacteriological examination of the samples was started as soon as the samples arrived at the laboratory. These samples were held at 10°C and delay in examination was limited to 30 hours.

3.4.2 Screening for heterotrophic bacteria

Standard plate count method was used for the quantification of heterotrophic bacteria. Water samples were analyzed for heterotrophic bacteria using total viable counts on tryptone glucose yeast agar in duplicates (APHA, 1985). Aseptic procedures were followed. Samples were thoroughly mixed by a rota-mixer and diluted to ensure the recovery of between 30 and 300 colonies per plate. The inocula were incubated at 35±0.5°C for 48±3hrs after which all colonies on the plates were counted manually using a Quebec colony counter (APHA, 1985).

3.4.3 Screening for total coliforms

The analysis of water for the presence of total coliforms was carried out using the multiple-tube fermentation technique and results of the examination of replicate tubes and dilutions made in terms of the Most Probable Number (MPN). This was done in two steps: the presumptive and the confirmed tests. Three batches of five tubes in each batch were inoculated with the water samples (APHA, 1985). In the presumptive test, a three series of five-tube set each containing 10ml, 1ml and 0.1ml portions of sample were inoculated with lauryl tryptose broth that was initially steam sterilized in an autoclave at 121° C for 15 seconds. Pure lauryl tryptose broth and distilled deionized water were sterilized in the same way and used as control samples. The inoculated tubes were then placed in an incubator at 37° C for 48±3 hours.

After the 24±3 hour period, the inoculated tubes were removed and checked for gas production. All tubes showing gas production after 24±3 hour period were transferred to brilliant green lactose bile broth by streaking and incubated for 48±3 hours at 37° C (APHA, 1985). Those without gas in the first 24±3 hour period were returned until the end of 48±3 hours when those with gas were transferred to brilliant green lactose bile broth by streaking and incubated for 48±3 hours at 37° C. If no gas was produced at the end of 48±3 hours, the samples were assumed to have shown a negative presumptive test.

Confirmatory test constituted the transfer of all positive presumptive test tubes to brilliant green lactose bile broth and incubated for 48±3hours at 37° C. The presence of gas production within the 48±3hour period constituted a positive confirmatory test while absence of gas within this period was indicative of absence of total coliform group of bacteria. For total coliform density estimates the following equation was used to calculate the MPN index per 100ml (APHA, 1985).

$$\text{MPN/100ml} = \frac{\text{Number of positive tubes x100}}{\sqrt{\text{ml sample (-ve tubes) x ml sample (all tubes)}}}$$

3.4.4 Screening for faecal coliforms

The test for faecal coliforms was conducted simultaneously with the test for total coliforms at the presumptive stage. Sterile loop transfers were made from all positive presumptive tubes from the total coliform MPN test to tryptose lactose bile broth (EC broth) and incubated at 45±0.2°C for 24±2hours (APHA, 1985). Gas production in a fermentation tube within 24hrs or less is considered a positive reaction. The estimate numbers for faecal coliforms present in 100ml were read from a tabulated probability table using corresponding results of various combinations of positive and negative reactions from each of the three batches.

3.4.5 Screening for *Escherichia coli (E.coli)*

Careful streaking (to ensure discrete colonies) of one or more Eosin Methlene Blue plates from each tube of Tryptose lactose bile broth showing gas (APHA, 1985) was done. The plates were then incubated at 37°C for 24±2hours. Colonies with a metallic sheen on the Eosin Methlene Blue (EMB) agar developed. Gram staining further yielded gram-negative rods confirming the presence of *E.coli*.

3.4.6 Chlorophyll-a

Samples for this parameter were collected in 2-litre plastic bottle water samplers (GEMS, 1992). At the laboratory, samples were filtered using ultra cellulose membrane filter papers (millipore-0.45μm) in a Buckner funnel, a filter flask and a filler pump (Choubey, 1994). The chlorophyll-a analyzed was extracted with methanol and then measured spectrophotometrically (Perkin Elmer UV/VIS spectrophotometer- Model: Lambda 3B) at 663, 665 and 750 nm as outlined in the GEMS (1992) and Golterman (1978). For calculation purposes the corrected 663a and 665b absorbencies were employed using the following equations:

$$\text{Chlorophyll } \mathbf{a} \text{ mg/m}^3 = \frac{26.73\ (663a - 665b)\ (Ve)}{(Vs)\ (l)}$$

$$\text{Phaeophytin } \mathbf{a} \text{ mg/l m}^3 = \frac{26.73\ (1.7(665b) - 663a)\ (Ve)}{(Vs)\ (l)}$$

Where, Ve =Volume of methanol extract in litres

Vs =Volume of water sample, m^3

L =Path length of cuvette, cm (GEMS, 1992).

3.5 DATA ANALYSIS

Data were subjected to the Ms-Excel spreadsheet and SPSS statistical package tools. Mean values were determined for each reservoir per month and the test of spread measured by way of variance, range and standard deviation. For determination of significant differences between reservoirs during the sampling period, t-test and one-way ANOVA were used to compare means, while correlation coefficients were performed to establish relationships of significance between variables. The test of significance was done using the multiple stepwise linear regression analysis procedure following a correlation analysis.

CHAPTER FOUR: RESULTS AND DISCUSSION

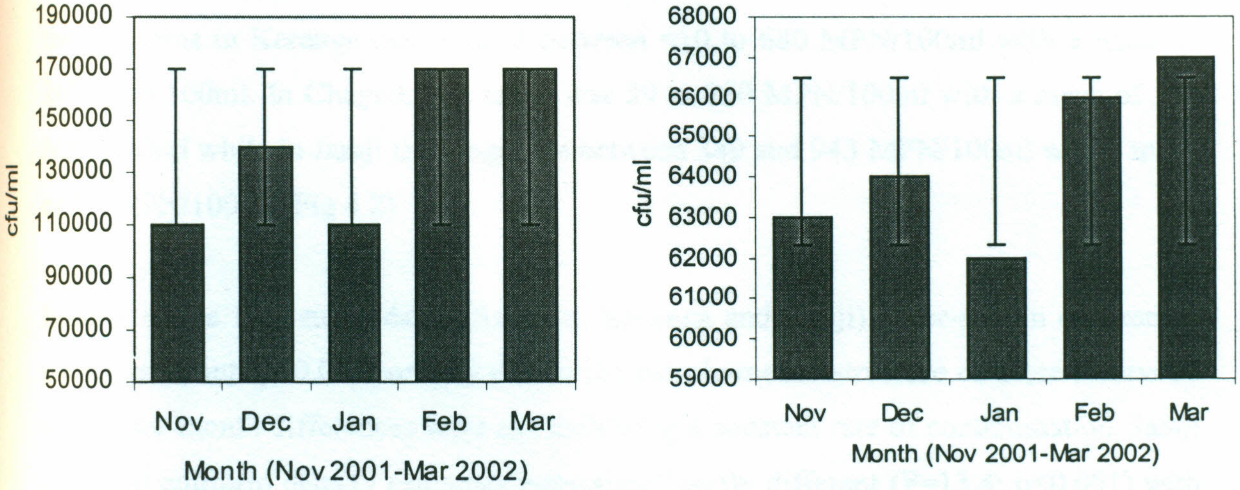
4.0 INTRODUCTION

This chapter presents the results and discussion of the physico-chemical and microbial quality of the dam waters studied for over five consecutive months. Forty samples were collected from each of the four studied dams from eight established sampling sites. The analytical data for the four reservoirs are summarized using descriptive statistics and presented in tables and graphs. The results of the analysis of Variance (ANOVA) and student T- test for the parameters are also presented.

4.1 MICROBIAL ASPECTS OF DAM WATER

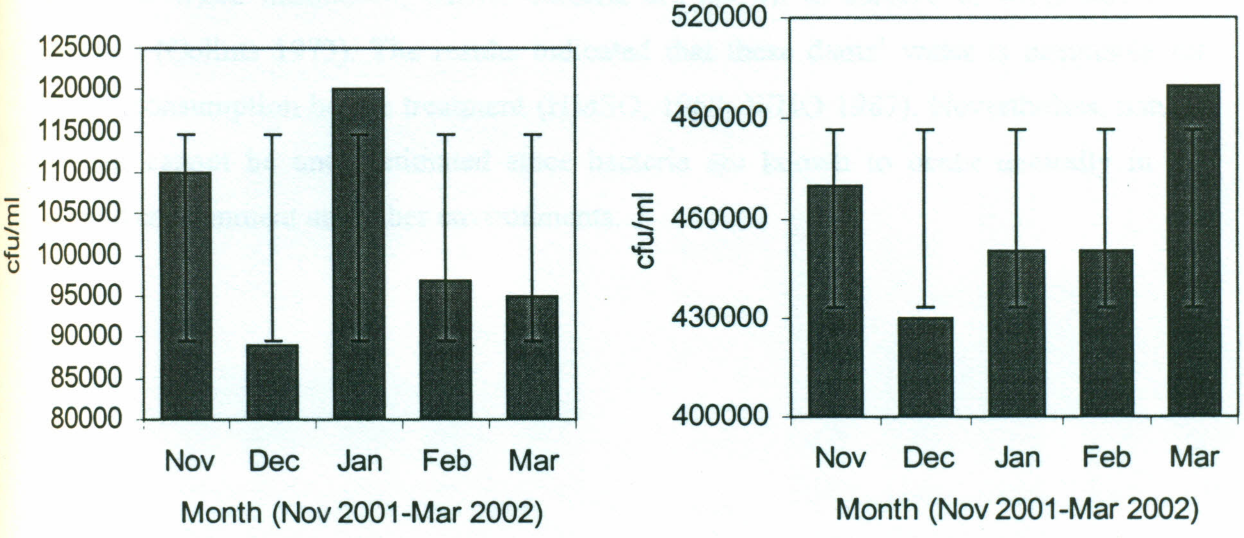
4.1.1 Total viable bacterial counts in the reservoirs

In Sambret dam, the total viable bacteria counts ranged from 2.2×10^4 to 4.0×10^5cfu/ml with a mean of 1.4×10^5cfu/ml. In Chagaik dam, total viable bacteria counts fluctuated between 2.2×10^4 to 1.4×10^5cfu/ml with a mean of 6.4×10^4cfu/ml. The estimate total viable bacteria counts in Kerenga dam was quite variable ranging from a minimum of 2.8×10^3 to a maximum of 2.5×10^6cfu/ml with a mean of 1.0×10^5cfu/ml. For Jamji dam estimate total viable bacteria, counts of between 1.0×10^5 and 9.9×10^5cfu/ml with a mean of 4.6×10^5cfu/ml were recovered (Fig 4.1). Although sampling stations differed significantly ($p=0.05$) in three of the four dams (except Chagaik), there was a non-significant difference between months. Nevertheless, viable bacteria count in Jamji dam differed significantly ($F=63.7$; $p<0.001$) with the other three dams. This was attributed to the higher organic enrichment common in agricultural environments (Dadswell, 1993; Olayemi, 1997; Okungu and Opanga, 2003).



a) Total viable bacteria in Sambret

b) Total viable bacteria in Chagaik



c) Total viable bacteria in Kerenga

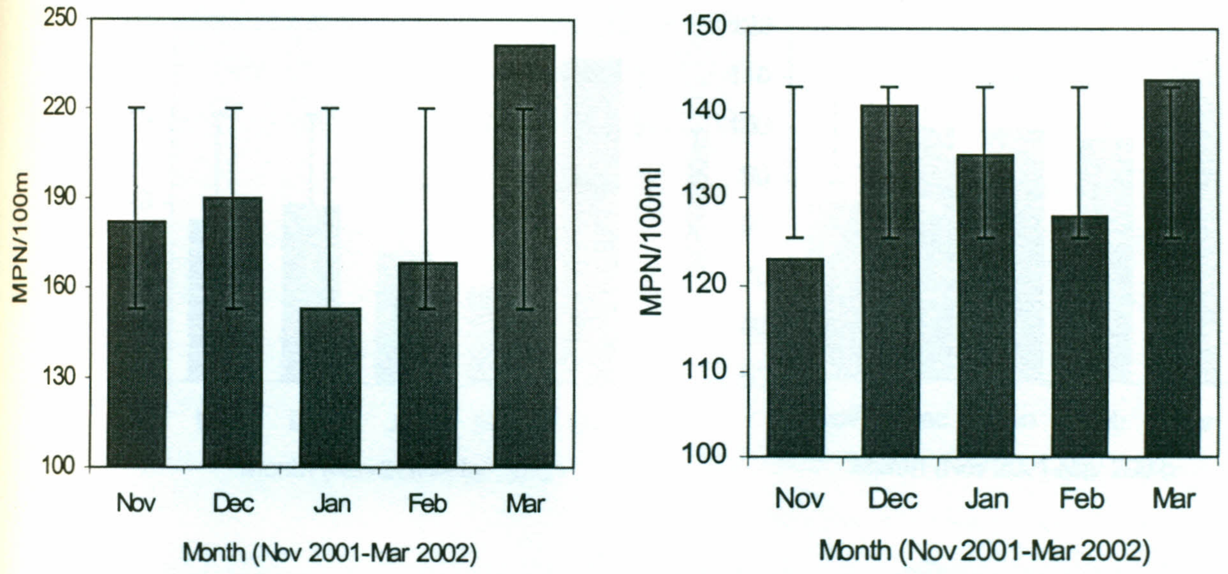
d) Total viable bacteria in Jamji

Figure 4.1 Mean monthly counts of Total viable bacteria in Kericho reservoirs between November 2001-March 2002

4.1.2 Total coliforms in the reservoirs

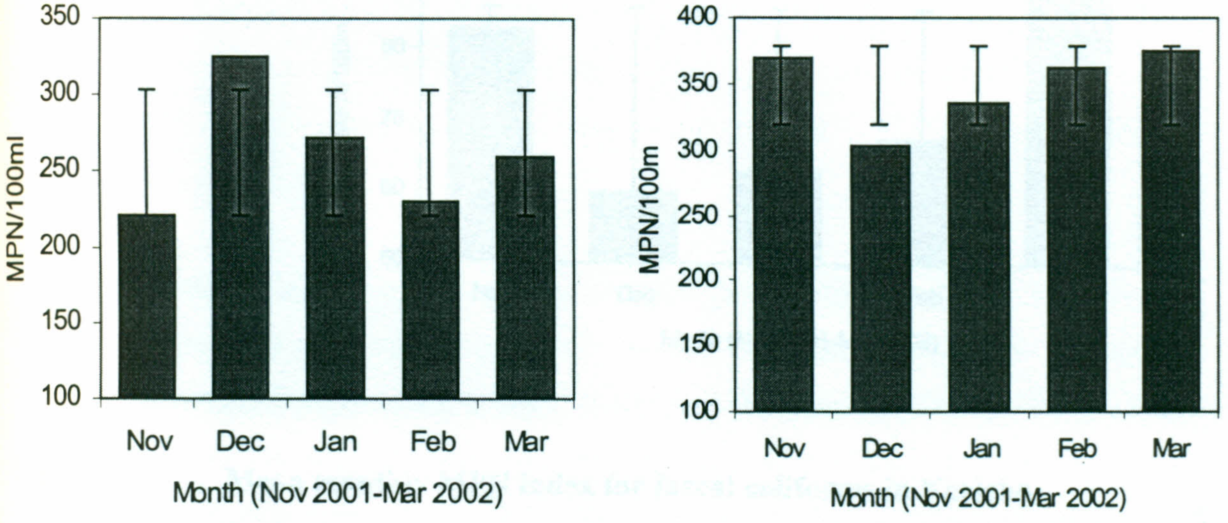
Screening for the coliforms indicated fluctuating densities between 75 to 250 MPN/100ml with a mean of 187 MPN index/100ml in Sambret dam. The fluctuation of the coliforms in Kerenga dam ranged between <10 to 680 MPN/100ml with a mean of 262 MPN/100ml. In Chagaik, the range was 39 to 250 MPN/100ml with a mean of 138 MPN/100ml while in Jamji the range was between 349 and 943 MPN/100ml with a mean of 349MPN/100ml (Fig 4.2).

In three of the four study dams (Sambret, Kerenga and Jamji), inter-station differences were significant ($p=0.05$) possibly due to the morphometric structure of these reservoirs while inter-month differences were not indicating a constant rate of contamination. Jamji dam total coliform density estimates were significantly different ($F=13.4$; $p<0.001$) with the coliform densities of the other three dams. The recovery of coliforms was attributed to human settlements in the study area, possible leakages from the latrines and municipal effluents. When introduced, enteric bacteria are known to survive in water and even multiply (Collins 1973). The results indicated that these dams' water is unsuitable for human consumption before treatment (HMSO, 1969; WHO 1987). Nevertheless, natural sources cannot be underestimated since bacteria are known to occur naturally in the aquatic environment and other environments.



a) Total coliforms in Sambret

b) Total coliforms in Chagaik



c) Total coliforms in Kerenga

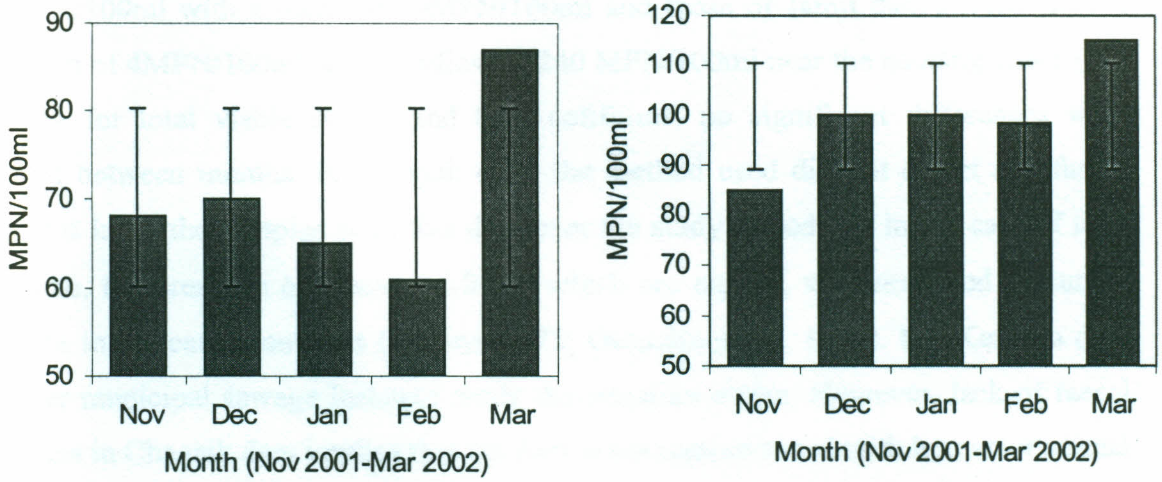
d) Total coliforms in Jamji

Figure 4.2 Mean monthly MPN index for Total coliforms bacteria in Kericho reservoirs between November 2001-March 2002

4.1.3 Faecal coliforms in the reservoirs

a) Faecal coliforms in Sambret

b) Faecal coliforms in Kerenga



c) Faecal coliforms in Jamji

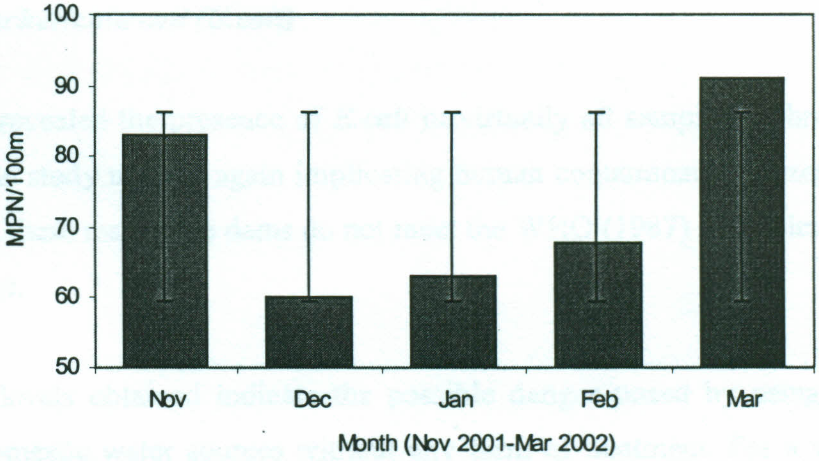


Figure 4.3 Mean monthly MPN index for faecal coliforms in Kericho reservoirs between November 2001-March 2002

Sambret dam estimate densities for faecal coliforms fluctuated between 4 to 240 MPN/100ml while Kerenga dam densities fluctuated between not detectable to 240MPN/100ml with a mean of 99MPN/100ml and those of Jamji dam ranged from a minimum of 4MPN/100ml at the outflow to 240 MPN/100ml near the housing estate (Fig 4.3). As for total viable counts and total coliforms, no significant differences were detected between months. In Chagaik dam, the method used did not detect any faecal coliforms in all the samples from this dam over the study period. As in the case of total coliforms, the presence of faecal colifons, which are enteric, was attributed to human presence in the catchment area (Collins, 1973; Ozeugbu *et al.,* 1996). For Kerenga dam however municipal sewage leakages made the situation worse. However, lack of faecal coliforms in Chagaik dam implies that the dam is not contaminated with human or animal faeces but natural causes. The results indicated that these dams' water is unsuitable for human consumption before treatment (HMSO, 1969; WHO 1987).

4.1.4 Presence of *Escherichia coli (E.coli)*

The bacterial isolates revealed the presence of *E.coli* in virtually all samples in three of the four dams in all the study months again implicating human contamination (Ozeugbu *et al.,* 1996). Based on these results the dams do not meet the WHO (1987) zero tolerance specifications for *E.coli*.

Results of microbial levels obtained indicate the possible danger posed by using this reservoirs water as domestic water sources without any form of treatment. For a water sample to be permitted as potable, faecal coliform $100ml^{-1}$ should be zero (WHO, 1987). In practice, this standard is not always attainable hence a recommendation that no sample should contain more than 2 *E. coli* per 100ml in conjunction with total coliform counts of not more than 3/100ml of water would be ideal. In addition, coliform organisms should not be detected in 100ml of any two consecutive water samples. The emphasis on WHO guidelines was placed first and foremost on the microbial safety of drinking water supplies because more than half the world's population is still exposed to water that is not free from pathogenic organisms resulting in infectious diseases that ultimately lead to increased mortality rates in the population.

The public health considerations in the use of polluted water for domestic purposes are centered on pathogenic organisms presence. Control of epidemics rests on forecasting and prevention when possible or on early detection and rapid control of the epidemic. The present study has provided some useful information on the state of microbial pollution in the reservoirs in Kericho tea estates.

4.1.5 Chlorophyll-a content in Kericho reservoir waters

The chlorophyll-a values of Sambret dam fluctuated between 0.001- 0.003mg/l with a standard deviation of 0.001mg/l and a mean of 0.002mg/l. In Chagaik dam, chlorophyll-**a** levels fluctuated between 5 - 150mg/m^3 with an overall mean of 49mg/m^3 while levels in Kerenga fluctuated between 8 - 140mg/m^3 with an overall mean of 55mg/m^3. The chlorophyll-**a** levels in Jamji fluctuated between 10 - 140mg/m^3 with an overall mean of 58mg/m^3. Sambret dam differed significantly with the other three dams ($F_{(3, 156)} = 24.43$; $p<0.001$) and was rated oligotrophic using total phosphorus concentration and chlorophyll-a content.

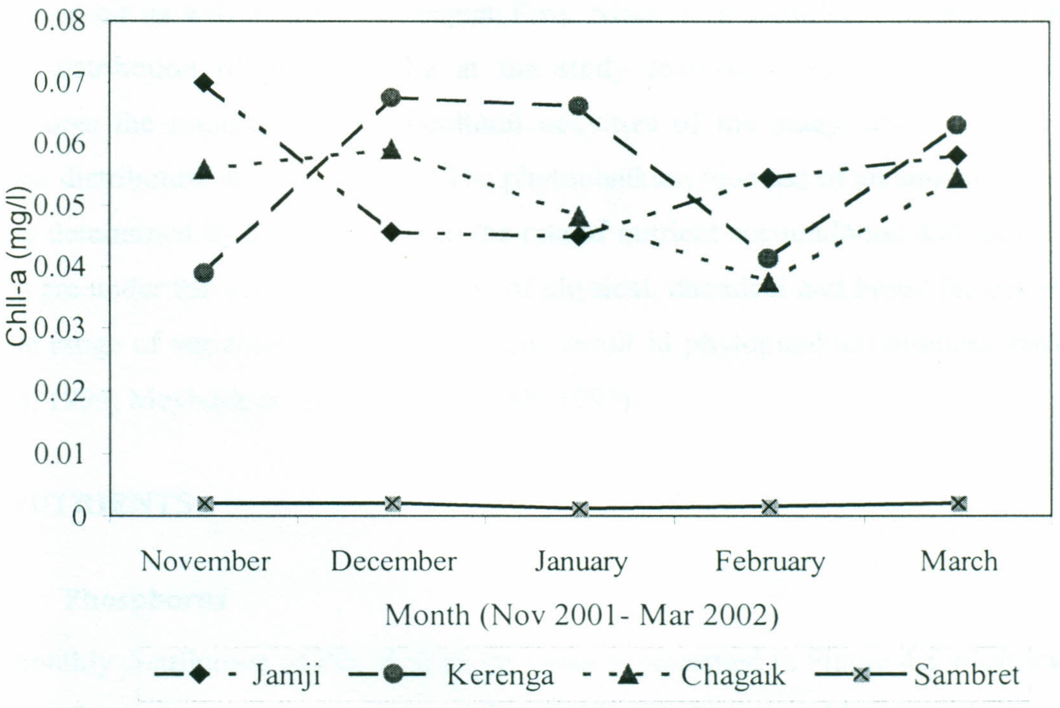


Figure 4.4 Line graph of monthly chlorophyll-a content in Kericho reservoirs between November 2001-March 2002

Three of the four dams seemed to provide a favourable environment for the proliferation of algal blooms as indicated by a mean chlorophyll-**a** of 49mg/m^3, 55mg/m^3 and 58mg/m^3 for Chagaik, Kerenga and Jamji dams respectively (Kalff, 1983; Kotut, 1998; LVEMP, 1995). The Monthly variation of algal densities in these three dams showed two maxima levels over the study period (Fig 4.4). In Chagaik dam, December and March recorded high levels of algal densities, which are observed to decline steadily between January and February with a sharp rise in March. Kerenga dam recorded high levels of algal densities in November, December and January, which declined steadily in February with a rise in March. The chlorophyll-a levels in Jamji dropped sharply in the month of December remaining stable through January with a relative smooth rise in February and March.

An investigation of the spatial relation between chlorophyll-a and some of the reservoir physico-chemical conditions found at the reservoirs revealed different pictures unique to each reservoir as will be seen in Chapter Five. Alack of a significant difference in the spatial distribution of chlorophyll-a at the study reservoirs within the Tea Estates underscores the importance of agricultural activities of the study area in influencing biomass distribution at the reservoirs. The phytoplankton biomass of an aquatic system is usually determined by balance between the rate of nutrient accumulation and loss. These in turn are under the control of a complex of physical, chemical and biotic factors whose infinite range of variability in space and time result in phytoplankton biomass variation (Kotut, 1998; Meybeck *et. al.*, 1998; LVEMP, 1999).

4.2 NUTRIENTS

4.2.1 Phosphorus

The monthly distribution of PO_4-P in all the dams is presented in Figure 4.5 while overall statistics for each reservoir are presented in Table 4.1. The monthly range for Sambret was between 0.004mg/l in November to 0.005mg/l in January with an overall mean of 0.004mg/l. In Chagaik, the levels for November, December, January, February and March were; 0.014, 0.012, 0.013, 0.012, and 0.014mg/l with an overall mean of 0.013mg/l while those of Jamji were 0.018, 0.012, 0.012, 0.009, and 0.013mg/l for November, December, January, February and March respectively. For Kerenga, the concentration ranged between 0.012mg/l in February to 0.024mg/l in November.

Table 4.1 PO_4-P concentrations in Kericho reservoirs between November 2001-March 2002

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	0.004	0.00	0.001	0.002	0.007
Chagaik	0.013	0.001	0.006	0.006	0.026
Kerenga	0.017	0.001	0.008	0.006	0.047
Jamji	0.013	0.001	0.005	0.001	0.025

The levels in Kerenga were always higher than all the other dams (Fig 4.5), a fact attributed to domestic effluents, municipal and urban run-off as well as contamination from Kerenga engineering department. Except Sambret dam that recorded PO_4-P levels of less than 5µg/l, the P levels in the other three dams did not fall below 10µg/l (Table 4.1). Monthly dynamics showed highest levels in November for Kerenga and Jamji (Fig 4.5) with a gradual decline until March when an increase is observed. This suggests that run off from farmlands and/or municipal effluents may have contributed to the high levels during the rainy months since the catchment is fairly hilly adding to the erodibility. The concentration of P in the dams shows a well-developed monthly cycle.

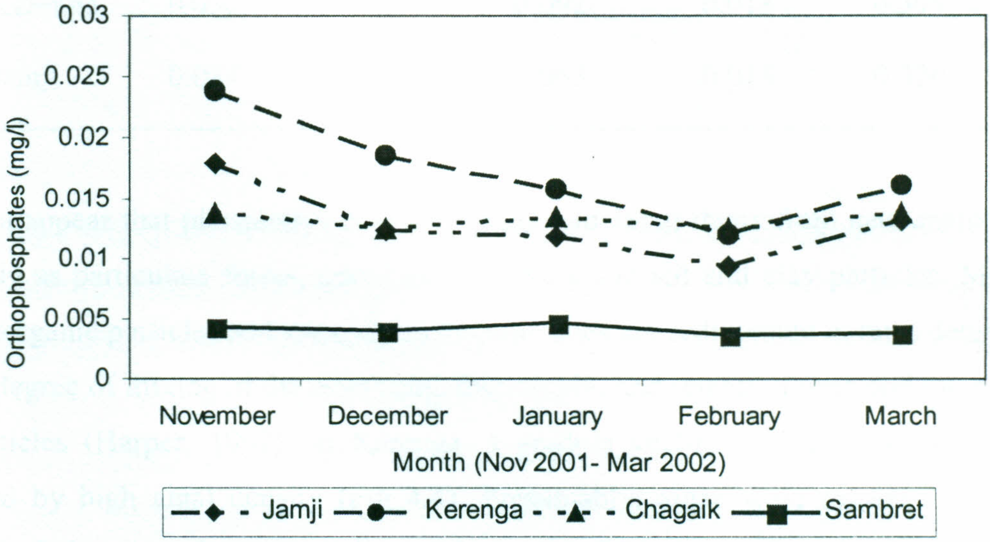


Figure 4.5 Five-month mean levels of PO_4-P in Kericho reservoirs between November 2001-March 2002

Total phosphorus monthly dynamics for Sambret were 0.013, 0.017, 0.014, 0.013, and 0.012mg/l for November, December, January, February and March respectively while Chagaik dam showed monthly levels of 0.041, 0.058, 0.036, 0.034,and 0.041mg/l with an overall mean of 0.042mg/l. Kerenga dam recorded levels of 0.159, 0.087, 0.066, 0.058, and 0.120mg/l for November, December, January, February and March respectively with a mean of 0.098mg/l while Jamji dam levels varied between 0.009mg/l in February and 0.018mg/l in November with an overall mean of 0.013mg/l. Much of the phosphorus was found to be in particulate form (determined as the difference between total and soluble reactive phosphorus).

Table 4.2 **Total phosphorus concentrations in Kericho reservoirs between November 2001-March 2002**

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	0.014	0.001	0.004	0.008	0.024
Chagaik	0.042	0.004	0.023	0.013	0.108
Kerenga	0.098	0.015	0.092	0.018	0.395
Jamji	0.057	0.010	0.063	0.015	0.320

It would appear that phosphorus enters Kerenga and Jamji dams from catchment runoff primarily as particulate forms, adsorbed onto inorganic silt and clay particles. Many of these inorganic particles and some of the organic ones are sedimented at rates determined by the degree of mixing in the reservoirs, their depth, and retention time and the mass of the particles (Harper, 1992). In Kerenga, a gradual decline in phosphate levels was followed by high algal density (Fig 4.4). Presumably, algae were responsible for the removal of phosphate from the surface of the water of this dam at the time.

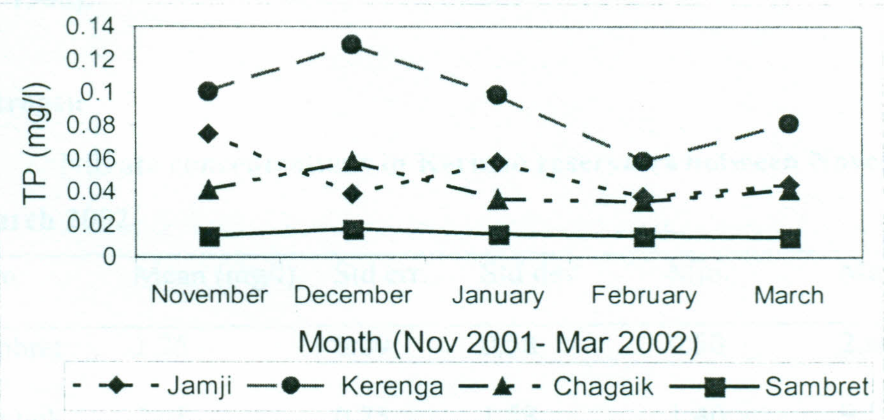


Figure 4.6 Five-month mean levels of TP in Kericho reservoirs between November 2001-March 2002

In Chagaik dam, concentration of phosphate-phosphorus remained constant. Chlorophyll-a levels declined between January and February even as phosphate levels remained constant in this dam in direct response to poor light penetration as evidenced by low transparency levels and high levels of suspended solids in these months (see figures 4.10 and 4.12). Phosphate-Phosphorus was often above 0.01mg/l in the three dams. It is therefore reasonable to assume that Phosphate did not check the growth of algae. Perhaps the recycling of phosphorus in these dams is so rapid that it is continuously available for and removed by the algae. Phosphate was always in adequate supply, the concentration being significantly and consistently greater in Kerenga dam.

The general relationship of total phosphorus and chlorophyll-a was positive(r=0.6249; 0.8397; 0.4999 for Chagaik, Kerenga and Jamji respectively) indicative of the efficiency of algae in utilizing the dissolved phosphorus. This was mainly achieved by either quick luxury uptake of phosphorus by algal cells in excess of their immediate needs before an increase in population (Currie and Kalff, 1984). The rate at which this occurs particularly in relation to chemical hydrolysis of phosphate from organic phosphorus is not understood but it was thought that higher phosphate activity was generally associated with inhibition of phosphatase enzymes due to high levels of phosphorus (Harper, 1992; Meybeck., 1998).

4.2.2 Nitrogen

Table 4.3 Nitrate concentrations in Kericho reservoirs between November 2001-March 2002

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	1.25	0.09	0.58	0.50	2.80
Chagaik	3.68	0.25	1.58	1.40	9.10
Kerenga	5.47	0.41	2.56	1.40	11.90
Jamji	5.15	0.45	2.82	1.40	14.90

The variations of nitrogen in the three dams are shown in Figures 4.7 and 4.8. NO_3- concentrations in the range of 0.5mg/l to 14.9mg/l were recorded during the study period (Table 4.3). Descriptive statistics for both nitrate-nitrogen and total nitrogen in the dams are presented in Tables 4.3 and 4.4. Nitrate- nitrogen loads increased gradually from Sambret dam to Kerenga (Fig 4.7). A careful study of the data revealed that the loads increased with runoff discharges possibly due to fertilizer loss from the farmlands. Plots of the spatial variation in mean nitrogen levels are provided in Figures 4.7 and 4.8 for a comparison in the four study reservoirs. The exceptionally high nitrogen loads in the three reservoirs in plantation tea estates (Chagaik, Kerenga and Jamji) could largely be attributed to agricultural activities in the area although domestic effluents from farm settlement units cannot be overruled.

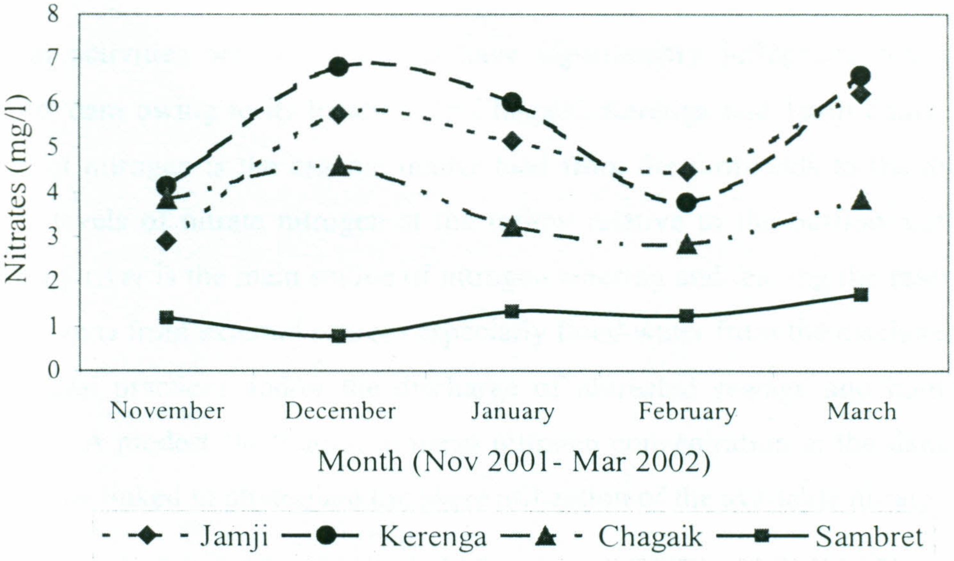


Figure 4.7 Mean monthly concentrations of nitrates in Kericho reservoirs between November 2001-March 2002

There was observed low levels of NO_3- in the wet month of November in all the reservoirs. Since the onset of the rains started in the month of August in the study area, this low concentration could be associated with its liberation diminishing rapidly due flushing out into rivers and reservoirs from the previous months and subsequent utilization by algae. Water nutrient concentrations in all dams remain relatively constant with small monthly fluctuations that are non-significant ($p=0.05$). Nevertheless, the concentrations were always above known limiting levels (Harper, 1992; MacCrimmon and Kelso, 1970; Ansa-asare and Asante, 2000).

Table 4.4 Total nitrogen concentrations in Kericho reservoirs between November 2001-March 2002

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	4.28	0.365	2.31	0.80	8.4
Chagaik	13.63	0.731	4.62	5.25	23.1
Kerenga	14.19	0.768	4.86	3.15	22.4
Jamji	12.91	0.889	5.62	1.40	24.9

Human activities are not likely to have significantly influenced nitrogen levels in Sambret dam owing to its location. In Chagaik, Kerenga and Jamji dams, an important source of nitrogen is the organic matter load from the farmlands to the draining rivers. Higher levels of nitrate nitrogen at the inflow relative to the outflow confirm that the inflowing river is the main source of nitrogen entering and leaving the reservoirs. This is due to inputs from external sources especially flood water from the catchment area due to agricultural practices and/or the discharge of untreated sewage and human settlement effluents. A modest fluctuation in mean nitrogen concentration at the dams (Figs 4.7 & 4.8) can be linked to phytoplankton algae utilization of the available nitrate.

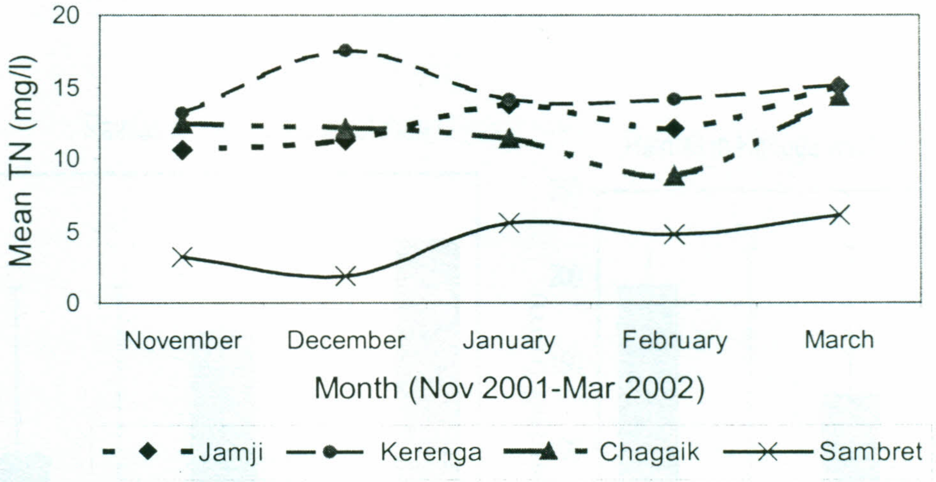


Figure 4.8 **Mean monthly concentrations of total nitrogen in Kericho reservoirs between November 2001-March 2002**

4.3 PHYSICO-CHEMICAL CHARACTERISTICS OF DAM WATER

4.3.1 Rainfall

Mean monthly rainfall data at the study area was colleted from two Brooke Bond weather stations at Jamji and Kimugu (Fig 4.9). The rainfall totals for the region ranged from a minimum of 18.9mm at the Kimugu weather station in the month of December to a maximum of 343.0mm at Jamji weather station in the month of March. December was the driest month followed by February, November, January and March respectively in each of the two stations. At the study area, December and February were relatively dry while March was the wettest month (Fig 4.9).

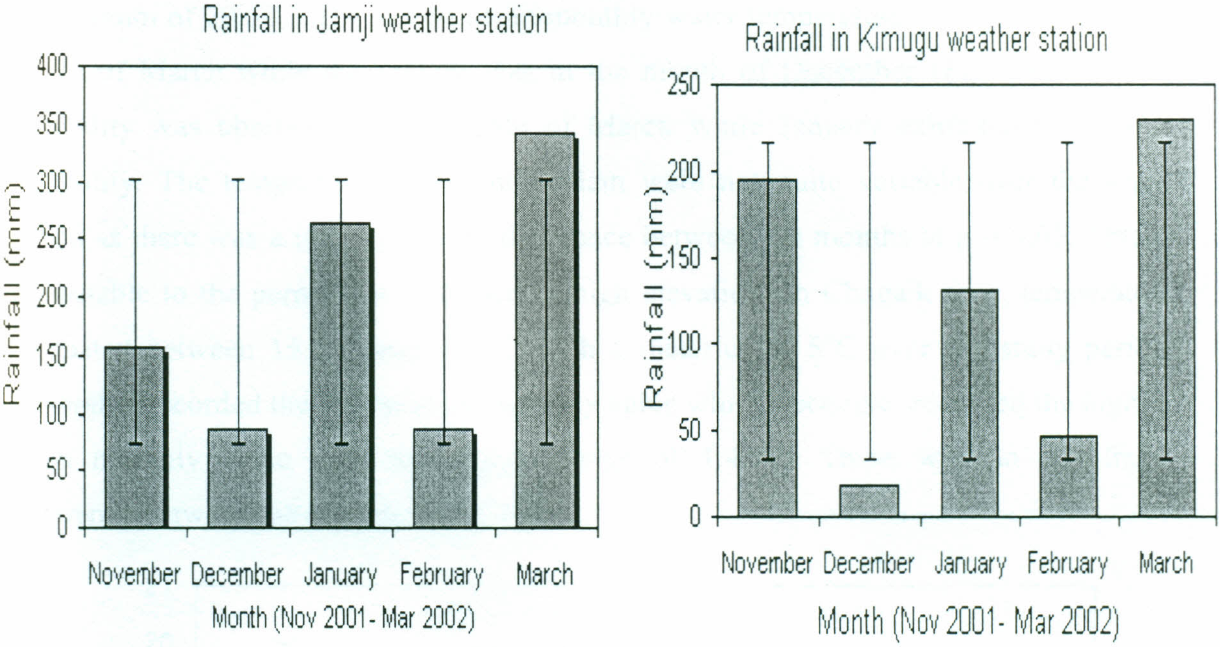


Figure 4.9 Monthly rainfall totals in Kericho district between November 2001-March 2002

It was expected that the rainfall pattern at the study area could be significantly related to nutrient loadings in the reservoirs. Nevertheless, a lack of clear relation between rainfall received at reservoirs and nutrient loadings is a common feature of lake nutrient budget (Harper, 1992). This study differed with observations made by Kotut (1998) and Tarus (1991) in that, in the latter two studies, rainfall was found to significantly lead to high nutrient levels whereas the relationship in the current study was quite erratic. These differences were attributed to the frequency of rainfall totals in the current study area relative to the other study areas coupled with the fact that the tea canopy is quite thick, served with very high soil organic matter due to the practice of leaving tea prunings *in situ*. Both aspects make runoff difficult. The ground seepage aspect is also reduced by riparian forests, which use up those nutrients that could otherwise land in the dams. In Kotut (1998) and Tarus (1991) case studies, rainfall is quite erratic and unreliable while in Kericho tea estates rainfall reliability is quite high.

4.3.2 Temperature

The water temperature range for Sambret dam was 4.9°C with a minimum of 15.6°C and a maximum of 20.5°C. The lowest mean monthly water temperature was recorded in the month of March while the highest was in the month of December (Fig 4.10). Great variability was observed in the month of March while January exhibited the lowest variability. The temperatures of Sambret dam were not quite variable over the study period as there was a non-significant difference between the months at $p = 0.05$. This is attributable to the permanent influence of high elevation. In Chagaik dam, temperature fluctuated between 15.5°C and 21.7°C with a mean of 17.8°C over the study period. November recorded the lowest mean monthly value while December recorded the highest mean monthly value with the biggest range of 1.48°C. There was no significant difference between the months (Fig 4.10).

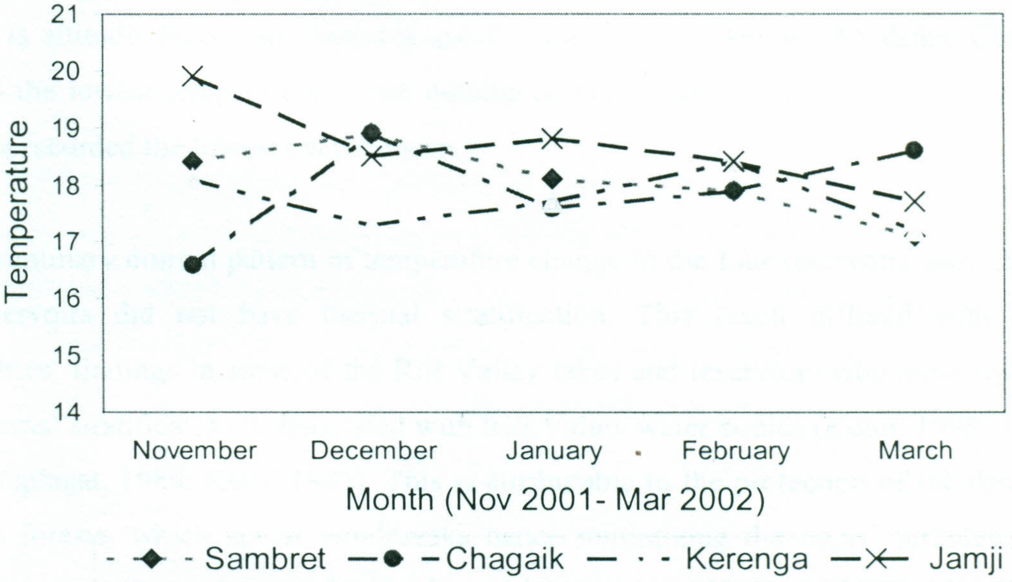


Figure 4.10 Line graph of monthly temperature variation in reservoirs in Kericho district between November 2001-March 2002

Kerenga dam recorded an overall temperature mean of 17.75°C with a minimum of 15.7°C and a maximum of 21.0°C. February showed the highest variability and range while the minimum mean temperature was observed in the month of March. The monthly water temperature did not seem to differ significantly at the p=0.05 level. The water temperature of Jamji dam fluctuated in a similar manner to those of the other dams. The temperature range for the dam was between 16.5-24°C.The highest mean value was recorded in the month of November while the lowest value was observed during the month of March. The water temperature of the four dams fluctuated in the range of 15.5°C to 24°C with a mean of 18.17°C over the study period. Jamji dam exhibited the largest range and variance while Sambret dam showed smallest range yet Kerenga had the lowest variability (Fig 4.10).

Temperature differentials between the dams were significant at $p=0.05$ ($F=4.37$; $p<0.05$). In particular, the significant difference was found between Jamji and Kerenga dams ($t=3.91$; $p <0.05$) and between Jamji and Chagaik dams ($t=2.2$; $p <0.05$). The variation in temperature between could be explained by the fact that sampling took place at different hours of the day (9:00- 10:00hrs) for different dams. In addition, temperature in Kericho district is altitude dependent (Jaetzold and Schmidt, 1983). Among the dams, Chagaik showed the lowest temperature in the months of November, January and February yet Kerenga recorded the lowest overall mean.

The preliminary diurnal pattern of temperature change in the four reservoirs showed that the reservoirs did not have thermal stratification. This result differed with other researchers' findings in some of the Rift Valley lakes and reservoirs who have reported that thermal stratification is associated with Rift Valley water bodies (Kotut, 1998; Tarus, 1990; Kiplagat, 1989; Kalff, 1983). This is attributable to the protection of the dams by riparian forests, which act as windbreaks hence minimizing the dams' turbulence by wind. However, the study agreed with observations made by William (2000) who studied several small manmade tropical reservoirs. Nevertheless, the variation of temperature in all dams compared well with other studies done in tropical freshwater bodies (Tarus, 1990; Sinada & Abdel Karim, 1984; Ndaruga, 1998; Ngetich, 1996) although with lower mean values. Measurement of temperature in lakes and reservoirs is important because the heating of the surface water controls, to a large extent, the layering and mixing characteristics of a water body (Lewis, 1996).

A mean surface water temperature range of 17.749°C to 18.662°C observed in these reservoirs is slightly lower when compared to some other Kenyan freshwater bodies like Baringo , Naivasha, Bogoria, Elmenteita, and Nakuru and Turkwell Gorge all of which are very low elevation water bodies hence influenced by the prevailing higher temperatures (Tarus, 1990 ; Abiya, 1996 ; Kalff, 1983 ; Kotut, 1998). Tarus (1990) showed that mean lake surface water temperature were consistently lower than atmospheric temperature. Similarly, the current study revealed that atmospheric temperature was always higher than water temperature at the sampling time. However, the air and water temperatures for the two studies are daytime measurements and hence only serve as guides to the usual day temperature ranges. As most measurements were made between 0800hrs and 1200hrs, it is possible that the range of variation could be higher.

4.3.3 PH

The pH of Sambret dam fluctuated between 6.2 and 7.6 with an overall mean of 6.94 and a variance of 0.098 over the study period. The highest mean PH units were recorded in the month of February while November recorded the lowest mean value yet the same month showed the greatest variability. Inter-month differences were not significant (Fig 4.11). The pH of Sambret dam was not very variable over the study period suggesting that the dam is well buffered. Chagaik dam monthly mean pH units are shown on Fig 4.11. The minimum pH units were recorded in the month of November while the maximum occurred in December. Great variability occurred in the month of March (s=0.868) whereas November recorded the lowest variability (s=0.203). A significant difference was observed between November and the other months ($F_{(4,39)}=11.45$; $p=0.05$). This difference was associated with the time of sampling since in November sampling in this dam was done before 0700hrs whereas in the other months it was done after 0800hrs. The dam showed a general inverse trend in pH variation with water levels implicating some external influences such as runoff from farmlands.

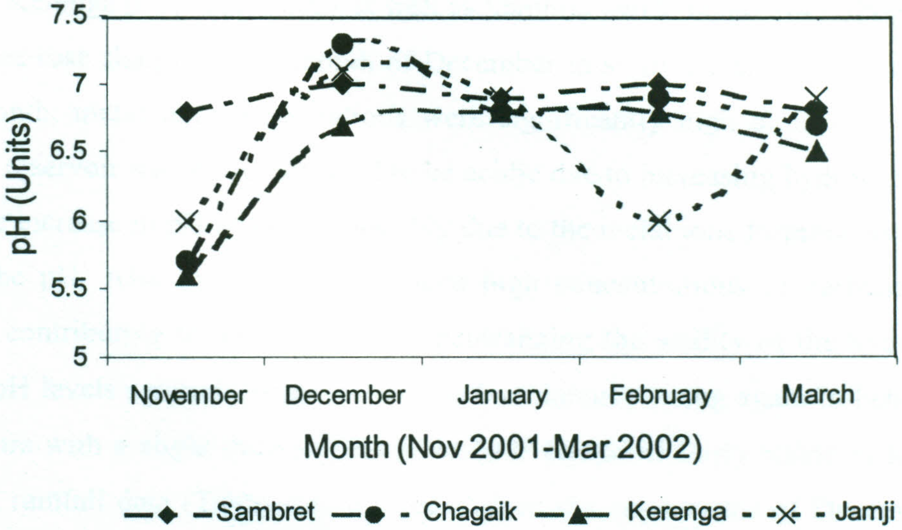


Figure 4.11 Mean monthly variation of pH in reservoirs in Kericho district between November 2001-March 2002

Figure 4.11 shows monthly mean pH values in Kerenga dam over the study period. It is observed that November recorded the lowest mean value while January recorded the highest. The pH readings for November differed significantly to those of December, January and February ($F_{4, 39}=3.95$; $p=0.05$) but not with March. The general trend shows a steady rise from November to a maximum in February with subsequent decline in March. While it is observed that great variability occurred in the month of December followed by November it was lowest in February. Jamji pH levels over the study period are presented in Figure 4.11. November recorded the lowest mean while December recorded the highest mean value with the greatest variability. November differed significantly with December, January and march ($F_{4, 39} =5.2$; $p= 0.05$) but not with February.

High variability was observed for Chagaik dam relative to other dams (Var=(0.568). Sambret dam showed the least variability (Var=0.098). Kerenga had the lowest mean pH value and this could have been due to higher metal anion and cation concentrations as compared to the other dams. A significant difference of pH between the dams ($F=3.78$; $p<0.05$) was observed. This significant difference was particularly observed between

Sambret and Kerenga ($t=3.62$; $p<0.05$) as well as Sambret and Chagaik ($t=3.02$; $p= 0.05$). The pH values rose sharply in the month of December in study dams (Fig 4.11). During the same month, metal ion concentrations were significantly high almost in all these dams. While reservoir water was expected to be acidic due to increasing hydrolyzing salts of metals, the increase in pH level was possibly due to the metal ions forming weak bases that raised the pH. Also there may have been high concentrations of carbonates and bicarbonates contributing to alkalinity hence neutralizing the acidity of the hydrolyzing metals. The pH levels again declined in the month of January rising again in February in three reservoirs with a slight drop in March while it remained fairly stable in Kerenga. Compared to rainfall data (Table 4.8), the pH rose in the dry months of December and February and declined in the relatively wet months of November, January and March. This observation implies that surface runoff and high water volume in the feeding rivers had a dilution effect on the ionic composition of the waters.

Under natural conditions, pH is usually dependent on the amount of carbonate and bicarbonate alkalinity and CO_2 in solution (Talling, 1966). Under these conditions, the balance between photosynthesis and respiration determine pH in an aquatic ecosystem (Kotut, 1998). In the current study, the mean pH units of the dams were relatively acidic to neutral. Possible sources of acidification of freshwater in Kericho could be the mineralization of organic bound nitrogen forming weak nitric acid. In addition, soils of Kericho are composed of acid humic topsoil (Jaetzold and Schmidt, 1983).

4.3.4 Electrical conductivity

Conductivity in the dams is presented in Figure 4.12. Sambret dam conductivity values fluctuated between 24.5 to 73.6μS with an overall mean of 47.48μS. November recorded the highest mean value while December recorded the lowest. Great variability was observed in March ($s=16.58$) with January recording the lowest. There was a non-significant difference between the months at $p=0.05$. The mean conductivity values for Chagaik over the study period were 36.1, 50.56, 42.35, 42.67 and 43.9μS for November, December, January, February and March respectively (Figure 4.12). The overall mean value was 43.12μS with a standard deviation of 16.43μS. The fluctuation of EC in Chagaik was fairly low with a non-significant monthly difference at p=0.05.

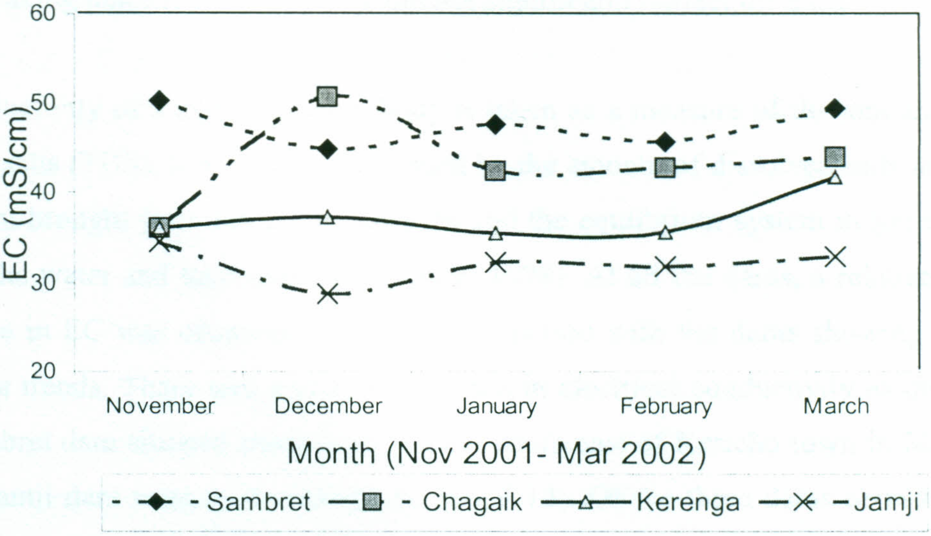


Figure 4.12 Five-month electrical conductivity in reservoirs in Kericho district between November 2001-March 2002

In Kerenga dam the overall mean of 37.2μS was recorded. March recorded the largest mean with lowest variability while January recorded the lowest mean with great variability occurring in November. No significant differences at p=0.05 was observed between months. The electrical conductivity of Jamji dam fluctuated between 25 and 48.5μS with an overall mean value of 32.01μS and standard deviation of 4.79μS. The monthly variations for November, December, January, February and March were 34.5, 28.8, 32.2, 31.7 and 32.8μS respectively (Figure 4.12). November showed the largest variability while February showed the lowest. There was no significant difference between the months at p=0.05.

The monthly averaged water conductivity over the eight sampling sites in two of the four dams exhibited fluctuations in direct response to changing water levels (Kerenga &Chagaik). In Sambret and Jamji, EC rose with rise in water levels and declined with decreasing water levels. However, the dams remained fresh (<75μS) throughout the study period. There was no significant differences at p=0.05 between dams over the study period as relates to electrical conductivity of the water. This suggests that agricultural activities taking place in the study area did not significantly affect the EC of these dams.

The conductivity of a standing water body is taken as a measure of the amount of total dissolved salts (TDS). It is usually influenced by the amount of dissolved salts in rainfall, the amount brought from the catchment area and the equilbrium system in ion exchange between the water and lake sediments (Kotut, 1998). At all the dams, a relatively stable state mode in EC was observed over the study period with the dams showing different fluctuation trends. There was a general decrease in electrical conductivity as one moves from Sambret dam situated about 4 kilometers south east of Kericho town in Mau forest through Jamji dam west of Kericho town (Fig 4.12). Of the three dams served by river Kimugu, Chagaik recorded the highest EC and this decreased downstream through Kerenga and further to Jamji. Progressive decline in reservoir conductivity from Sambret to Jamji is possibly a short-term change that can be attributed to a decline in inflow water volume. The resulting decline in reservoir volume and surface area (as evidenced by observed decline in the reservoirs water level) led to the reduction in hydraulic residence time and evaporation losses, hence low TDS.

The conductivity range of the study reservoirs was slightly lower from that of other tropical water bodies like turkwell Gorge (160-200μS cm^{-1}), Lake Kossou (90-150μS cm^{-1}), Lake Kariba (36-120μS cm^{-1}), and Lake Kainji (34-80μS cm^{-1}) (Coche, 1974; Hall *et. al..,* 1977 ; Kotut, 1998). A mean conductivity of 37.575μS cm^{-1} observed at the reservoirs indicate that the inflowing water has modest quantities of dissolved solids. Rivers with a conductivity of less than 180μS are associated with drainage basins predominantly of volcanic nature mostly igneous (Hutchinson, 1973). Igneous rocks usually supply soft water as oppsed to calcerous rocks. The Kericho geology system is predominantly underain by volcanic phonolites that give rise to And- Humic Nitisols with acid humic topsoils.

4.3.5 Dissolved Oxygen

The overall mean value for DO in Sambret dam was 81.98% with a standard deviation of 8.213%. The dam was well oxygenated with the Minimum dissolved oxygen occurring in the month of February (68%). The overall range for this dam was 26% with great variability occurring in January (s= 9.38%). Chagaik dam showed a fluctuation of DO ranging from 15% to 98% with a mean and standard deviation of 72.4% and 20.28% respectively (Table 4.12). The minimum mean value was recorded in November (40.63%) while the maximum mean value occurred in December (88.25%). November recorded the greatest variability (s=21.11%) followed by March (s= 10.13%). The November D.O was significantly ($F_{4,\ 39}$ =18.03; p=0.05) different compared to other months (Table 4.5). Low level of DO saturation (40.6%) in Chagaik dam in the month November 2001 was attributed to early sampling time (6.00 a.m)

Table 4.5 Monthly percentage dissolved oxygen levels in reservoirs in Kericho district between November 2001-March 2002

Dam	Sambret	Chagaik	Kerenga	Jamji
Month	Mean%	Mean%	Mean%	Mean%
Nov	79.1±3.13	40.6±7.46	71.8±4.08	73.4±4.07
Dec	82.3±3.10	88.3±2.81	64.9±3.68	68.4±7.60
Jan	82.0±3.32	76.7±2.85	65.6±4.40	67.0±4.26
Feb	79.8±2.81	79.4±3.00	75.1±5.18	65.9±2.74
Mar	86.8±2.27	77.1±3.58	74.1±2.39	64.9±3.68

The dissolved oxygen of Kerenga dam fluctuated between 40-92% with an overall mean of 70.3% (Table 4.5). Great variability occurred in the month of February (s=14.64%) while March recorded the lowest variability (s=6.77%). There was no definite trend and the inter-month differences at p=0.05 were non-significant. The variation of percentage dissolved oxygen in Jamji dam ranged between 20% and 90% with March recording the lowest mean (64.87%) while November recorded the highest (73.38%) (Table 4.5) with December showing the greatest variability and February the lowest. There were no significant (p=0.05) inter-month differences.

Percentage dissolved oxygen for all the dams fluctuated between 15% and 98% over the study period in all the dams with an overall mean value of 73.14%. Chagaik dam showed the greatest Variability (Var=411.221) followed by Jamji (Var=176.092). The lowest variability was found in Sambret dam (Var=67.461). The mean percentage saturation in all dams did not drop below 67%. Super saturation was not observed at any one sampling station over the study period in all the dams. There was a significant difference of dissolved oxygen between Sambret dam and the other three dams ($F_{(3,\ 156)}=7.69$; $p<0.05$).

A wide range of DO measured during the study period (15-98%) indicates that some spatial heterogeneity in reservoir dissolved oxygen levels occurred during periods of high discharge. A nearly uniform dissolved oxygen levels observed in the three reservoirs fed by Kimugu river suggest that the reservoir surface waters never showed a longitudinal gradient of change in DO saturation and compared well with other tropical reservoirs (Coche, 1974; Hall *et. al.,* 1977; Kalff, 1983; Kotut, 1998). There was observed some temporal variation in DO measurements in the reservoirs over the study period. This variation was attributed to increased DO release by photosynthesis and decreased rate of circulation. This happens to be a typical feature of plankton-rich tropical African freshwater bodies. Data from lake Chad, Naivasha, Chilwa, Turkwell and Oloiden all show that DO levels throughout the entire water column can change from anerobic to supersaturation within a day (Coche, 1974; Hall *et. al.,* 1977; Kalff, 1983; Kotut, 1998).

4.3.6 Biochemical Oxygen Demand (BOD)

Sambret dam BOD fluctuations ranged between 19 and 34mg/l with an overall mean of 26mg/l and standard deviation of 3.277mg/l. Significant differences did no occur between months (Table 4.13). Since the dam appeared to be oligotrophic due to low algal densities the BOD levels observed were not associated with trophic level or to anthropogenic pollutants but rather to natural causes. This dam differed significantly with Kerenga ($t=2.27$; $p<0.05$).

Chagaik dam oxygen demand for different months were 16.25, 41.88, 30.87, 36.37 and 28.75, for November, December, January, February and march respectively (Table 4.13). Statistically, there was a non-significant difference ($p=0.05$) between months. The oxygen demand for this dam may be attributed to suspended solids ($r=0.6044$; $p<0.001$). The positive relationship with oxygen saturation ($r=0.5794$) could be due to the fact that algal blooms, which constituted much of the suspended solids, released oxygen to the water column during photosynthetic respiration but exerted an oxygen demand during incubation. Regression analysis showed that nitrates accounted for about 24% of the total BOD variation, algal blooms 18%, orthophosphates 13%, and suspended solids 36% while rise in temperature accounted for 12%.

Table 4.6 Biochemical oxygen demand levels in Kericho reservoirs between November 2001-March 2002

Dam	Sambret	Chagaik	Kerenga	Jamji
Month	**Mean (mg/l)**	**Mean (mg/l)**	**Mean (mg/l)**	**Mean (mg/l)**
Nov	27.4±0.844	16.3± 2.27	38.4±4.41	24.4±3.36
Dec	27.1±0.833	41.9 ±7.09	34.4±2.98	22.5±3.13
Jan	24.8±0.885	30.9 ±4.38	25.4±3.28	26.9±3.13
Feb	23.8±1.78	36.4 ±5.04	28.9±2.85	25.4±1.50
Mar	26.1±0.818	28.8± 3.50	28.8±2.11	32.3±2.05

Biochemical oxygen demand fluctuation for Kerenga dam ranged between 5 and 55mg/l with a mean of 31.2mg/l with no significant differences between months (Table 4.6). This parameter was positively correlated with dissolved oxygen ($r=0.4054$; $p<0.01$) but negatively related to chlorophyll-a content ($r=0.5531$; $p<0.001$). Total suspended solids accounted for 39% of the total BOD variation while total phosphorus accounted for 30%. At the same time total coliforms accounted for 14% of the variation. The fact that suspended solids accounted for the largest variation may be suggestive of the level of organic pollutants in the waters of Kerenga dam. The dam differed with Sambret ($F_{(3, 39)}=2.86$; $p<0.05$).

Biochemical oxygen demand in Jamji dam fluctuated between 5 and 40mg/l with a mean of 26.28mg/l and a standard deviation of 8.05mg/l (Table 4.13). Monthly mean levels were 24.38, 22.5, 26.88, 25.38, 32.25mg/l for November, December, January, February and march respectively (Table 4.6). These demand levels were not statistically significant between months. BOD was observed to be inversely related to manganese; that is, as manganese levels increased BOD levels decreased indicating that manganese levels may have interfered with microbial activities responsible for breakdown of organic constituents in the water sample thus consuming the oxygen dissolved in the water during incubation (Collins, 1973).

Biochemical oxygen demand is a measure of the concentration of organic pollutants in the water samples. The demand levels in all the dams exceeded WHO specifications in drinking water. This implies that the dams are polluted by organic pollutants and are thus not suitable as direct sources of potable water abstractions. Values of BOD in the waters under considerations are three to six folds higher in excess of maximum permissible levels of 3mg/l (WHO, 1987). The values are however lower than those obtained by Davies (1994) in freshwater bodies draining the flourite mining industry in Kerio Valley.

4.3.7 Total Suspended Solids

The monthly means for total suspended solids are presented in Figure 4.13 for all the dams. Sambret dam recorded the lowest levels throughout the study period with a mean of 52 Mg/l. Jamji dam recorded the highest mean values of 174mg/l while great variability was recorded by Kerenga dam(s=63.82). Overall, the fluctuation of TSS ranged between 10mg/l in Kerenga to 320 mg/l in Jamji and Chagaik dams. There was found to be a significant difference of TSS between the four dams ($F_{(3,\ 39)}=43.21$; p=0.05). When paired, significant difference occurred between all of them (p=0.05) except Kerenga and Jamji.

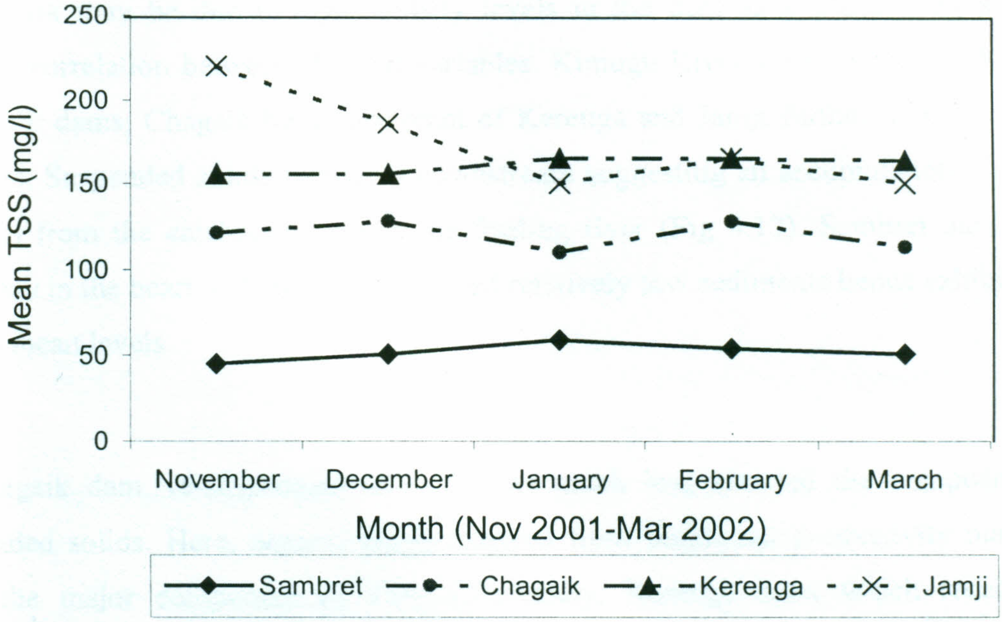


Figure 4.13 Total suspended solids in Kericho reservoirs between November 2001-March 2002

From Fig 4.13, it is noted that Jamji had high and variable concentration of suspended solids throughout the study period. In Chagaik there seemed to be two peak periods. The first TSS peak period coincides with the first peak period for algal density whereas in the second TSS peak period algal densities in this dam decline to a minimum. This suggests that the observed TSS during this period may actually be as a result of floating phytoplankton algae. Kerenga and Sambret dams show relatively stable suspended solids with very poor correlation values with chlorophyll-a (-0.3< r <-0.1). The TSS is therefore due to silt but where the riparian reserve is dense like in Chagaik, the TSS levels were mainly due to algal growth and not silt. In Kerenga the sediments settled at the water sediment interface thus becoming a nuisance for environmental aesthetics besides reducing the reservoir water carrying capacity, which in turn has affected the effectiveness and efficiency of H.E.P production.

The higher levels of suspended solids in Kerenga and Jamji dams could be attributed to silt levels in these dams as a result of sediment runoff from the catchment area while that in Chagaik may be due to algal density levels in the dam as evidenced by a strong positive correlation between the two variables. Kimugu River serves Chagaik, Kerenga and Jamji dams; Chagaik being upstream of Kerenga and Jamji further down stream of Kerenga. Suspended solids increased downstream suggesting an accumulation of eroded material from the catchment area in the feeding river (Fig 4.13). Sambret dam, being relatively in the heart of Mau forest received relatively low sediments hence exhibited the lowest mean levels.

In Chagaik dam, re-suspension of sediments much less affected the composition of suspended solids. Here, organic matter derived from biological productivity may have been the major component of TSS. Conversely, Kerenga dam, which receives its suspended matter from eroded sediments take up a separate position. The suspended solids in this dam may have inhibited the biological productivity of the dam by controlling light penetration as evidenced by a negative correlation between suspended solids and chlorophyll-a ($r=-0.3115$; $p<0.05$).

4.3.8 Transparency

Figure 4.14 shows the variation of transparency for the four dams. Sambret Secchi depth varied between 34 and 65cm, Chagaik between 10 and 32cm, Kerenga dam Secchi depth varied between 10 and 80cm while Jamji between 8 and 27cm. The low water transparency in Chagaik, Kerenga and Jamji dams is due to the heavy suspended solids observed in the three dams. The Secchi depth of Sambret dam varied considerably with those of the other dams ($F_{(3, 156)}=53.25$; $p<0.001$). In all the dams, there was observed very strong correlation values between transparency and TSS (Figure 4.14). This agrees well with Choubey (1994) who compared the concentration of TSS with the depth of penetration in lake waters.

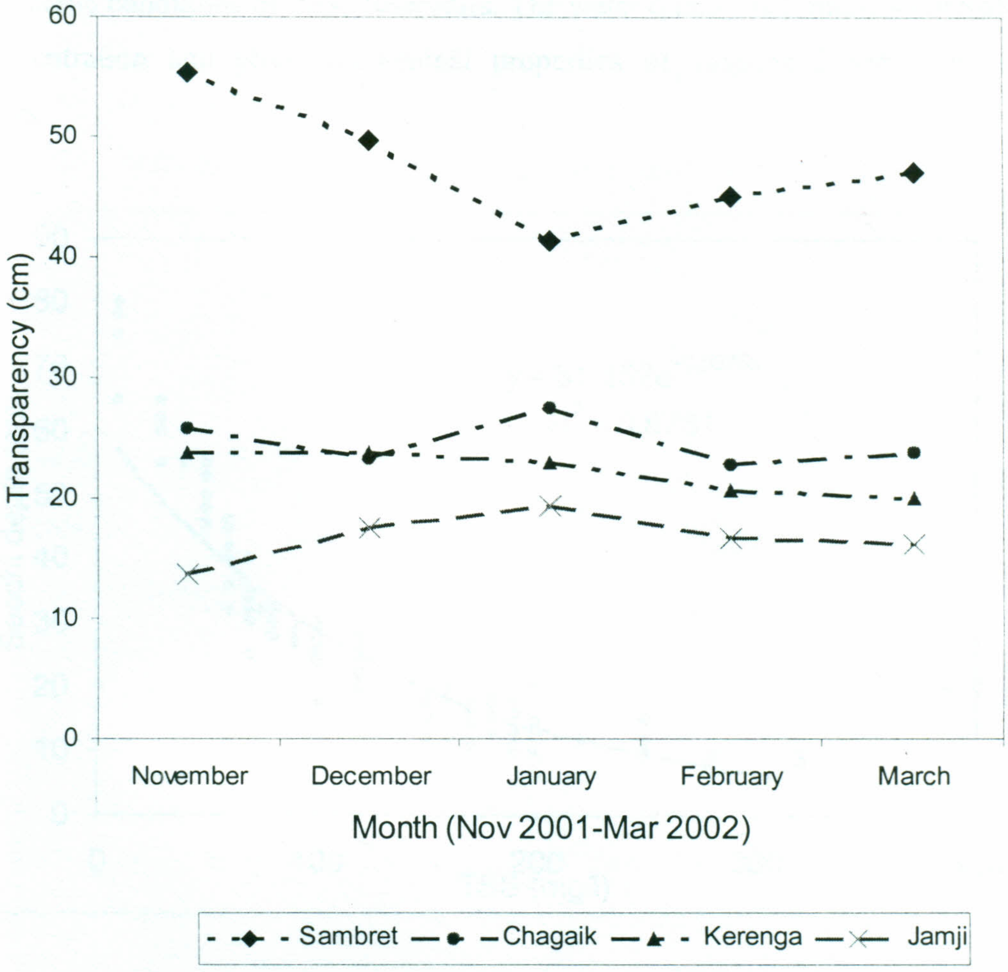


Figure 4.14 Monthly variation in Secchi depth in Kericho reservoirs between November 2001-March 2002

Light penetration appeared to be above saturation in Sambret dam at the water surface. Water transparency was primarily found to be controlled by suspended solids ($r=-0.8606$; $p<0.001$). Fig 4.14 above shows that the Secchi depth measurements of light extinction decreases when the concentration of suspended solids increases, which indicates that Secchi depth is exponentially related with suspended matter concentrations. The functional relationship between Secchi depth and suspended matter indicate that a generalized estimator equation (Fig 4.15) can be developed and used to predict hydrodynamic conditions of these reservoirs. The water quality is primarily controlled by the concentration and physical-chemical properties of suspended sediments in the reservoirs.

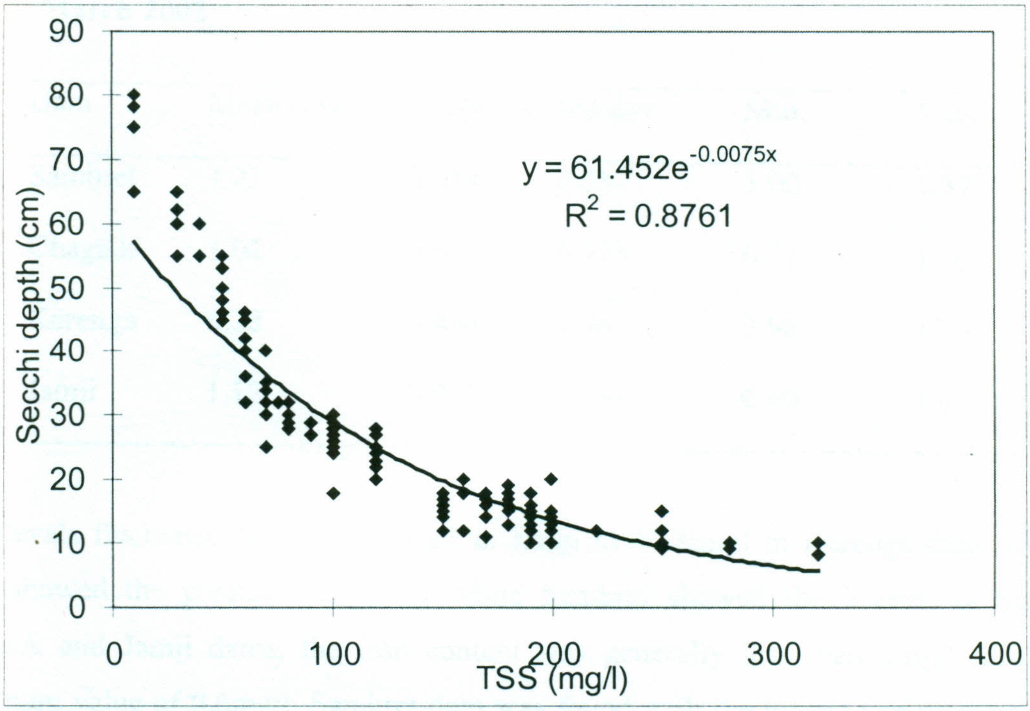


Figure 4.15 Scatter diagram for transparency and TSS in Kericho reservoirs between November 2001-March 2002

High concentrations of suspended particulates are common in the reservoirs as demonstrated by low mean Secchi disc transparency (Fig 4.15). Such turbidity result from the high erosivity in the catchment, which lead to soil erosion, dead plant organic matter derived from falling leaves and fringing papyrus, and algal suspension in the reservoirs. Kotut, (1998) and Choubey (1994) also observed low Secchi disc transparency in their work. In both cases, the low Secchi depth levels were attributed to sediment erosion from the catchment area and/or the trophic state of the water body. Our data therefore is a confirmation of the commonly held principle that Secchi disc transparency decreases with an increase in trophic status, which breaks down at higher trophic levels.

4.4 HEAVY METAL CONCENTRATIONS IN THE DAMS

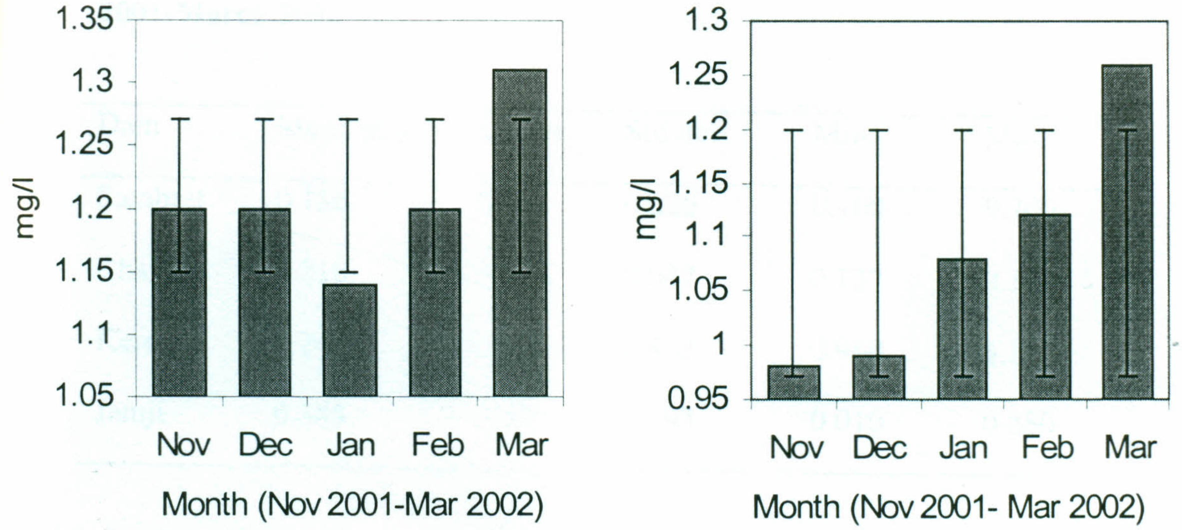
4.4.1 Iron

Table 4.7 Iron concentrations in Kericho reservoirs between November 2001-March 2002

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	1.21	0.014	0.087	1.00	1.37
Chagaik	1.08	0.027	0.173	0.72	1.60
Kerenga	6.38	0.434	2.74	2.98	12.8
Jamji	1.12	0.037	0.237	0.60	1.48

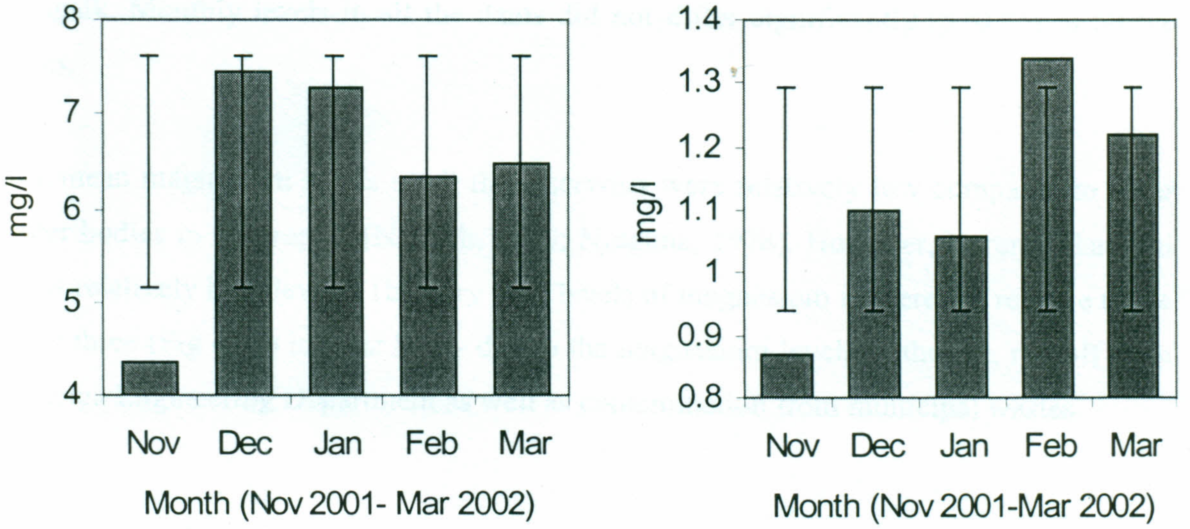
Iron levels fluctuated between 0.6mg/l in Jamji to 12.8mg/l in Kerenga dam. Kerenga dam showed the greatest variability while Sambret showed the lowest. In Sambret, Chagaik and Jamji dams, the iron content was generally less than 2mg/l reaching a minimum value of 0.6mg/l. Sambret dam was found with the lowest variation (s=0.087) while Kerenga had the highest variation (s= 2.74). There was a significant difference between the dams (F=144.3; $p<0.05$). Kerenga dam Differed significantly with Chagaik (t=12.2; $p<0.05$), Sambret (t=11.9; $p<0.05$) and with Jamji (t=12.23; $p<0.05$), with the dam consistently showing the highest concentration (Table 4.7). Inter-month iron levels within the dams did not differ significantly (Fig 4.16). In addition, iron concentrations between Sambret, Chagaik and Jamji were not significantly different (p=0.05).

The mean iron levels in all the reservoirs were excess because of the nature ferruginous nature of the Kericho soils (Jaetzold and Schmidt, 1983). These high levels were attributed to high silt levels in the dam. These levels must have caused the low pH levels observed in the study area because Fe, Cu and Pb are precipitated at high pH (Solomons and Forstner, 1984). Nevertheless, the levels were higher than those of the Birim basin in Ghana (Ansa- Asare and Asante, 2000).



a) Fe levels in Sambret

b) Fe levels in Chagaik



c) Fe levels in Kerenga

d) Fe levels in Jamji

Figure 4.16 Mean monthly iron concentrations in Kericho reservoirs between November 2001-March 2002

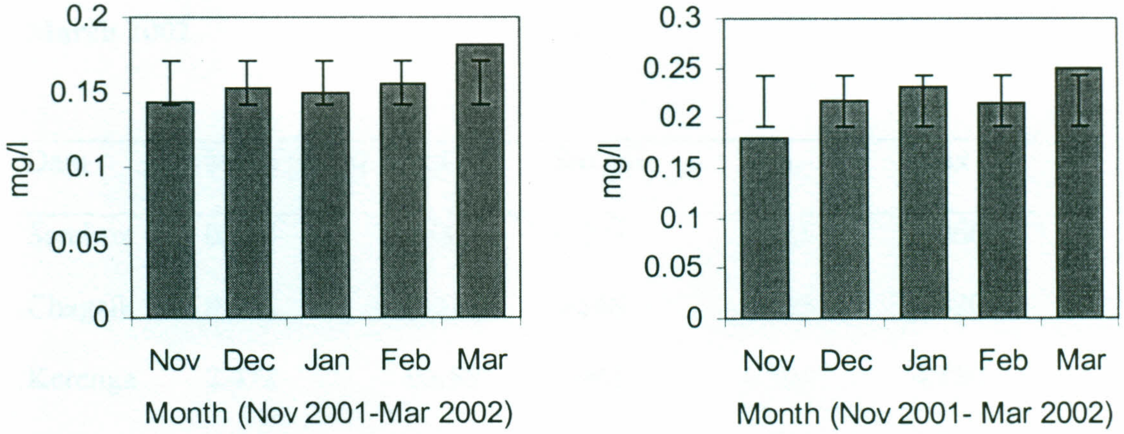
4.4.2 Magnesium

Table 4.8 **Magnesium concentrations in Kericho reservoirs between November 2001-March 2002**

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	0.156	0.004	0.026	0.100	0.200
Chagaik	0.218	0.007	0.047	0.137	0.320
Kerenga	1.749	0.071	0.452	0.960	3.100
Jamji	0.385	0.031	0.193	0.010	0.880

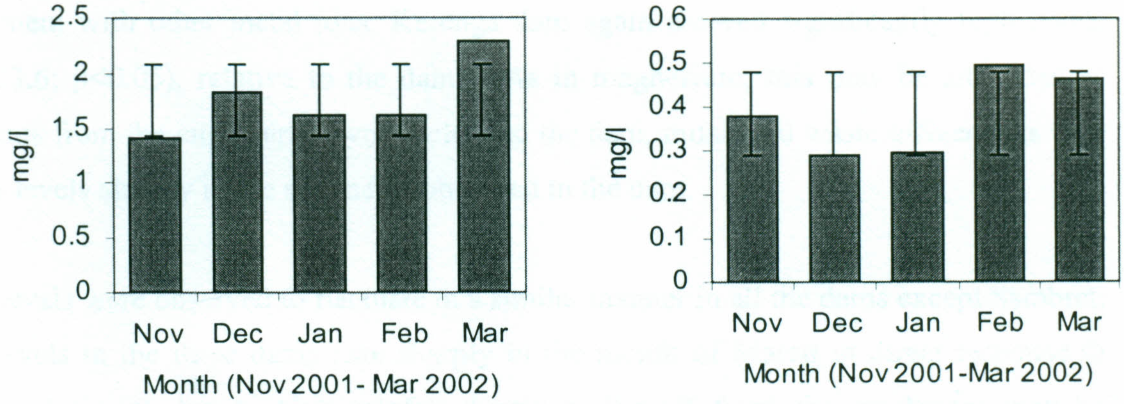
The levels of magnesium in the four dams ranged between 0.01 and 3.1mg/l (Table 4.8). There was a significant difference between Kerenga and all the other dams ($F_{(3,\ 156)}$= 372.8 ; $p<0.05$), Sambret dam and Jamji ($t=7.68$; $p<0.05$) and between Chagaik and Jamji ($t=5.25$; $p<0.05$). However there was no significant difference between Sambret and Chagaik. Monthly levels in all the dams did not differ significantly ($p=0.05$) in all the dams.

The mean magnesium levels in all the reservoirs were relatively low compared to other water bodies in the tropics (Ngetich, 1996; Njuguna, 1978). However, Kerenga dam did show relatively high levels. The very high levels of magnesium in Kerenga relative to the other three (Fig 4.17) is most likely due to the magnesium levels in the silt, run off from Kerenga Engineering Department as well as contamination from municipal wastes.



a) Mg levels in Sambret

b) Mg levels in Chagaik



c) Mg levels in Kerenga

d) Mg levels in Jamji

Figure 4.17 Five-month mean magnesium levels in Kericho reservoirs between November 2001-March 2002

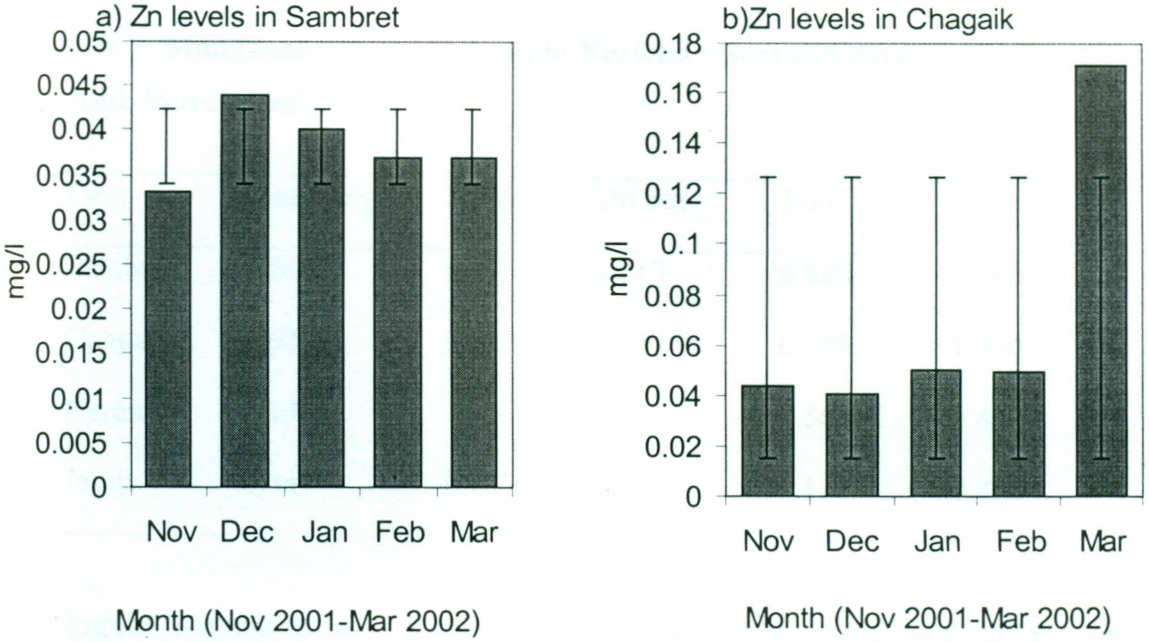
4.4.3 Zinc

Table 4.9 Zinc concentrations in Kericho reservoirs between November 2001-March 2002

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	0.038	0.001	0.009	0.021	0.066
Chagaik	0.071	0.016	0.103	0.035	0.520
Kerenga	2.472	0.152	0.961	1.200	4.580
Jamji	0.170	0.045	0.282	0.038	1.070

Zinc determination showed a fluctuation of between 0.021 and 4.58 mg/l over the study period. Table 4.9 and Figure 4.18 shows mean Zinc concentration in the four dams. In agreement with other metal ions, Kerenga dam again showed significantly high levels ($F=223.6$; $p<0.05$), relative to the dams. As in magnesium, this may be attributed to effluents from the engineering works close to the dam, municipal waste effluents as well as the levels already in the sediments observed in the dam.

Zinc levels were observed to flactuate in a similar manner in all the dams except Sambret. The levels in the three dams rose sharply in the month of March in direct response to increased runoff due to high rainfall densities. Runoff from the catchment may be contributing to these levels since zinc is applied in the farms as zinc oxide (ZnO) at the rate of 1.5kgha^{-1}a^{-1}.



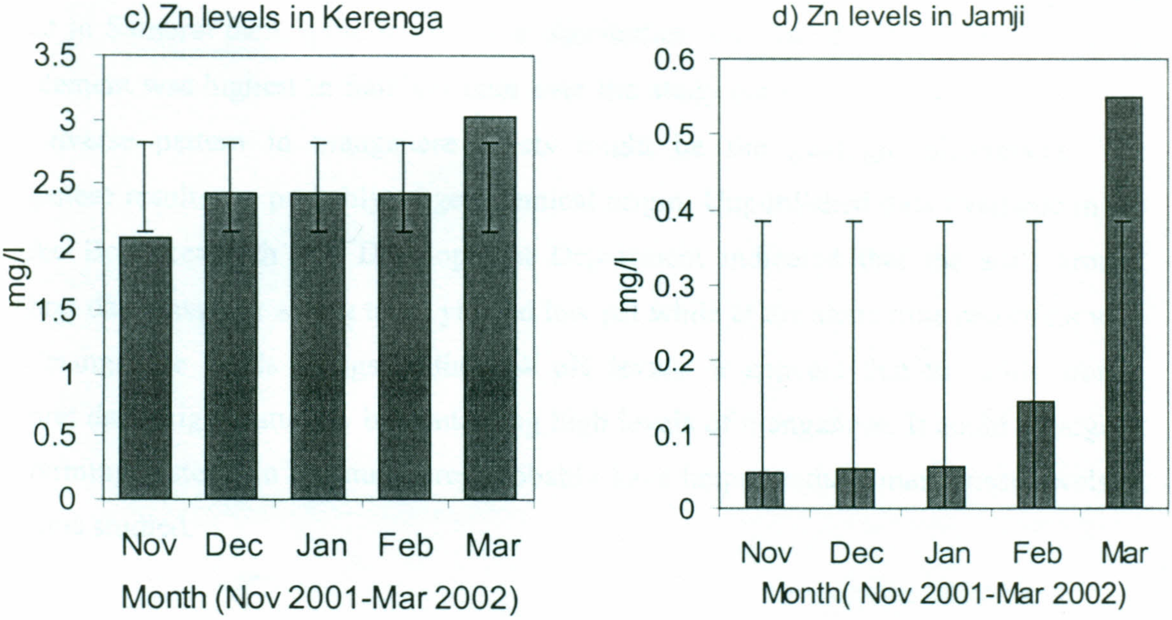


Figure 4.18 Mean monthly zinc concentrations in Kericho reservoirs between November 2001-March 2002

4.4.4 Manganese

Table 4.10 **Manganese concentrations in Kericho reservoirs between November 2001-March 2002**

Dam	Mean (mg/l)	Std err.	Std dev	Min.	Max
Sambret	1.560	0.035	0.219	0.980	2.000
Chagaik	1.087	0.022	0.139	0.920	1.800
Kerenga	1.172	0.069	0.433	0.560	2.480
Jamji	0.445	0.033	0.206	0.122	0.850

While higher concentrations of iron, zinc, copper, magnesium, and silver were consistently and significantly highest in Kerenga dam while at the same time being lowest in Sambret dam, quite an opposite distribution was found with manganese since this element was highest in Sambret dam over the study period. The possible reason for that inverse pattern in manganese levels might be the geologic differences. The manganese results are probably of geochemical origin. Unpublished data available in the Brooke Bond research and Development Department indicated that the soils around Sambret dam have, for a long time, yielded low pH while at the same time recording very high manganese levels alongside the low pH levels. It appears that the soils around Sambret dam might naturally be containing high levels of manganese. It could be argued that farming systems in the study area probably have helped reduce manganese levels in the dams studied.

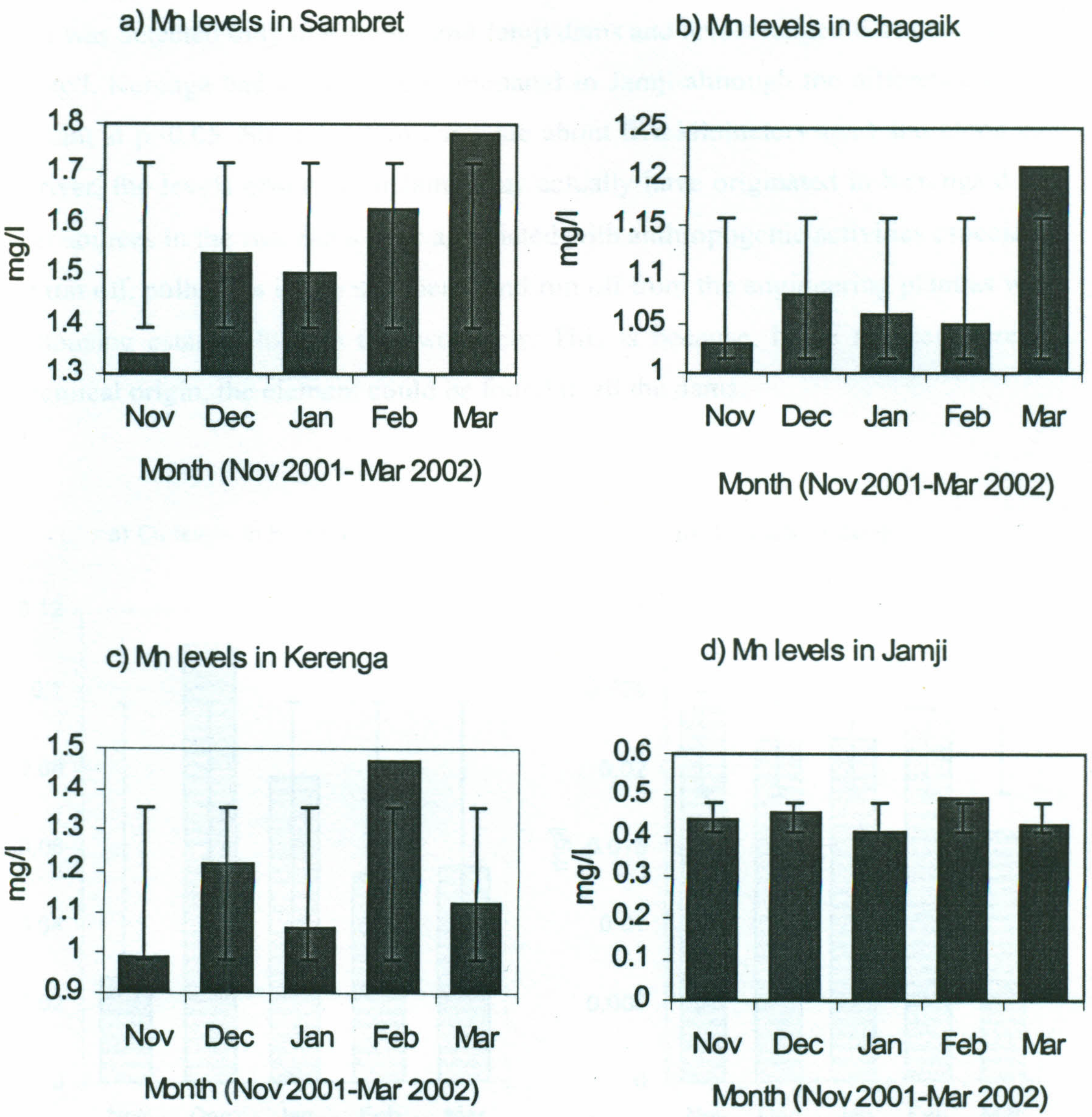
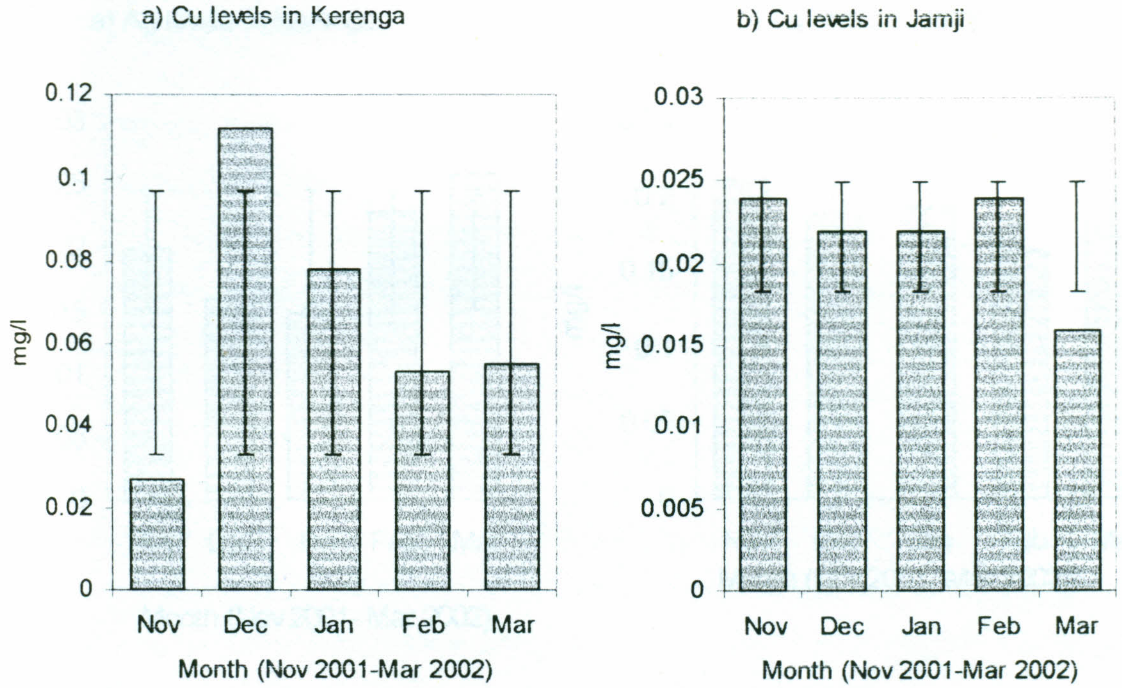


Figure 4.19 Mean monthly manganese concentration in Kericho reservoirs between November 2001-March 2002

4.4.5 Copper

Copper was detected only in Kerenga and Jamji dams and levels ranged between trace to 0.256mg/l. Kerenga had a high mean compared to Jamji although the difference is not significant at p=0.05. Since the two dams are about five kilometers apart and along the same river, the levels observed in Jamji may actually have originated in Kerenga dam. Copper sources in the two dams were associated with anthropogenic activities especially urban run off, pollutants in the sediments and run off from the engineering plant as well from housing estates close to the two dams. This is because, if the sources were of geochemical origin, the element could be found in all the dams.


a) Cu levels in Kerenga

b) Cu levels in Jamji

Figure 4.20 Five-month mean levels of copper in Kericho reservoirs between November 2001-March 2002

4.4.6 Silver

Silver was observed to fluctuate between non -detectable to 0.284 mg/l only in Kerenga and Jamji dams. There was no significant difference between the means of the two dams. The fact that Silver was not detected in Sambret and Chagaik water samples suggests that like Copper, the element may have originated from human settlement areas, municipal wastes and/or the engineering plant next to Kerenga dam. Also factory effluents, especially from Kericho and Jamji factories could be another source of silver levels into the reservoirs.

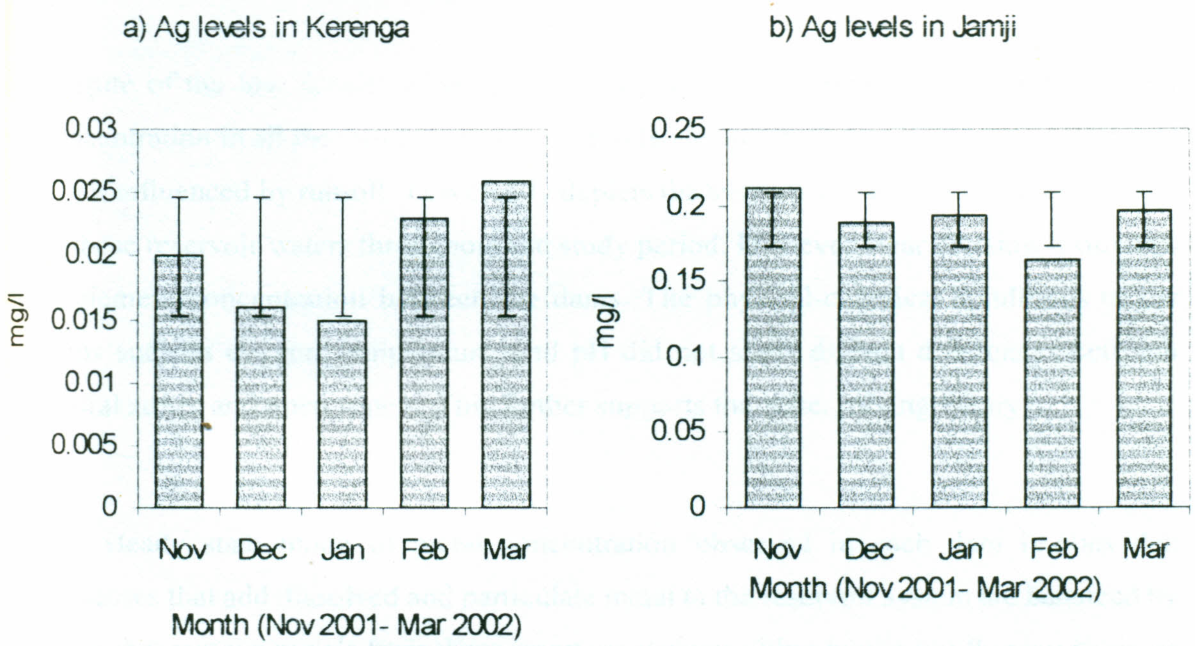


Figure 4.21 Five-month mean levels of Silver in Kericho reservoirs between November 2001-March 2002

4.4.7 Distribution of metal concentrations in the dams

The chemical composition of reservoir water is dependent upon the hydrogeochemical nature of the watershed, the water chemistry of the rivers feeding the reservoir, the internal chemical processing of the reservoir itself and the soil usage (Tundisi *et al.*, 1993). While metal ions were appreciably high in some dams (e.g. Kerenga), their levels had no direct or indirect relationship with algal density. It is therefore apparent that these substances did not control the increase and /or decrease in algal populations in the present study. The concentrations found were, in general, within the normal reported range (except for manganese and iron). The manganese results are probably of geochemical origin (Garcia-Miragaya and Sosa, 1994).

In spite of the low density of sampling sites per dam, the general uniformity of metal concentration in all the months in each dam indicate that their distribution is uniform and is not influenced by run-off. This clearly depicts the evenness as well as complete mixing of these reservoir waters throughout the study period. However clear division is obvious in element concentration between the dams. The physical-chemical conditions of the dams such as oxygen, temperature, and pH did not show distinct differences between littoral zones and open waters. This further supports the water mixing theory.

The steady state mode of metal concentration observed in each dam implies that processes that add dissolved and particulate metal to the reservoir system are balanced by those that remove metals from these reservoir systems either by the out flowing rivers or by transfer into the reservoir sediments. Even when it is difficult to establish a given source of pollution, one can postulate that moderate factors of enrichment originate from mixed inputs of agricultural, factory, domestic, urban and natural sources. The important factors that actually controlled the concentration of metals in these reservoirs were thought to be the concentration of metals in the inflowing river(s) and the relative residence time of the metals in the systems. This relative residence time was in turn dependent on distribution coefficients, the amount of allochtonous and autochthonous material imported or produced per unit time and the settling velocity of this particulate matter as expressed by its residence time.

Inorganic constituents may have dominated particulate matter in Kerenga dam relative to the other three dams. Sedimentation of heavy metals in Kerenga dam may largely be controlled by adsorption and/or uptake by biota (Sigg, 1987). In the absence of evidence of metal pollution in three of the four dams (Sambret and Chagaik to a large extent and Jamji to some extent), the concentrations found could be ascribed to geochemical factors. Lack of evidence for pollution of metals when agro-based tea processing factories have been in operation for more than 70 years could be attributed to limited data due to the scope of the current study. There is thus a need for a detailed research that would take into account runoff coefficients from tea processing factories, sewerage effluent coefficients from settlements as well as natural release coefficients and sediment characteristics- all of which will provide data that will be used to model water resources in the region.

CHAPTER FIVE: PHYSICO-CHEMICAL FACTORS AND MICROBIAL RELATIONSHIPS

5.0 INTRODUCTION

This Chapter presents the discussion of microbial activity in relation to the physico-chemical characteristics in Kericho reservoirs. Only significant variables are discussed in this chapter. Multiple Stepwise linear regression equations were developed to explain significant variables contributing to microbial activities in dams. Seven variables namely PO_4-P, nitrates, TP, TN, TSS, transparency and BOD were entered in the multiple stepwise linear regression equations developed.

5.1 FACTORS ENHANCING ALGAL DENSITIES IN THE RESERVOIRS

5.1.1 Nutrients

5.1.1.1 Phosphorus

An increased supply of PO_4-P resulted in higher chlorophyll-a level and hence total biomass turnover in the reservoirs. PO_4-P alone accounted for 69% of the total variation in chlorophyll-**a** content in Chagaik dam, 22% in Kerenga and 50% in Jamji (Fig 5.1-5.3). This suggests that PO_4-P was not limiting at any one moment in the dams over the study period. Indeed the levels of PO_4-P were significantly high to be limiting as suggested in many studies (Kalff, 1983; OECD, 1988; Harper, 1992; Kotut, 1998; Williams, 2000). Phosphorus limitation occurs at concentrations of biologically available phosphorus of less than 0.01mg/l (Meybeck, 1998; OECD, 1988).

The relationship between chlorophyll-a and total phosphorus (Figs 5.4-5.6) represents the part of nutrients present in the tissues of the algae (Mcdougall and Ho, 1991). Prediction of the chlorophyll-a content of Chagaik, Kerenga and Jamji dams could be done with 39%, 65% and 59% respectively if the concentrations of total phosphorus were known (Kalff, 1983). Thus, the limnological relationships governing the behavior of phosphorus in a reservoir and its transfer to primary producers were found to be common to all water bodies.

Figure 5.1 **Linear regression for chlorophyll-a and PO$_4$-P in Chagaik**

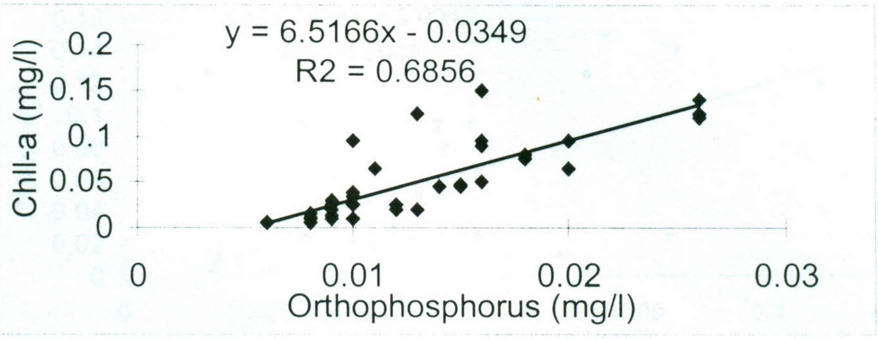


Figure 5.2 **Linear regression for Chlorophyll-a and PO$_4$-P in Kerenga**

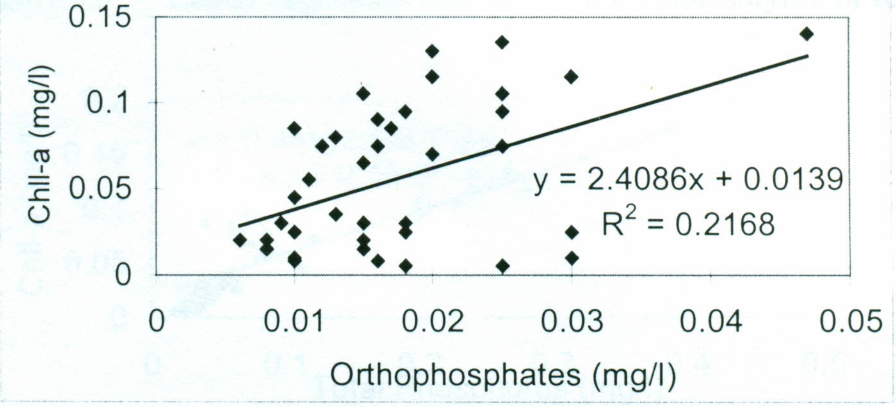


Figure 5.3 **Linear regression for PO$_4$-P and chloropyll-a in Jamji**

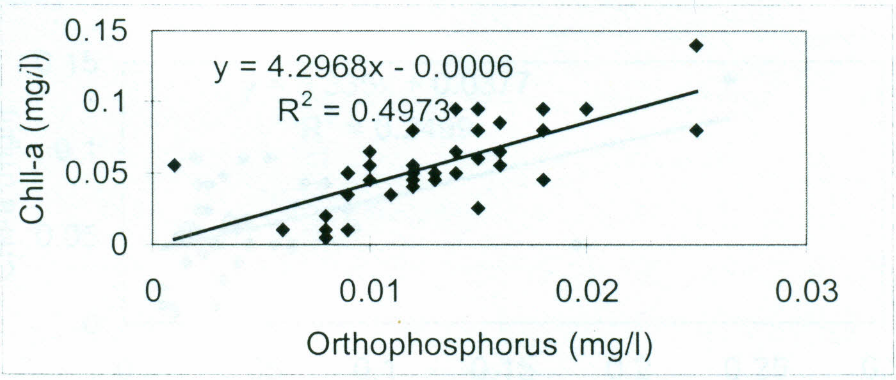


Figure 5.4 Linear regression for chlorophyll-a and TP in Chagaik

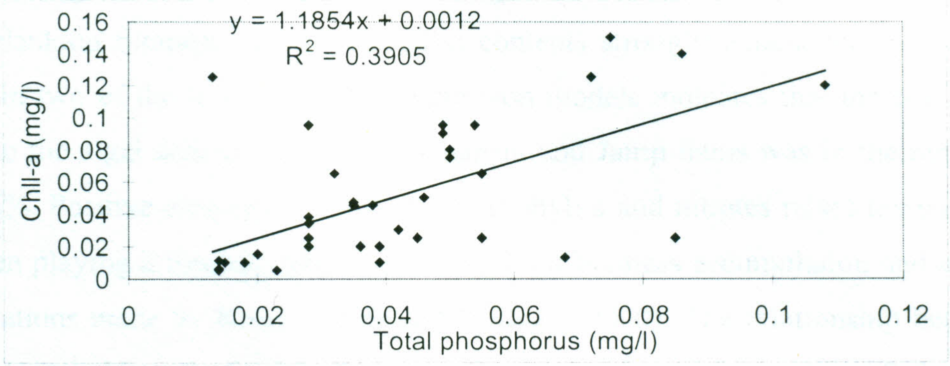


Figure 5.5 Linear regression line for TP and chlorophyll-a in Kerenga

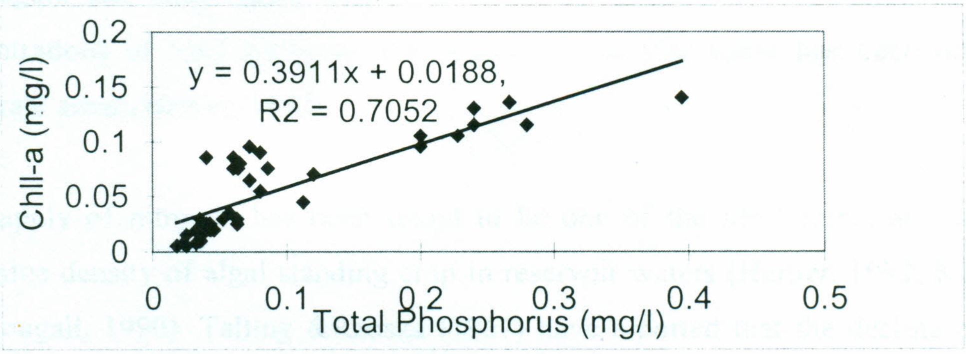
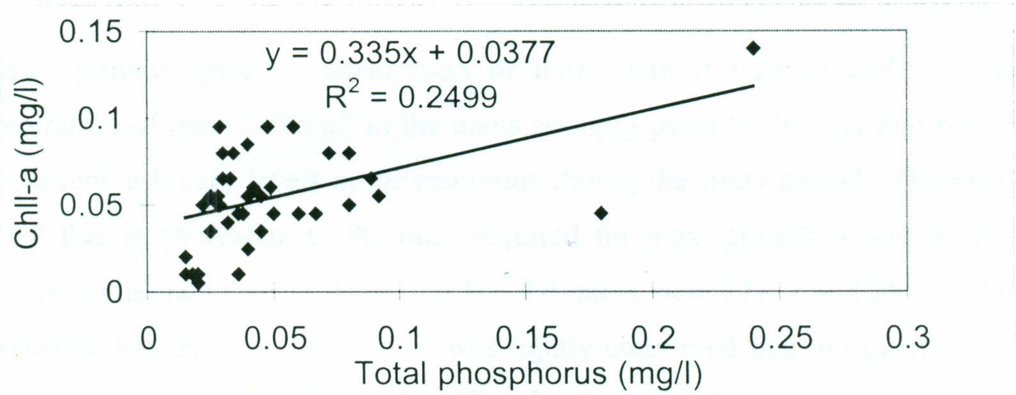


Figure 5.6 Linear regression for chlorophyll-a and TP in Jamji



5.1.1.2 Nitrogen

From the regression equations presented (Figs 5.7 & 5.8), it is observed that the yield of phytoplankton biomass (as chlorophyll-a content) strongly dependent upon the nitrate levels in two of the four dams. The regression models indicates that the contribution of NO_3- to the algal density variation in Chagaik and Jamji dams was in the range of 40% and 16%. Positive correlation between chlorophyll-a and nitrates raises the possibility of nitrogen playing a limiting role to phytoplankton biomass accumulation and agrees with observations made by Kotut (1998) and William (2000). The relationship between total nitrogen and chlorophyll-a was linear in Chagaik and Jamji dams (Fig 5.9 & 5.10). This relationship was thought to explain the part of nutrients present in the tissues of the algae (Mcdougall and Ho, 1991). This suggests that one could predict the chlorophyll-a content of Chagaik and Jamji dams with 75% and 59% confidence level respectively if the concentrations of total nitrogen were known. A similar trend has been observed in temperate areas (Harper, 1992).

The supply of nitrogen has been found to be one of the most important factors that determine density of algal standing crop in reservoir waters (Harper, 1992; Kalff, 1983; McCdougall, 1990). Talling &Rzoska (1967) have reported that the decline of NO_3- is responsible for the primary check to the increase of algae density. Nitrogen limitation occurs at concentrations of biologically available nitrogen of less than 2mg/l (Rast and Lee, 1983).

A mean orthophosphate concentration of more than 0.012mg/l and a mean nitrate concentration of over 3.88mg/l in the dams strongly point to the fact that both nutrients were present at luxury levels in the reservoirs during the study period. The ideal ratio of TN: TP that is equivalent to the ratio required for algal growth would be 16:1 (Ellis, 1989). In Jamji and Chagaik dams, the TN: TP ratios were 221: 1 and 281:1. These ratios demonstrate the fact that phosphorus was tightly conserved than nitrogen (Kalff, 1983). These observed ratio help to explain the observed distribution of nutrients within the dams

Figure 5.7 Linear regression for chlorophyll-a and nitrates in Chagaik

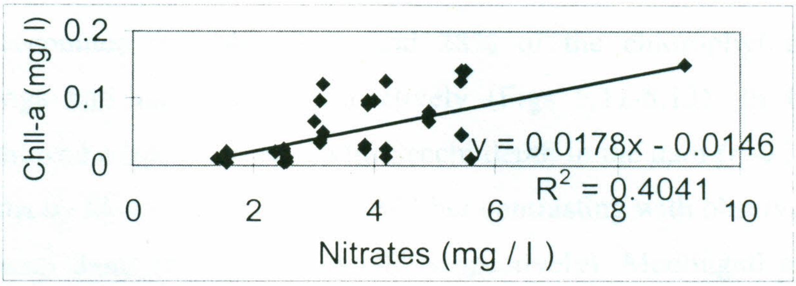


Figure 5.8 Linear regression for chlorophyll-a and nitrates in Jamji

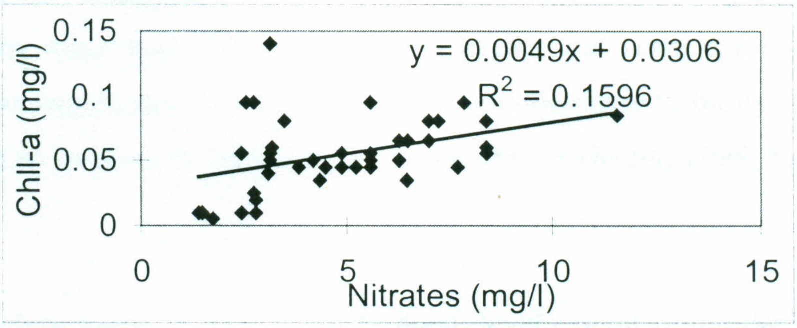


Figure 5.9 Linear regression for chlorophyll-a and TN in Chagaik

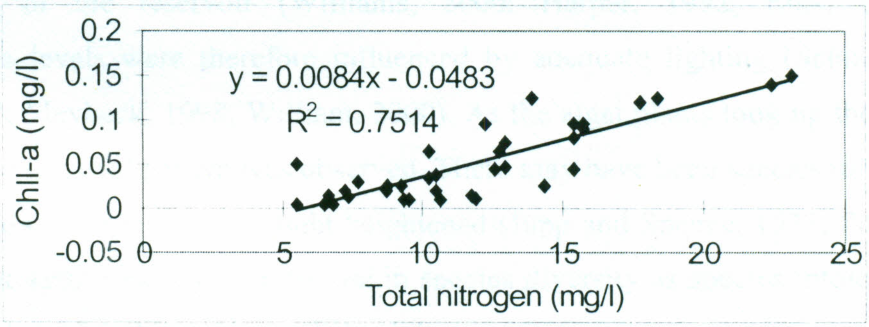
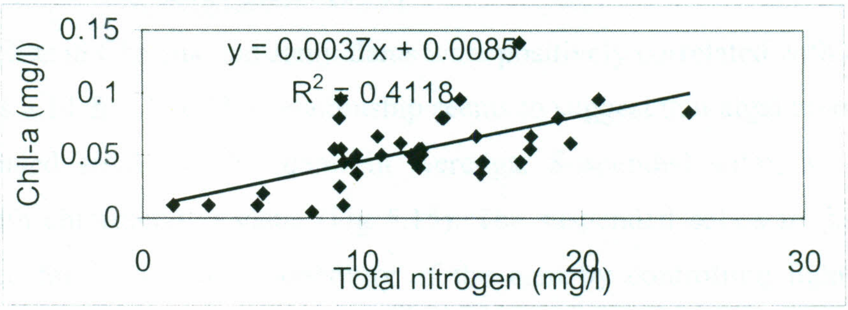


Figure 5.10 Linear regression for chlorophyll-a and TN in Jamji



5.1.2 Light penetration (Secchi disc transparency)

Transparency accounted for 24%, 16% and 28% of the chlorophyll-a variation in Chagaik, Kerenga and Jamji dams respectively (Figs 5.11-5.13). In Kerenga, dam chlorophyll-**a** showed a linear increase with Secchi depth in the dam (r=0.3969) agreeing with observations by Mcdougall and Ho (1990) but contrasting with observations made in Chagaik and Jamji dams (r=-0.4916; -0.5287 respectively). Mcdougall and Ho (1990) observed that the amount of light penetrating the water column of north lake, western Australia was a very important factor contributing to the growth of aquatic plants in that mass of standing water body. The situation in Chagaik and Jamji dams is possibly the result of environmental conditions bringing a bout a reduction in turbidity and at the same time promoting an increase in chlorophyll-a concentration (Kotut, 1998, Meybeck *et. al.*, 1998).

Light was therefore found to be a factor to algal development in the dams. Even when nutrients are in excess in a water body, the amount of light penetrating can limit primary productivity of the reservoir (Williams, 2000; Harper, 1992; Ellis, 1989). The chlorophyll-a levels were therefore influenced by adequate lighting (Schindler, 1978; Harper 1992; Meybeck, 1998; William, 2000). As the algal plants took up the nutrient, a change in the seasonal pattern was observed. There may have been species differentiation as competition for nutrients and light heightened (Jupp and Spence, 1977; Phillips *et al,* 1978; Harper 1992) leading to a decline in species diversity as species intolerant of low light, low nutrients and high suspended solids disappear.

5.1.3 Total suspended solids (TSS)

Suspended solids in Chagaik and Jamji dams were positively correlated with chlorophyll-**a** values (Figs 5.14 & 5.16). This relationship seems to suggest that algal blooms were the major suspended solids in this dam. In Kerenga, Suspended solids were inversely correlated with chlorophyll-**a** value (Fig 5.15). The suspended solids in the dams may have inhibited the biological productivity of the dam by controlling light penetration evidenced by low Secchi disc transparency in the dam.

Figure 5.11 Linear regression for chlorophyll-a and transparency in Chagaik

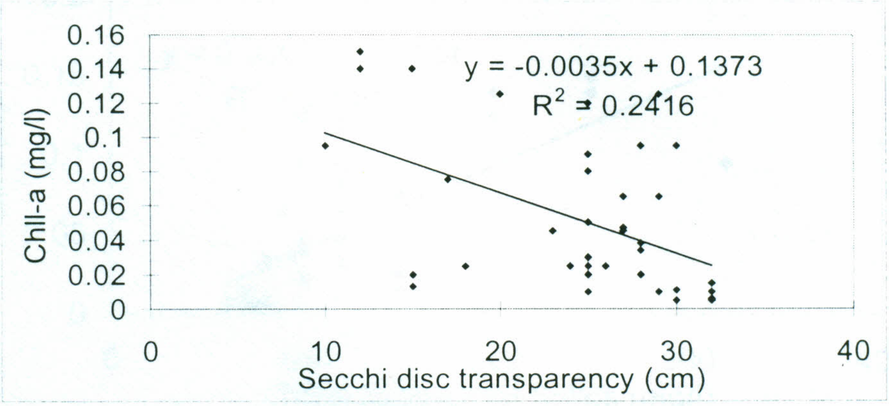


Figure 5.12 Linear regression for chlorophyll-a and transparency in Jamji

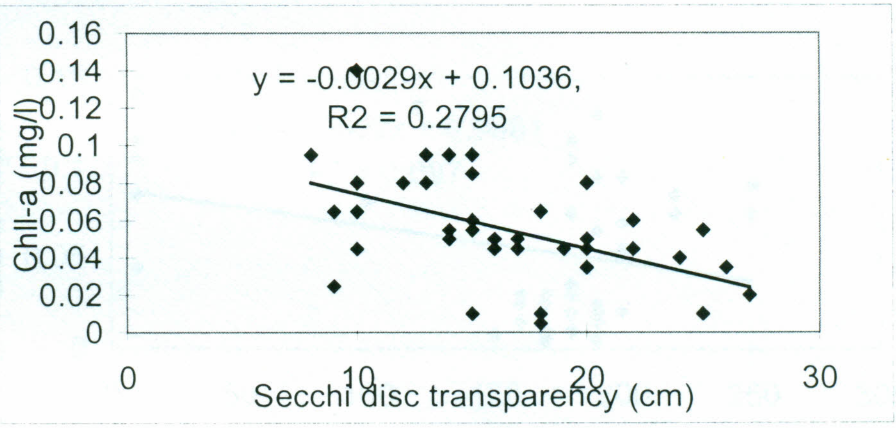


Figure 5.13 Linear relationship for transparency and chlorophyll-a in Kerenga

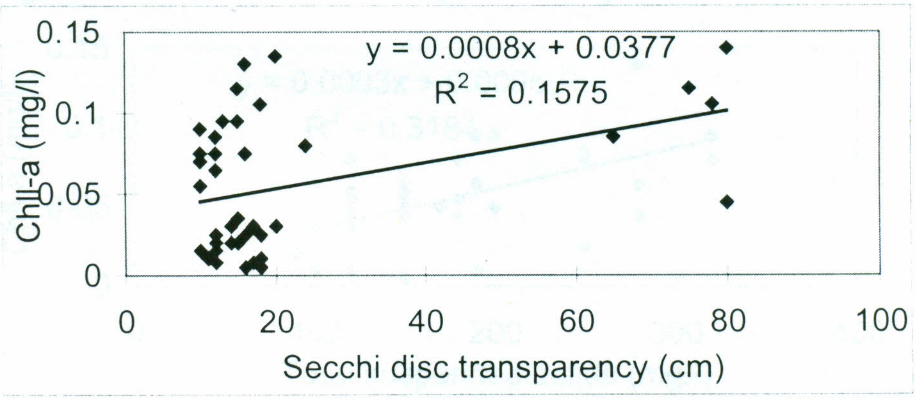


Figure 5.14 Linear regression for chlorophyll-a and TSS in Chagaik

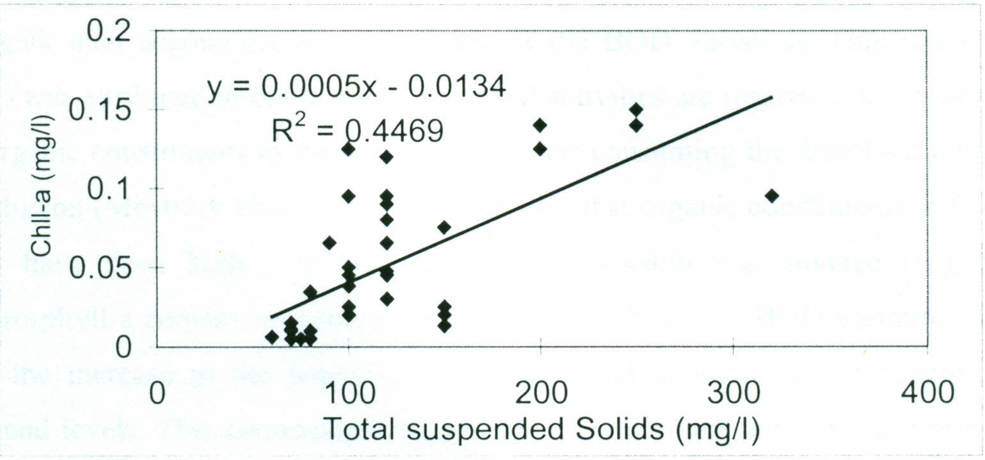


Figure 5.15 Linear regression for chlorophyll-a and TSS in Kerenga

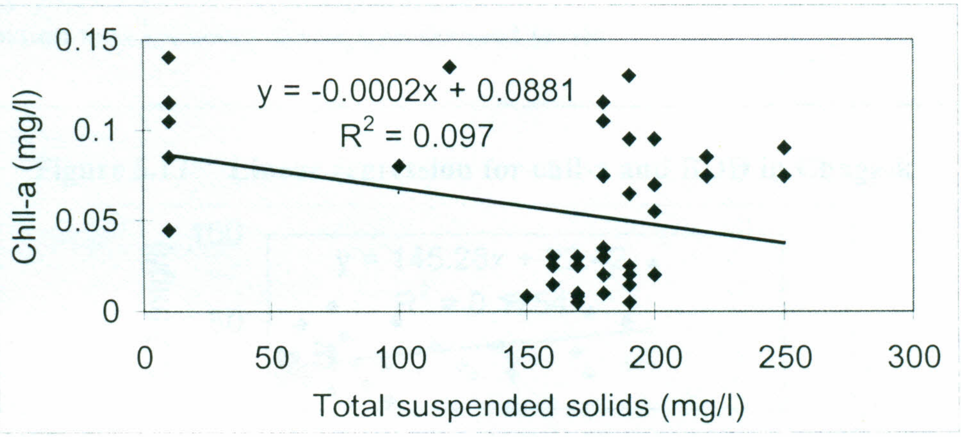
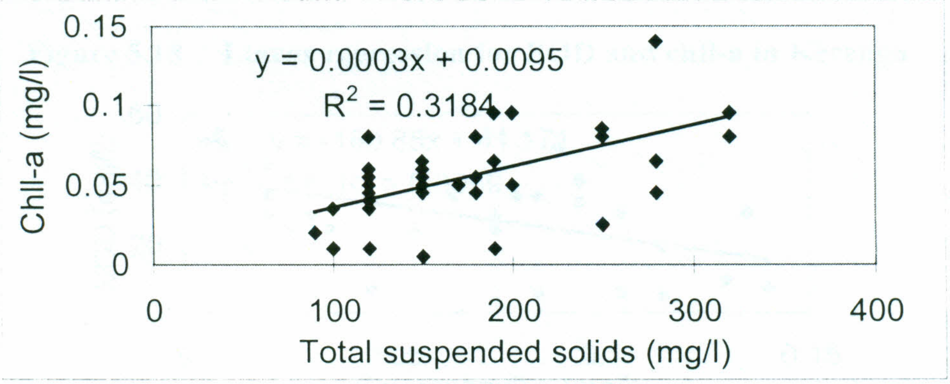


Figure 5.16 Linear relationship for chlorophyll-a and TSS Jamji



5.1.4 Biochemical oxygen demand

Chlorophyll-a content was positively related to Biochemical Oxygen Demand (BOD) in Chagaik dam accounting for about 18% of the BOD variation. This relationship (Fig 5.17) was attributed to the fact that microbial activities are responsible for the breakdown of organic constituents in the water sample thus consuming the dissolved oxygen during incubation (Meybeck *et al.*, 1998). This implies that organic constituents in Chagaik dam may have been high. In Kerenga, the relationship was inverse (Fig 5.18) with chlororphyll-a content accounting for more than 31% of the BOD variation. This means that the increase in the populations of algae lead to decreasing biochemical oxygen demand levels. This contrasted with the fact that microbial activities are responsible for the breakdown of organic constituents in the water sample thus consuming the dissolved oxygen during incubation (Meybeck *et al.*, 1998). This relationship was therefore attributed to the possibility of the algae continuing to respire oxygen even during incubation thus lowering the oxygen demand levels.

Figure 5.17 Linear regression for chll-a and BOD in Chagaik

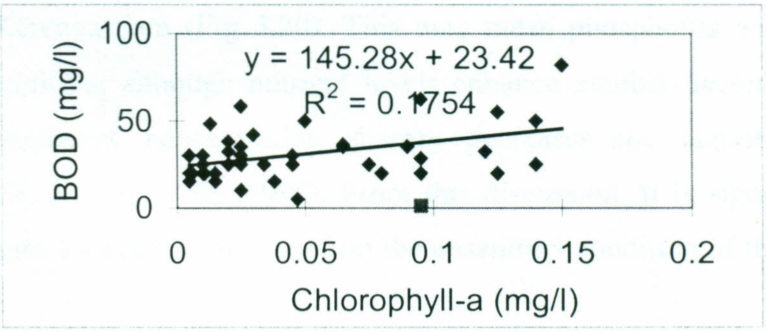
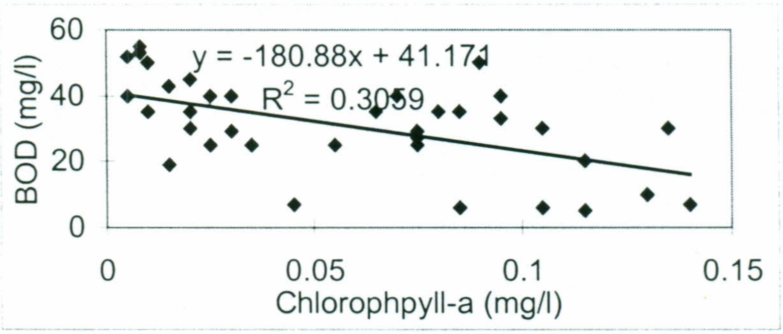


Figure 5.18 Linear regression for BOD and chll-a in Kerenga



5.2 FACTORS INFLUENCING BACTERIAL DENSITIES IN THE DAMS

5.2.1 Nutrients

5.2.1.1 Phosphorus

Orthophosphate levels were positively correlated (r=0.3212; 0.4628)) to faecal coliforms in Sambret and Jamji dams (Figs 5.19 & 5.21). This may be because phosphorus enhances aerobic decomposition of organic matter (Meybeck, *et al.,* 1998). The positive relationship could be attributed to microbial oxidation of the organic carbon sources of detritus for growth, which liberates dissolved phosphorus in the process (Harper, 1992). Faecal coliforms were attributed to anthropogenic activities. Also phosphorus contamination in aquatic ecosystems is mainly associated with human activities such as sewerage systems and effluents from settlements among others From these discussions, it is significant that the faecal coliform counts for both months in Jamji dam confirm the unsanitary condition of the reservoir.

The increase in phosphorus level was observed to lead to decrease in total coliform counts in Kerenga dam (Fig 5.20). This may mean phosphorus was present at luxury levels. In addition, although nutrient levels enhance aerobic decomposition of organic matter, phosphorus concentration sharply decreases the activity of heterotrophic organisms (Kronvang *et al.,* 1995). From this discussion, it is significant that the total bacterial count for both months confirm the unsanitary condition of the reservoirs.

Figure 5.19 Linear regression for PO4-P and faecal coliforms in Sambret

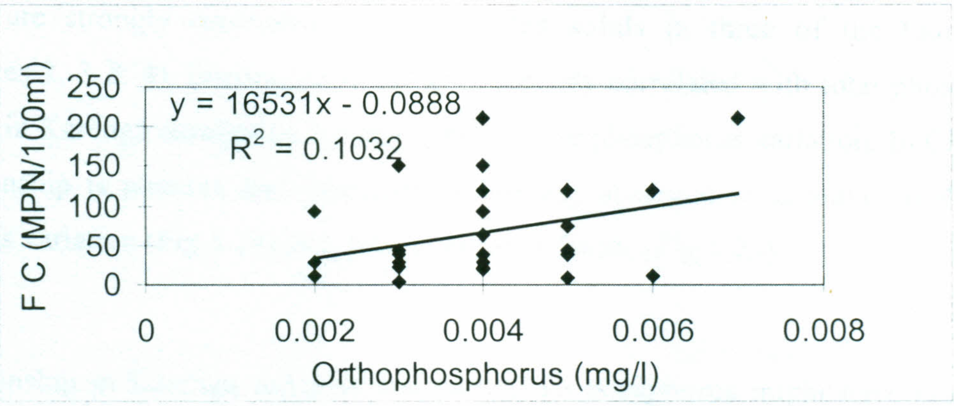


Figure 5.20 Linear regression for TP and total coliforms in Kerenga

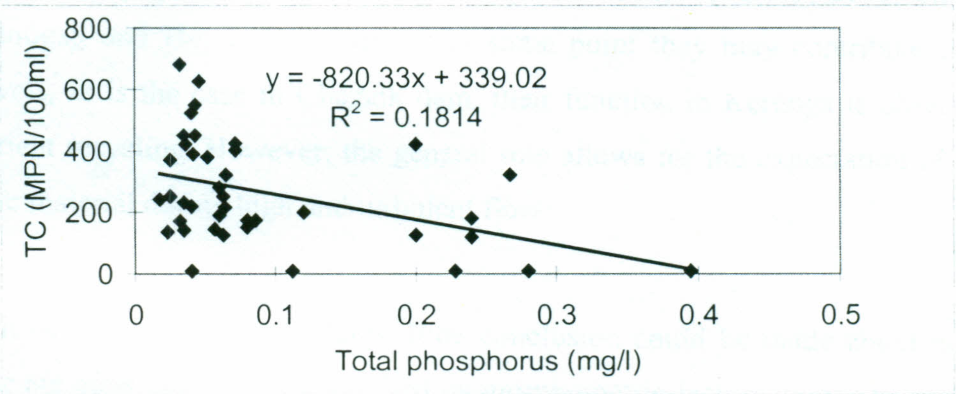
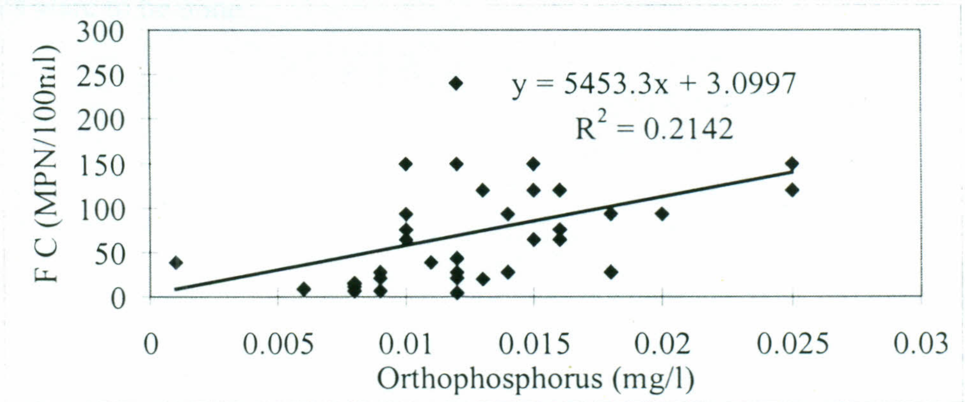


Figure 5.21 Linear regression PO4-P and faecal coliforms in Jamji



5.3 FACTORS AFFECTING NUTRIENT RELEASE TO RESERVOIR WATERS

5.3.1 Total suspended solids

Nutrients are strongly correlated with suspended solids in three of the four dams (Appendices 2, 3 & 4). Suspended solids are inversely correlated with total phosphorus (Fig 5.22) in Kerenga accounting for about 24% of the phosphorus variation. In Chagaik, the relationship is positive and suspended solids are observed to account for 40% of phosphorus variation (Fig 5.24) and 34% of nitrogen levels (Fig 5.23).

The relationship in Kerenga suggests that particulate phosphorus might have been low compared to dissolved molybdate reactive phosphorus (DMRP). Nevertheless, suspended solids are important in the recycling of nutrients in water bodies (Parson, 2001; Choubey, 1994; Mcdougall and Ho, 1991). Whereas at some point they may contribute to high nutrient levels, as is the case in Chagaik dam, their function in Kerenga is observed to inhibit nutrient recycling. However, the general role allows for the expectation of heavy minerogenic material during high and turbulent flow.

Due to high nutrient levels in the dams, little conclusion could be made about nutrient sinks. These are most likely to be controlled by morphometric factors unique to each dam and principles governing retention will only be possible if a more widespread comparison of larger data were to be done.

Figure 5.22 Linear relationship for TP and TSS in Kerenga

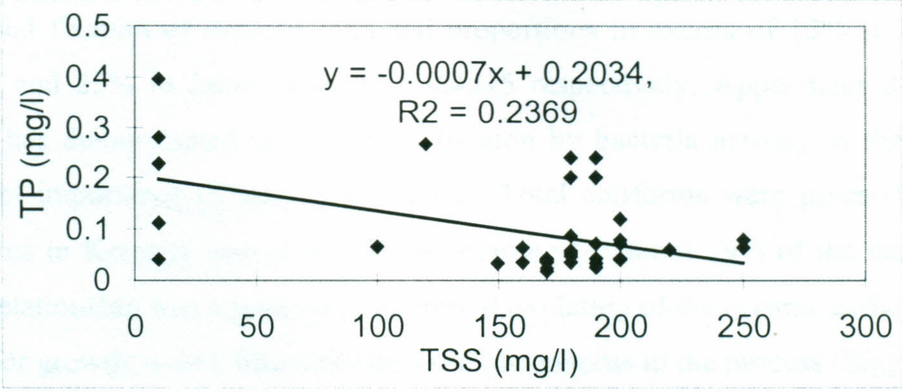


Fig 5.23 Linear regression for TN and TSS in Chagaik

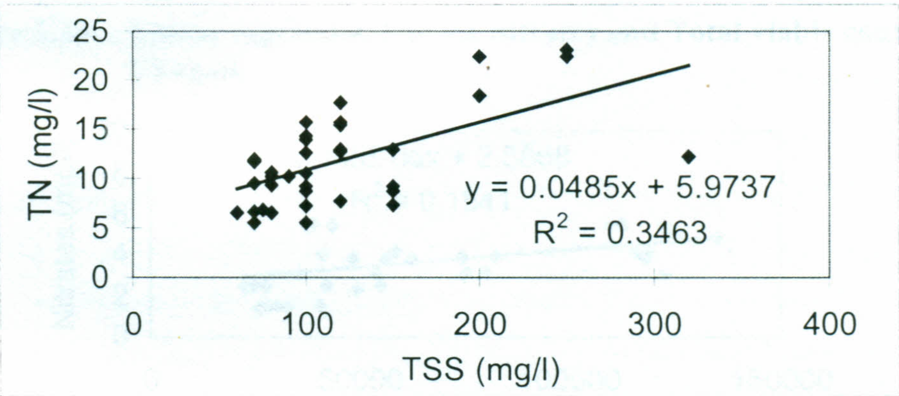
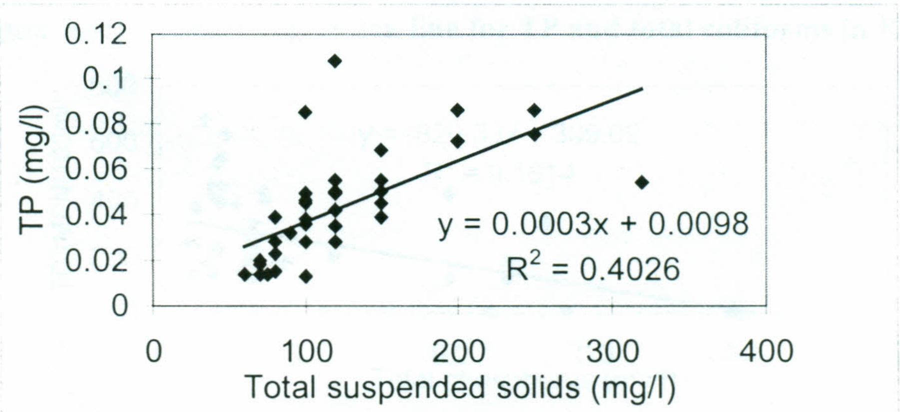


Figure 5.24 Linear regression for TP and TSS in Chagaik



5.3.2 Microbial Activities

There was a strong positive relationship between bacteria densities and nitrogen in Jamji and Chagaik dams. The relationship with total viable counts suggested that the processes of bacterial fixation of nitrogen supplied proportions in excess of 15% in the Chagaik reservoir and 25% in Jamji (r=0.3930; 0.4515 respectively; Appendices 2 & 4). This research has demonstrated that nitrogen fixation by bacteria activity in the dams is of paramount importance (Clarke *et al.,* 2000). Total coliforms were inversely related to phosphorus in Kerenga dam (Fig 5.26) accounting for about 19% of the variation. This inverse relationship was attributed to microbial oxidation of the organic carbon sources of detritus for growth, which liberates dissolved phosphorus in the process (Sigg, 1987).

Figure 5.25 Linear regression line for nitrates and Total viable counts in Chagaik

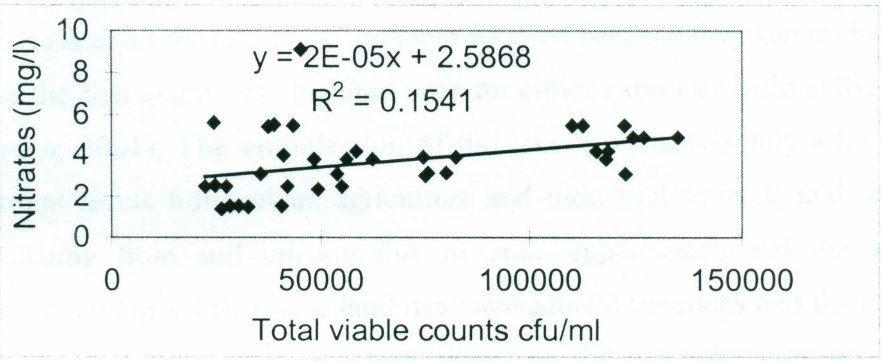
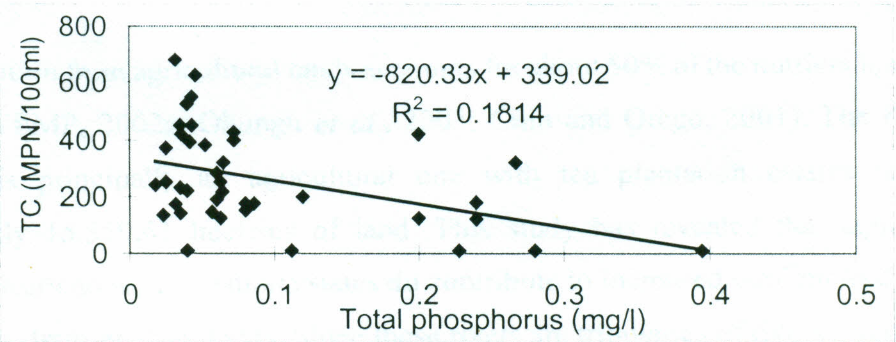


Figure 5.26 Linear regression line for TP and total coliforms in Kerenga



5.4 IMPLICATIONS OF RESULTS ON THE LAKE VICTORIA BASIN ENVIRONMENTAL MANAGEMENT

Lake Victoria Environment Management Programme (LVEMP), funded by the World Bank and European Union, is concerned with the management of the lake ecosystem for sustainable utilization of the lake resources in order to enhance socio-economic development of the riparian communities. The Programme is carrying out an intensive water quality and Limnology studies on Lake Victoria to gather information and shed light on the present condition of the lake ecosystem and the potential impact of human activities in the catchment. The programme recognizes the fundamental importance of proper land-use management practices in relation to the lake's ecology (LVEMP, 1999).

Following the lake's colonization by the water hyacinth (*Eichhornia crasipes)*, which blocked water transport, and fishing activities (LVEMP, 1995), the predominantly fishing community living around the lake has been most affected because they can no longer go out to fish and the fish quality has become unfit for either export or local consumption (Chin and Orego, 2001). The colonization of the lake has been largely attributed to increased nutrient levels from urban, agriculture and industrial sources, and sediment deposits originating from soil erosion due to poor upper catchment management practices. It has been argued that poor land use management practices and the free flow of nutrients and sediments have a negative impact on the eutrophication of the lake (Lamb, 2003).

The contribution from agricultural lands accounts for about 50% of the nutrient loads into the lake (LVEMP, 2002a; Okungu *et al.*, 2003; Chin and Orego, 2001). The Kericho catchment is principally an agricultural one with tea plantation estates covering approximately 15,559.61 hectares of land. This study has revealed that agricultural practices in Kericho tea plantation estates do contribute to increased nutrient loads to the river systems draining their lands. Since these rivers are tributaries of rivers Nyando and Sondu-Miriu that drain into lake Victoria, nutrients lost into them are transported into the lake in both dissolved and particulate forms. The algae blooms also accumulate these nutrients in the aquatic systems and increases at each trophic level. It therefore follows that the long-term future of lake recovery strategies will be bleak unless the high nutrient and sediment load from the Kericho catchments are controlled. Several interventions to prevent the lateral flows of water, sediments and nutrients from these landscapes into the lake need to be identified.

Water quality assessments and sanitary surveys within the catchment of the lake basin have revealed that water borne and water related diseases are very common. The most common diseases occurring mostly during the rainy seasons include cholera, typhoid and dysentery. These are associated with faecally polluted waters and poor sanitary conditions along the riparian communities. This research has obtained high levels of faecal coliforms in the water samples. This may be transported to the lake and contribute to the pollution level both in the lake and along the riparian communities. The diseases are dilapidating leading to reduced socio-economic performance of the communities and hence the associated poverty to the riparian communities.

Overall, sedimentation and nutrient run-off and urban and factory point source pollution have induced the rapid eutrophication of lake Victoria. Studies in the L. Victoria Catchment Rivers have revealed that human activities are the major causes of pollution in these rivers principally through agricultural and urban runoff, industrial effluents and domestic sewage (LVEMP, 2003; Otieno, 1995; LVEMP, 1995; Okungu *et al,* 2003). These studies have shown that nutrient influx into lake Victoria have had a significant impact in the physical chemistry and ecology of the lake as a whole. Loadings of nutrients and suspended solids have generally been related to individual river discharge as well as the kind of human activities along its course (Okungu *et al,* 2003).

To be able to contain the problems aforementioned, improved land use management practices for increased and sustained productivity and reduced non-point pollution loads into the rivers draining the catchment need to be implemented. Greater intervention measures against further deterioration of the Kericho catchment, particularly destruction of soil cover and poor land use practices should be intensified.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Reservoir waters of Kericho district contain a number of substances and the concentrations of each is determined by many processes: generation or transport from catchment areas, inflow into the reservoirs through runoff, and the physical-chemical and biological environments in these reservoirs. From the results discussed in chapter four and five the following conclusions were reached and drawn:

- The results of this study show that there is a significant occurrence of low pH values in these dams. Situations occurred where the pH values were as low as 4.8 units. The reservoir water was therefore found to be weakly acidic to neutral. Soil acidification or acidity was implicated in this scenario.

- The total amounts of copper, silver, magnesium, and zinc were within the normal range reported in literature. The average loads of such metal ions like iron and manganese were found to be above the average WHO (1987) specifications in drinking water.

- A consistent pattern of total metal was observed; that Kerenga showed highest levels virtually in all the metals except manganese. This fact suggest evidence of pollution in Kerenga dam from anthropogenic activities e.g. quarrying near the dam, the engineering works in Kerenga engineering department, the municipal council wastes as well as diffuse runoff from housing units. In addition, the solid residuals (TSS) were observed to be both a function of eroded material from farmlands and floating algae.

- Water quality was primarily observed to be controlled by the concentration of physical-chemical properties of suspended solids in the reservoirs given the correlation coefficients.

- The microbial densities found seem to express the conditions in the drainage basin rather than runoff itself. The data therefore has demonstrated the unsanitary condition of the reservoirs. This means that it is a health hazard for the people around the reservoirs to use this water for domestic purposes without any form of treatment.

- The sequence of phytoplankton algae change occurring in the reservoirs, subject to cultural eutrophication, is both a direct and indirect consequence of an increase in concentration of nutrients flowing through each component of the reservoirs' ecosystem. Both phosphorus and nitrogen were identified as possibly playing a limiting role for algae growth in the reservoirs of Kericho district.

- The study has demonstrated that there is a relationship between both phosphorus and nitrogen concentration in the dams on the one hand and chlorophyll-a content on the other. Water pH was also shown to influence phosphorus release from the sediment-water column in ways not fully understood (Ellis, 1989). Microbial activity was another parameter that was found to affect by either fixation in the case of nitrogen and /or microbial oxidation of the organic carbon sources to liberate phosphorus.

- Using nutrient concentrations and chlorophyll-a content the dams compared above were categorized as highly eutrophic for Chagaik, Kerenga and Jamji while Sambret was rated oligotrophic.

- Total suspended solids were positively correlated with trophic state of Jamji and Chagaik dams. In contrast some useful parameters were either uncorrelated or poorly correlated. For example, it was not possible to report on the relationship between metal ion concentration and the reservoirs trophic state using statistical methods applied. These methods have indicated that the levels of metals obtained did not, in any way, affect the growth of algal blooms. Also, temperature was not shown to be related to the trophic level of the reservoirs even when existing research has demonstrated such a relationship (Harper, 1992 ; Meybeck *et al.*, 1998 ; Kalff, 1983).

The study was able to come up with baseline information on the physico-chemical conditions of Kericho reservoir waters. The data obtained confirm that the reservoirs studied are subject to enrichment and contamination from agricultural activities and exhibit eutrophication and/or microbial responses. The data suggest that water contamination and enrichment is a regular occurrence in these reservoirs for both natural and cultural reasons. Since Kericho district forms a catchment for Rivers Sondu and Nyando that flow into lake Victoria, there is need to relate how the tea industry in Kericho, which uses high nitrogenous inorganic fertilizers contributes to the nutrient and suspended solid loads into the lake through nutrient loss and soil erosion to surface water bodies.

6.2 RECOMMENDATIONS

Extensive attempts to manage the adverse effects of eutrophication that could occur in these reservoirs have been proposed following the findings of this research. The control strategies have been divided into two main areas-those concerned with the reduction of nutrient loads to the reservoirs or in-reservoir concentrations, particularly of phosphorus, and those concerned with managing the existing high nutrient state within these reservoirs to minimize the adverse biological and chemical effects. The nature of tea crop yield is mainly determined by the economic decisions of the company management with little considerations of the effects upon the waters receiving runoff. Long-term catchment's management practices for control of diffuse sources nutrients in the drainage basin need to be developed and implemented. This can be achieved through some of the following:

- Land use management through the sparing use of fertilizer, farm practices intended to control topsoil erosion, application of surface layer mulch during periods of tea pruning, and the use of natural vegetation along the riparian reserve.

- Correct timing of quantities of fertilizer applications based upon crop needs rather than other farm management considerations such as labour and equipment availability.
- The use of slow-release fertilizers in pelleted form coupled with more accurate predictive models, which can be used to produce optimum crop response to fertilizer application.
- Use of a carefully planned and coordinated strategy at the individual farm holdings, incorporating education, soil conservation and careful and more scientific fertilizer application strategies.

The majority of point source discharges of wastewaters contributing to the nutrient and other pollutants in the reservoirs of Kericho district originated from urban and factory effluents. The sewage treatment processes primarily designed to reduce gross nutrient pollution otherwise referred to advanced wastewater treatment which help in the removal of BOD are recommended. Technologies to remove nutrients identified include:

- ❖ The use of biological processes that utilize the natural microbial transformations of the nitrogen cycle. This technology initially converts ammonia to oxidized nitrogen through nitrification and then denitrification to nitrogen gas.

- ❖ Phosphorus removal can be effected by chemical methods through chemical precipitation using iron or aluminium coagulants prior to primary sedimentation during the sewage treatment processes. This requires the corporate partnership with the Kericho municipal council.
- ❖ Creation of the pre-reservoir's upstream impoundment to function as a settling pond with a retention time of five days, may help to eliminate some percentage of total P and N from the inflow, as well as providing important reductions in coliform bacteria.

Alternatives or supplements to the removal of nutrients from catchment sources are their removal from within the reservoirs. A number of methods can be proposed.

- Sediment removal from the reservoirs especially Kerenga dam. The use of suction dredging by a watermaster dredger can be used in the desilting process of the dams. Although environmental impacts may occur especially as relates to the communities of organisms in the reservoirs, downstream consumers as well as silt disposal issues, these can be eliminated by carrying out an environmental impact assessment.

- Biomass harvesting of phytoplankton algae can also be employed which will remove its accumulated phosphorus. This is a widely used management tool for reducing nuisance growths and is short-term as relates to nutrient removal. It is therefore only recomended as a short term management strategy of controlling eutrophication.

Bacterial density was identified as one of the serious problems associated with the reservoirs studied. The stabilization ponds proposed above are only feasible for point sources of pollutants. Since other pollution sources identified include grazing of animals at the fringing zones of the reservoirs as well as human faeces due to use of pit latrines, it is recommended that:

- Cattle should be restricted from grazing at these zones. This can be achieved by planting more trees around the riparian reserve to protect the reservoirs from animal droppings.

- Strategies should be developed for monitoring the state of the pit latrines used by the farm workers and their state upgraded appropriately to minimize bacterial runoff during storm seasons.

- Ideally, all samples taken for domestic use especially food preparation and drinking should be free from coliform organisms. In practice, this standard is not always attainable hence a recommendation that no sample should contain >2 E. coli per 100ml in conjunction with total colifrm counts of <3/100ml of water would be ideal. Also coliform organisms should not be detected in 100ml of any two consecutive water samples.

6.3 FURTHER AREAS OF RESEARCH

- A study focusing on the sequence of change of phytoplankton species should be undertaken to provide a clear demonstration of the effects of artificial enrichment. Manifestations of eutrophication is best expressed qualitatively before quantitative measures are considered.

- Need for a study to consider a range of land-uses within the catchment areas of Kericho district and their relative magnitude of nutrient contribution to receiving water bodies in the region that drains into Lake Victoria in an attempt to understanding the source and nature of the pollution load in the lake.

- A similar study in public reservoirs within the district for comparison purposes is proposed. This study will be used to compare farm management strategies between the small-scale farmers and private sector holdings as a way of telling the best approaches as indicated by minimal adverse effects to receiving water bodies.

- A study on the nutrient levels in the sediments within the reservoirs can also be of great value in the understanding of nutrients recycling within the reservoirs.

- Fractional composition of heavy metals in the sediments of Kerenga dam should be studied. This is because sediments may act as a source of metals to overlying water when environmental conditions are altered. Therefore, bottom sediment is a suitable indicator when assessing and monitoring water quality of the dam. Within the total metal concentrations, only certain chemical forms are toxic to organisms. Therefore, a study on the bioavailability and mobile fractions of sediment-bound metals in Kerenga dam is proposed.

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APPENDICES

Appendix1 Multiple Stepwise Linear Regression matrix in Sambret reservoir

	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO$_3^-$	PO$_4^+$	pH	TC	TVC	Temp	TN	TP	Secchi	TSS
BOD	1																	
EC	-0.3293^{1}	1																
DO	-0.1428	0.0611	1															
FC	-0.079	0.0739	0.0413	1														
Fe	-0.2919	0.0916	0.0893	-0.1929	1													
Chll-a	0.1038	0.0033	0.0039	0.2841	-0.063	1												
Mg	-0.0704	-0.0645	0.1642	0.1095	0.2201	0.0358	1											
Mn	-0.3882^{1}	0.1764	0.2355	0.1553	0.3153^{1}	0.0094	0.4317^{2}	1										
NO$_3^-$	-0.2178	-0.2102	-0.0194	-0.1365	0.1155	-0.0471	0.0561	0.0389	1									
PO$_4^+$	-0.1039	0.0333	0.1989	0.3212^{1}	-0.218	-0.0517	0.0328	-0.0865	-0.1129	1								
pH	-0.1076	-0.148	-0.151	0.1282	-0.1312	-0.0731	0.1678	-0.0496	-0.1456	0.1079	1							
TC	-0.116	0.0755	-0.029	0.8111^{3}	0.0466	0.2742	0.2023	0.1633	-0.1408	0.1603	0.0229	1						
TVC	-0.0442	-0.0013	0.0302	0.4328^{2}	0.181	0.2854	0.1283	0.2453	-0.2339	-0.198	-0.1847	0.4524^{2}	1					
Temp	0.2041	-0.0329^{1}	0.0095	0.0474	-0.3286^{1}	0.0922	-0.0483	-0.3459^{1}	-0.3169^{1}	0.046	0.5593^{3}	0.0203	-0.2872	1				
TN	0.0302	-0.1514	-0.2171	0.0622	0.0499	0.1379	0.2462	0.201	0.4138^{2}	-0.0713	0.0381	0.0553	0.2092	-0.307	1			
TP	0.2383	0.0803	-0.0524	-0.312^{1}	-0.0918	0.0416	-0.3321^{1}	-0.0811	-0.1754	0.1559	0.0064	-0.2274	-0.143	-0.0255	-0.1526	1		
Secchi	0.1662	-0.2085	0.1185	0.0229	-0.0044	0.2889	0.1103	-0.2176	0.0493	0.1916	0.0898	0.0126	-0.1736	0.2902	-0.3382^{1}	0.0376	1	
TSS	-0.0851	0.1346	-0.2257	-0.0318	0.0185	-0.2865	-0.0804	0.103	-0.0977	0.2395	-0.0955	-0.0238	0.2182	-0.2696	0.2419	-0.0657	-0.9213^{3}	1
Zn	0.0086	-0.3165^{1}	0.0385	0.0055	-0.157	-0.1859	0.3544^{1}	0.1659	-0.2271	-0.0644	0.1517	0.046	-0.1062	0.202	-0.2003	-0.1915	0.0374	0.0057
	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO$_3^-$	PO$_4^+$	pH	TC	TVC	Temp	TN	TP	Secchi	TSS

r^{1} Significant at $p=0.05$, r^{2} Significant at $p=0.01$, r^{3} Significant at $p=0.001$

Appendix 2 Multiple Stepwise Linear Regression matrix in Chagaik reservoir

	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO_3^-	PO_4^+	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn
BOD	1																		
EC	0.1377	1																	
DO	0.5794^3	0.3894^1	1																
FC	N/A	N/A	N/A	1															
Fe	0.0289	-0.0043	0.1366	N/A	1														
Chll-a	0.4188^2	0.0492	-0.0899	N/A	0.1245	1													
Mg	0.0678	0.1431	0.2918	N/A	0.1245	-0.1577	1												
Mn	-0.0128	-0.0349	0.0228	N/A	0.1877	0.0533	0.0484	1											
NO_3^-	0.4876^2	-0.167	-0.0345	N/A	-0.061	0.6357^3	-0.0474	0.0347	1										
PO_4^+	0.3629^1	0.1483	-0.0657	N/A	0.1627	0.828^3	-0.0367	0.0023	0.4793^2	1									
pH	0.4329^2	0.1946	0.5488^3	N/A	0.0833	0.0598	0.06	0.2299	0.0408	-0.1018	1								
TC	0.0707	0.0011	0.01177	N/A	0.1819	0.2503	-0.0491	0.322^1	0.2105	0.2069	0.1534	1							
TVC	0.0244	-0.2083	-0.0993	N/A	0.1749	0.331^1	0.1183	0.1086	0.3926^1	0.2054	-0.0687	0.532^3	1						
Temp	0.3455^1	0.2634	0.4953^2	N/A	0.2204	0.1309	0.1851	0.2782	0.0382	0.0833	0.774^3	0.1748	-0.0905	1					
TN	0.3091	-0.0029	-0.1592	N/A	0.1654	0.8668^3	-0.1711	0.1109	0.669^3	0.7406^3	0.0131	0.1079	0.1793	0.1246	1				
TP	0.5947^3	0.2109	0.0833	N/A	0.0079	0.6249^3	0.0136	-0.0248	0.5625^3	0.7506^3	0.0948	0.0989	0.1779	0.2957	0.6038^3	1			
Secchi	-0.5797^3	0.1923	-0.0498	N/A	-0.1064	-0.4916^2	-0.1027	0.0448	-0.5168^3	-0.5482^3	-0.088	-0.0239	-0.0379	-0.2152	-0.458^2	-0.6506^3	1		
TSS	0.6044^3	-0.1845	-0.0234	N/A	-0.0293	0.6685^3	-0.0018	-0.0749	0.5875^3	0.6562^3	0.0257	0.0073	0.01	0.0873	0.5885^3	0.6345^3	-0.8829^3	1	
Zn	-0.0083	0.1826	0.1958	N/A	0.3076	0.08	0.3877^1	-0.0145	0.1381	0.1016	-0.0417	0.1186	0.1945	0.1143	0.1939	0.0001	-0.0355	0.0015	1
	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO_3^-	PO_4^+	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn

r^1 Significant at $p=0.05$, r^2 Significant at $p=0.01$, r^3 Significant at $p=0.001$

Appendix 3 Multiple Stepwise Linear Regression matrix in Kerenga reservoir

	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO$_3^-$	PO$_4^+$	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn	Ag	Cu
BOD	1																				
EC	0.0317	1																			
DO	0.4054^2	0.0026	1																		
FC	0.229	0.0173	0.1124	1																	
Fe	0.1723	0.2276	-0.0034	0.0622	1																
Chll-a	-0.5531^3	-0.0241	-0.4331^2	-0.3396^1	0.0531	1															
Mg	-0.0443	0.0922	0.015	0.1281	0.0219	0.0045	1														
Mn	-0.0288	-0.1331	-0.2195	0.0355	0.0141	-0.0844	0.1837	1													
NO$_3^-$	0.1066	-0.0577	0.0351	0.1778	0.0977	0.1328	0.2549	-0.0994	1												
PO$_4^+$	-0.1844	0.1583	-0.312	-0.1627	0.0595	0.4656^2	-0.2142	-0.0998	0.0242	1											
pH	-0.4739^2	0.0808	-0.2812	0.3111	0.1687	0.1774	0.2016	0.1231	-0.0852	-0.0476	1										
TC	0.4612^2	0.1804	0.186	0.7361^3	0.2338	-0.412^2	0.0925	-0.156	0.0973	-0.2395	0.1619	1									
TVC	0.0936	-0.212	-0.0552	0.5545^3	-0.0395	-0.1098	-0.0277	0.0548	-0.0637	0.0191	0.0697	0.2482	1								
Temp	-0.2406	0.024	-0.0716	0.1569	-0.2628	-0.0865	-0.1565	-0.026	-0.3682^1	0.0575	0.3834^1	0.0961	0.1391	1							
TN	-0.1951	-0.1675	-0.422^2	0.19	0.6669^3	0.1442	0.1981	0.0402	0.3525^1	0.1182	0.1759	-0.0883	0.1582	-0.0943	1						
TP	-0.5646^3	-0.1398	-0.3912^1	-0.3165^1	-0.122	0.8397^3	0.0126	-0.098	-0.0098	0.5959^3	0.2593	-0.4259^2	-0.1456	0.089	0.1872	1					
Secchi	-0.6818^3	-0.1001	-0.0482	-0.4404^2	-0.3066	0.3969^1	-0.049	-0.169	-0.0086	-0.2724	0.1779	-0.538^3	-0.4613^2	0.1742	-0.0775	0.5468^3	1				
TSS	0.622^3	0.0721	0.0751	0.3224^1	0.3196^1	-0.3115^1	-0.0438	0.0231	-0.005	-0.2201	-0.2336	0.4897^2	0.4331^2	-0.1893	0.0193	-0.4868^2	-0.9374^3	1			
Zn	0.1123	0.0226	0.1322	0.3218^1	0.0036	0.0581	0.2242	-0.0401	0.0965	-0.0827	0.11	0.1732	0.3636^1	-0.267	0.0296	-0.0007	-0.353^1	0.3393^1	1		
Ag	0.4043^2	0.1348	0.2026	-0.0248	0.1768	-0.0757	-0.043	0.0229	-0.0023	0.0822	-0.1064	0.1144	-0.0413	-0.0267	-0.1548	-0.1351	-0.2957	0.2556	0.0406	1	
Cu	0.1704	0.33^1	-0.0053	0.2958	0.2244	-0.2148	0.0825	-0.0083	0.0463	-0.1949	0.2502	0.5848^3	-0.0627	0.0739	0.1228	-0.1895	-0.3284^1	0.3311^1	0.0343	0.0307	1
	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO$_3^-$	PO$_4^+$	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn	Ag	Cu

r^1 Significant at $p=0.05$, r^2 Significant at $p=0.01$, r^3 Significant at $p=0.001$

Appendix 4 Multiple Stepwise Linear Regression matrix in Jamji reservoir

	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO_3^-	PO_4^+	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn	Ag	Cu
BOD	1																				
EC	0.1096	1																			
DO	0.2037	-0.0263	1																		
FC	0.097	0.1638	-0.0812	1																	
Fe	-0.0582	-0.1172	-0.1314	0.0369	1																
Chll-a	-0.0639	0.0496	0.0073	0.4803^{2}	-0.0099	1															
Mg	0.0686	-0.35^{1}	-0.2251	0.0591	0.2629	0.0646	1														
Mn	-0.3199^{1}	0.0555	-0.306	0.0868	0.0366	0.1031	0.1945	1													
NO_3^-	0.2566	-0.1829	-0.08	0.537^{3}	0.2107	0.3995^{1}	0.0633	-0.103	1												
PO_4^+	-0.079	0.278	0.0875	0.4628^{2}	-0.2391	0.7052^{3}	-0.0625	0.0913	0.1628	1											
pH	-0.0207	-0.2679	-0.0684	-0.1966	0.2235	-0.306	-0.1165	-0.4795^{2}	0.308	-0.4676^{2}	1										
TC	-0.0003	-0.0091	-0.0959	0.5338^{3}	0.1466	0.465^{2}	0.0632	-0.2011	0.3823^{1}	0.1846	0.0267	1									
TVC	-0.1125	-0.0779	-0.1391	0.1941	0.2962	0.2737	-0.0202	-0.0676	0.1856	0.2868	0	0.4375	1								
Temp	-0.0359	-0.0728	0.001	-0.1679	-0.2589	-0.0062	-0.075	-0.2928	-0.1855	0.0237	0.166	0.1847	0.1572	1							
TN	0.1294	-0.0518	-0.0519	0.4717^{2}	0.1749	0.6417^{3}	0.0874	-0.1596	0.7223^{3}	0.3726^{1}	0.153	0.4515^{2}	0.3985^{1}	-0.0619	1						
TP	-0.0391	0.0484	-0.0452	0.2011	-0.1718	0.4999^{2}	0.0031	-0.0998	0.0103	0.5536^{3}	-0.1224	0.1692	0.2043	0.3927^{1}	0.2275	1					
Secchi	0.1115	0.0292	0.2387	-0.279	-0.0987	-0.5287^{3}	-0.1641	-0.0833	-0.049	-0.525^{3}	-0.3903^{1}	-0.286	-0.3823^{1}	0.0541	-0.2412	-0.3793^{1}	1				
TSS	-0.1542	-0.0342	-0.1709	0.3178^{1}	-0.0145	0.5643^{3}	-0.0179	-0.1326	0.1516	0.6131^{3}	-0.4111^{2}	0.3821^{1}	0.4012^{2}	0.0979	0.218	0.3941^{1}	-0.8596^{3}	1			
Zn	0.1458	0.2174	-0.1774	0.1627	0.2244	-0.1809	-0.179	-0.1326	0.1516	-0.1613	-0.1695	0.0602	0.0191	-0.1891	0.0445	-0.2057	0.1101	-0.2444	1		
Ag	0.1255	0.2583	-0.043	0.0607	-0.0643	0.1398	0.0032	-0.062	0.0628	0.2665	-0.0338	0.0938	0.1736	0.2246	0.0989	0.295	-0.3421^{1}	0.298	0.1182	1	
Cu	-0.2592	0.1115	-0.0571	0.3544^{1}	-0.1093	0.2371	-0.139	0.0913	0.1372	0.3038	-0.081	0.0002	0.1244	0.0684	0.1448	0.2282	-0.0193	0.1484	-0.0277	0.1159	1
	BOD	EC	DO	FC	Fe	Chll-a	Mg	Mn	NO_3^-	PO_4^+	pH	TC	TVC	Temp	TN	TP	Secchi	TSS	Zn	Ag	Cu

r^1 Significant at $p=0.05$, r^2 Significant at $p=0.01$, r^3 Significant at $p=0.001$