

**ASSESSMENT OF WATER QUALITY AND FISH
PRODUCTIVITY IN THREE UNDRAINABLE RESERVOIRS
OF NAROMORU, NYERI COUNTY, KENYA**

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**A thesis submitted in partial fulfillment of the requirement for
the award of the degree of Master of Science (Animal Ecology)
in the School of Pure and Applied Sciences of Kenyatta
University**

November, 2011

Declaration

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

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Dedication

This work is dedicated to my beloved parents Moses Ndiwa and Janepher Ndiwa, my Wife Tabitha Magero, Brother Dr. Dan Ndiwa and Sister Mercy Ndiwa.

Acknowledgement

I wish to express my deep and sincere gratitude to Dr. Benson M. Mwangi and Dr. Eunice Kairu of Department of Zoological Sciences, Kenyatta University and to Dr. Dorothy Wanja Nyingi of Ichthyology Section, Department of Zoological Sciences, National Museums of Kenya for their supervision and guidance that led to successful completion of this work. May the almighty God bless you abundantly. I would also like to acknowledge the technical assistance given to me by S. Gichobi, P. Makokha, L. Munyua, J. Mwangi and P. Wambua from Kenyatta University, and E. Njagi and J. Gathua of the Ichthyology Section (NMK).

This research was made possible through funding from the Kenya Agricultural Productivity Projects (KAPP), whom I am greatly indebted for their support. I am also grateful to Kenyatta University and the National Museums of Kenya (NMK) for allowing me to use their laboratory and library facilities.

Last but not least, I wish to thank my parents Mr. Moses Ndiwa and Janepher Ndiwa for sacrificing their resources so as to see me through this course. Special thanks also go to my brother Dan Ndiwa and my wife Tabitha Magero for their financial and moral support they gave me during my studies. My prayer is that may God bless you all for your assistance.

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Abbreviations and acronyms

APHA – American Public Health Association

DO - Dissolved oxygen

ESP – Economic Stimulus Plan

FAO – Food and Agricultural Organization of United Nations

GPP – Gross primary production

MEI – Morpho-Edaphic Index

NMK – National Museums of Kenya

NPP – Net primary production

PCA – Principal Component Analysis

TDS – Total dissolved solutes

WHO - World Health Organization of United Nations

Abstract

Naromoru is a semi-arid area located on the leeward side of Mt. Kenya, and has more than 15 small sized reservoirs constructed to provide water for livestock, irrigation and domestic use. To increase their usefulness, some reservoirs have been stocked with fish, even though no studies have been carried out to establish their suitability and potential for fish culture. This study therefore aimed at assessing the water quality, fish food availability and fisheries productivity of three undrainable reservoirs of Naromoru, selected on the basis of their location, accessibility, size and fish availability. The study was carried out between September 2008 and February 2009. Water quality was determined by assessing the physical (temperature, water depth, transparency) and chemical (pH, dissolved oxygen, electrical conductivity and total dissolved solutes) characteristics. Water samples were also collected and concentrations of the major anions (bicarbonates, sulphates and chloride), cations (potassium, calcium, magnesium and sodium), heavy metals (copper and lead) and nutrients (nitrates and phosphates) measured using Atomic Absorption Spectrophotometer (ASS). Phytoplankton communities were sampled by filtering 15 litres of water through 0.063 μ m mesh plankton net, and their relative abundance, species composition and diversity determined. Similarly, zooplanktons were sampled by filtering 10 litres of water through 100 μ m, while benthic invertebrates were sampled using an Ekman grab sampler and their species composition, diversity and relative abundances determined. Fish were caught by seine and gill nets, identified and measured for standard lengths (cm) and weights (g). Length and weight measured were used in analysis of relative condition factors and length-weight relationship. Data was analysed by Kruskal-Wallis test, principal component analysis and Mann-Whitney test. Results showed that physical and chemical characteristics fell within the recommended guidelines for fish culture in all the three reservoirs, with the exception of water transparency, which measured 7.4 \pm 0.11cm at Kianda Dam. Lusoi Dam had the lowest water quality status with pH, TDS and conductivity measuring 9.6 \pm 0.05, 833 \pm 35.3mg l⁻¹ and 1283 \pm 48.1 μ S cm⁻¹, respectively. Concentration of heavy metals in the dams was generally low. The three reservoirs had abundant fish food supply, with phytoplankton dominated by the blue green algae, *Microcystis aeruginosa* while zooplanktons were dominated by rotifers and copepods. Cladocera only occurred in Kianda Dam. Benthic invertebrates were similarly abundant dominated by chiromids and oligochaetes. The fish had good relative condition which ranged from 1.7 to 1.9. A highly significant length-weight relationship was obtained with an R² value of 0.9908, 0.9708 and 0.9495 at Gathathini, Lusoi and Kianda Dams, respectively, indicating an allometric fish growth. Fish productivity in the dams ranged from 47 \pm 29.6g/m²/hr to 259 \pm 150.2g/m²/hr. These results show that the undrainable reservoirs of Naromoru are generally suitable for fisheries production, even though management interventions are needed to deal with pollution problems and fish seed quality in order to achieve maximum fish productivity.

Chapter 1: Introduction

1.1 Background

Undrainable reservoirs are man-made lakes or impoundments that are typically constructed by erecting a dam structure across a flowing river thereby pooling the previously flowing river. They can also be formed as an accidental by-product of mining and quarrying activities (Moyle, 1993; Wootton, 1992). Constructed reservoirs are of no geologic age. Reservoirs have been constructed in many countries that lack natural lakes in order to trap run-off water to meet future water demand and to enhance food security (Sena de Silva, 1988). The first small reservoirs were constructed about 4,000 years ago in China, Egypt and Mesopotamia (present Iran), primarily for drinking water supply and irrigation purposes. Since then, a 40 fold increase in Latin America and 100 fold increase in Africa and Asia has been reported (Dams, 2000).

Most reservoirs in Africa are located in semi-arid zones and experience extensive water level fluctuations due to seasonal climatic changes (Thornton and Rast, 1993). Most of these reservoirs are in small to medium categories. In Kenya there are over 3,000 minor reservoirs (<0.1km square) that have been constructed to supply water for industrial and domestic use, irrigation farming and watering livestock and wildlife (Balarin, 1985). Many of the existing reservoirs have been stocked with fish, with the aim of increasing their productivity and support local livelihoods. The Kenyan government plans to construct 2,000 reservoirs countrywide by the year 2030 most of which will be in arid areas (Safaricom Foundation, 2007).

The Naromoru region in central Kenya has more than 15 reservoirs that were constructed to solve periodic water and drought related problems. The reservoirs are constructed along streams and rivers to store water especially during the rainy season. The first reservoirs were constructed by white settlers in early 1960's to provide water for irrigation and domestic use. More recently, Non-Governmental Organizations have also constructed reservoirs ranging in size from 25000m³ to 5000m³ to supply farmers with water for irrigation (Waterman Foundation, 2003). Some of the constructed undrainable reservoirs in the area have been stocked with fish. However, their suitability and potential for fish rearing and production is not known.

Productivity of reservoirs depends largely on their physical and chemical characteristics. According to Chapman (1996) and Dorstch (1981), temperature is an important determinant of physical, chemical and biological processes in reservoirs regulating both the biotic growth rate and life stages of fish and hence defining the fish habitats. Turbidity on the other hand is of considerable interest because of its effect on light transmission and water clarity. Generally, the more turbid the water, the less the biota it will be able to support. Turbidity inhibit light penetration into the deeper layers of water column therefore negatively affecting primary productivity and the amount of dissolved oxygen available to support other organisms (Bruckner, 2009).

Dissolved oxygen influences nearly all chemical and biological processes within a reservoir. Concentrations below 5mg/l may adversely affect the survival and

functioning of biological communities and below 2mg/l may lead to death of most fish (Chapman, 1996). Conductivity of the water is another important chemical parameter. According to Kutty (1987), the productivity of a water body is directly correlated with conductivity. Most water bodies have pH levels ranging from 6.0 to 8.5, although lower values can occur in dilute waters high in organic content and higher values in eutrophic waters (Chapman, 1996). Low pH in reservoirs has been found to reduce the decomposition rate of organic matter and inhibit nitrogen fixation. High pH on the other hand is lethal to fish at high dissolved oxygen levels, especially to juveniles. Fish have maximum productivity at pH values ranging from 6.5 to 8.5 (Alabaster and Lloyd, 1980).

Nitrates, ammonia and phosphates are macronutrients required by aquatic organisms in large amounts as they make up the major cellular components of organisms (Wetzel and Likens, 1991). Nitrate concentrations in fresh waters are usually very low, 0.001mg/l $\text{NO}_2\text{-N}$, and rarely higher than 1mg/l $\text{NO}_2\text{-N}$. On the other hand, concentration of $\text{PO}_4\text{-}$ in most natural surface waters ranges from 0.005mg/l to 0.02mg/l (Chapman, 1996). $\text{NO}_2\text{-N}$ and $\text{PO}_4\text{-P}$ tend to have high concentrations during wet season than dry season (Kemdirim, 2005). In addition, major cations and anions concentrations are naturally very variable in surface layers of fresh waters. High concentrations of metallic ions such as copper and lead in water, and the bottom sediments are of special interest as indicators of industrial pollution (Odum, 1975). Concentrations of different metals in water vary widely, 0.001 to 0.1 micrograms per litre, and can rise to concentrations dangerous to organisms (Chapman, 1996). The recommended

concentration of major ions in fresh water bodies are; Na^+ 1mg/l, Ca^{2+} <15mg/l, Mg^{2+} 1mg/l to 100mg/l, HCO_3^- <500mg/l, Cl^- <10mg/l and SO_4^{2-} 2mg/l to 80mg/l (Chapman, 1996).

Fish survival in undrainable water reservoirs depends also on their biological characteristics. Phytoplankton community plays an important role as primary producers consumed by zooplanktons (Kumar and Sinha, 1986). In fresh waters, cladocerans and rotifers dominate the zooplankton community. These small food particles are ideal for fish larvae, and the larvae of most bony fishes feed on planktonic crustaceans, whatever they eat as adults. Adult fish on the other hand have a variety of feeding ways ranging from sieving phytoplankton or grazing algae, to suction feeding on benthic invertebrates and devouring other fishes (Bone *et al.*, 1999).

Despite wide spread of small undrainable reservoirs in Africa, few limnological studies have been carried out (Mwaura *et al.*, 2002), explaining why they are either under or over-exploited in terms of fisheries. This study therefore aimed at examining the limnological conditions of the undrainable reservoirs and their effects on the productivity and condition of the fish.

1.2 Justification and Statement of the Problem

Demand for fish protein has been increasing exponentially due to rapid increase in human population. Fresh water fisheries play an important role in providing

proteins for humans especially in areas far from the sea. Apart from supplying proteins, fresh water fisheries generate employment opportunities and earn the local people income as a result of fish sales. However, there has been a decline in the natural stocks of fish (Mbugua, 2008). Therefore, improvement of fisheries production in small water bodies will greatly contribute to food security and eradication of poverty. Water quality is one of the major factors affecting fish production in undrainable reservoirs. This is because fish perform all their body functions in water. Therefore, water condition determines the success or failure of an aquaculture operation to a great extent. However, most of undrainable water resources in Naromoru area have been stocked with fish but their suitability and potential for fish rearing and production has not been investigated. This study therefore, was aimed at assessing the water quality status and fisheries productivity status in order to determine their potential for utilization for fish rearing.

1.3 Research Questions

1. What is the water quality status of the undrainable water reservoirs in the dry land area of Naromoru?
2. What is the present fisheries productivity status of the undrainable water reservoirs of dry land area of Naromoru?
3. Is there any relationship between fisheries productivity and water quality status?

4. Do the Naromoru undrainable reservoirs have any potential for fish rearing?

1.4 Research Hypothesis

Fish production varies with water quality in undrainable water reservoirs of dry lands.

1.5 General Objective

The general objective of the study was to assess the water quality and fisheries productivity of undrainable water reservoirs of Naromoru in order to gain insight into their potential for aquaculture development.

1.6 Specific Objectives

The specific objectives were to:

1. Assess the status of water quality of the undrainable water reservoirs of Naromoru.
2. Determine the availability of natural fish food in the reservoirs.
3. Establish the fish species composition, variability and body condition in the undrainable water reservoirs of Naromoru.
4. Assess the catch per unit effort of the existing fisheries in the reservoirs and estimate realisable potential.

Chapter 2: Literature review

2.1 Characteristics of undrainable water reservoirs

Undrainable reservoirs in general are relatively small, perennial or seasonal water bodies constructed for multiple uses. Undrainable reservoirs vary greatly in their dimensions ranging from 0.02 ha to over 25 ha in water surface area and from 50 to 250 cm in depth (Kumar, 1992). According to Dortsch (1981), existing reservoirs are being subjected to intense multi-objective demands on limited resources, and thus, water use attracts more attention causing water quality to draw closer scrutiny.

An aquatic environment encompasses a wide variety of biological, chemical and physical parameters, virtually all of which influence the maintenance of homeostasis, which is essential in growth and reproduction of fishes (Aloo, 1995). According to Roberts (1989), the above parameters if altered beyond acceptable limits may weaken the fish and can cause disease outbreaks. Because fish are totally dependent upon water to breathe, feed and grow, excrete waste, maintain salt balance, and reproduce, understanding the physical and chemical qualities of water is critical to the success of aquaculture (Swann, 2008).

2.2 General state of fisheries productivity in the world

World aquaculture production has increased over the last ten years from 32.4 million tonnes in 2000 to 55.7 million tonnes in 2009. This increase has mainly been as a result of continued rapid growth in aquaculture especially in India and

China, whose production in 2009 was estimated to be 3.8 and 34.8 million tonnes, respectively (FAO, 2009). Farmed tilapias have been an important global commodity since 1990, and its production reached 2.8 million tonnes in 2008. However, Carps were the most preferred species in the world and accounted for 14.9 million tonnes of the total fish produced in 2009 (FAO, 2009).

Establishment of reservoirs and ponds in various parts of the world has helped fisheries largely in boosting fish production. Production of many reservoirs has been enhanced by the production of non-endemic fish species (Dadzie and Odera, 1989). The form and operation of a reservoir can also have an influence on their water quality characteristics. For instance, undrainable reservoirs in densely populated areas or agricultural areas which receive little management control have a tendency to be nutrient enriched (Thornton and Rast, 1993). Research indicates that this kind of disturbance will lead to eutrophication and large changes in fresh water communities (Downing, 1998).

2.3 Fisheries production in water reservoirs

Aquaculture in Kenya is undertaken in many different forms ranging from the small hand-dug 'kitchen ponds' to fairly large earth ponds of 1 000 m². According to FAO report (2009), total fisheries production from Kenya reached 144,290 tonnes with 4,895 tonnes being from aquaculture. Production from aquaculture in Kenya is expected to greatly increase as a result of the

establishment of Economic Stimulus Plan (ESP) that aims at constructing 200 ponds in 140 constituencies through the ministry of fisheries (ESP, 2010). In many arid and semiarid areas, a large number of undrainable reservoirs occur and most have been stocked with fish. But here water is scarce and coupled with high evaporation, the reservoirs are severely affected by salinization. Irrigation in these areas can lead to leaching of salts from the soil, and their transport in return flows to the reservoirs resulting in great variations of pH (Thornton and Rast, 1993). PH fluctuations below optimal levels has a number of adverse effects on fish culture such as stress, susceptibility to diseases, low production levels and poor growth (Primary Industries and Resources South Australia, 1999).

High fish productivity is usually not long sustained in undrainable reservoirs. It remains only high for one to a few years and then declines rapidly to a much lower level which may be maintained or may gradually rise to somewhere near a half the magnitude of the initial phase (Ploskey, 1981). During the filling period of the reservoir, water leaches nutrients from the newly inundated soils, submerged plant debris and other organic matter. The impounded water therefore is of high fertility which encourages the growth of bacteria, phytoplankton, zooplankton and benthic invertebrates. These organisms serve directly or indirectly as food for fish (Bhukaswan, 1980). The fish that live in open water of the lakes and reservoirs must feed primarily on zooplanktons, perhaps some on phytoplankton whereas those on littoral zones may choose

from more diverse prey array, including terrestrial insects, macrophytic vegetation, benthic invertebrates and forage fish (Thornton *et al.*, 1990).

There is a linear relationship between net primary productivity and fish biomass in reservoirs (Garg and Bhatnagar, 2001). Kwak and Waters (1997) carried out a study on trout production dynamics with eight water quality variables in Minnesota and found no correlation between eight water quality variables describing ionic and nutrient content of the streams, but when data from other streams with a wide range of alkalinity were incorporated, salmonid production was strongly and positively correlated with alkalinity.

2.4 Phytoplankton

Phytoplankton's stand at the baseline of many aquatic food webs in aquatic environment and globally are amongst the most important primary producers. Different classes of phytoplankton have been found to make varying contributions to primary productivity depending on their abundance (Boney, 1989). Phytoplankton are affected by variation in chemical, physical and biological conditions in space and time (Canter-Lund, 1995). According to Downing (1998), general analysis suggests that tropical freshwaters are more frequently nitrogen limited than temperate zones.

In Kenya, research in high altitude tropical man made reservoirs of Eastern Rift valley by Mwaura *et al.* (2002) established that phytoplankton diversity is higher towards the end of year, during the time when overall phytoplankton

mass was quite low. At the end of dry season, most reservoirs were dominated by *cyanobacteria* with *chlorophytes* being subdominant. During the long rains on March, there was a switch from blue-green algae to green algae (Mwaura *et al.*, 2002). Another study by Kotut *et al.* (1999) in dry land area of Kenya on temporal changes in structure and composition of phytoplankton revealed a seasonal pattern. Wet season was characterized by higher levels of chlorophyll 'a', biomass and primary production and a lower diversity. There was also a positive correlation between changes in chlorophyll to changes in nitrogen and total phosphorus (Kotut *et al.*, 1999).

2.5 Zooplanktons

Zooplanktons are the major herbivores as well as important predators in aquatic ecosystems (Allaby, 2005). Zooplanktons consume phytoplankton and also utilize oxygen synthesized by phytoplankton through the process of photosynthesis. Different species of Zooplanktons have been found to have habitat preferences that further accentuate both their temporal and spatial heterogeneity (Wetzel and Likens, 1991). Some zooplanktons have been found to migrate into deep water during part of their life cycle in order to avoid higher predation rate in the euphotic zone (Barnes, 1980). In undrainable reservoirs zooplanktons that have been found to inhabit them comprises of *copepods*, *cladocerans* and *rotifers* (Kumar, 1992). Research by Lusweti (1992) showed that zooplanktons had a positive correlation with phytoplankton in terms of chlorophyll 'a' in water. The study further established distinct temporal seasonality in zooplankton composition and abundance in the reservoir, with

higher numbers of zooplankton in cool and dry months of June to August. Relatively lower numbers were obtained during the wet months of March to April. Research carried out in small reservoirs of Eastern Rift valley Kenya found out that zooplankton community was composed of crustaceans, rotifers, and protozoa with the most dominant group being *Keratella* and *Brachionus*, and *Nauplius* being equally abundant (Mwaura, *et al.*, 2002).

2.6 Benthic invertebrates

Much emphasis in the study of benthic fauna has been given to immature stages of insects living on and in the sediments. Fresh water invertebrates have been found to perform many roles in ecosystem processes and these roles are frequently associated with diverse array of feeding habits (Palmer *et al.*, 1997). Invertebrates have been shown to alter organic resource in streams by various mechanisms, including grazing periphyton assemblages by scrappers (grazers), feeding on microphytes shredding of leaf detritus and processing of woody debris. These activities can affect ecosystem structure by reducing standing crops and modifying assemblage of both primary producers and heterotrophs (Coleman, 2000). According to Marchese and Ezcurra (1992) the shore regions of the freshwater environments have higher food diversity and are more oxygenated therefore providing favourable regions for benthic organisms' development. Benthic organisms are also known to have physiological tolerance limits to both physical and chemical changes in water (Bechara, 1996). Studies have also shown that there is an increase in the abundance of benthic

invertebrates after the wet season. Peak diversity was noted at the onset of long rains and later during wet season (Mwaura *et al.*, 2002).

Fish community forms an important link in the food web in the aquatic ecosystems as food for humans, birds as well as other invertebrates. They are also useful in maintaining the ecological balance of plankton and other aquatic invertebrates (Coleman, 2000). According to Wellcome (1979) the fish community that establishes itself in a given reservoir is based on that pre-existing in the river basin unless exotic species are introduced. Research by Kumar (1992) established that perennial undrainable water reservoirs in tropical monsoon lands with year round warm water under plenty of light, offer an excellent possibility for fish culture. Most of the species of fish cultured depend on natural fish food resources with a limited dependence upon artificial supplementary feed.

2.7 Culture of *Oreochromis spirulus spirulus*

Tilapia fish are not only second most important fish to farmed carps globally, but is also described as the most important aquaculture fish species of the 21st century (Shelton, 2002). In Africa, selective breeding of Tilapias has been aimed at increasing their growth rate so that farmers can realise quicker and higher yields (Behrends *et al.* 1990; Fitzsimmons, 2000). Dams and other impoundments used for storing water have also been stocked with fish and are harvested periodically (Fisheries Department, 2003; Tacon, 1993).

Oreochromis spirulus is the most northerly of the five species of *Oreochromis* inhabiting lower parts of eastward flowing rivers of East Africa (Trewavas, 1983). Three subspecies have been described in Kenya namely *O. spirulus spirulus*, and *O. spirulus niger* of the upper Athi system and *O. spirulus percivali* (Boulenger) found in a pool near northern Ewaso Nyiro (Trewavas, 1983). The areas of its natural distribution in Kenya were fairly known by 1930s. However, its introduction in many dams and river system has made it difficult to find pure subspecies of *O. s. spirulus* and *O. s. niger* (Trewavas, 1983; Lothar *et al.* 2003). The culture of *O. spirulus* in ponds in Kenya has also been reported by Balarin (1985) and Pullin *et al.* (1993). Studies by Luc (2002) reported the occurrence of *O. spirulus* in swamps of Amboseli. Introduction in L. Kamnarok, Kerio drainage and L. Turkana system has also been reported although it has not been confirmed (Trewavas, 1983; Lothar *et al.* 2003). The species has also been cultured in brackish water of Kuwait (Cruz *et al.* 1998).

Chapter 3: Materials and methods

3.1 Study Area

The study was conducted in Naromoru a semi-arid area, located in Nyeri county, central Kenya. Naromoru occurs on the western leeward side of Mt. Kenya (Figure 3.1) and on the upper Ewaso Ng'iro river basin (Gichuki *et al.*, 1998). The highest amount of rainfall in the area is received from March to May and from October to December, and it ranges from 500mm to 1200mm per annum. Day temperatures in Naromoru vary from 20°C to 25°C while night temperatures can go as low as 10°C to 15°C (Mathooko, 1992). The area is mainly fed by undrainable water reservoirs. Three reservoirs (Gathathini, Lusoi and Kianda) were selected for the study based on local knowledge about their occurrence and use, to represent different localities, and differing in habitat and ecoclimatic conditions. The dams occur in the same semi-arid area and were not expected to differ markedly in their biodiversity community and major environmental variables such as hydrology, water temperature and chemistry. Gathathini Dam located at 00° 22'N, 037° 01'E and altitude of 1756m asl was reconstructed after the El Nino rains destroyed its banks in 1997. The banks of the Dam had scanty grass vegetation, and its feeding river was dry throughout the sampling period. As a result, the reservoir depended entirely on rainwater for its filling. On the contrary, the oldest Dam (Lusoi) located at 00° 16'N, 037° 03'E and 1960m asl had its feeding stream running throughout the sampling period. Its banks were well covered by grass and macrophyte vegetation. In addition, irrigation farming was a major economic activity practised around the

Dam. Kianda Dam located at 00° 05'N, 037° 00'E and 1852m asl had bare banks, and farming was practised to a few metres from it. Its feeding river was dry throughout the sampling period due to abstraction by farmers.



Naromoru

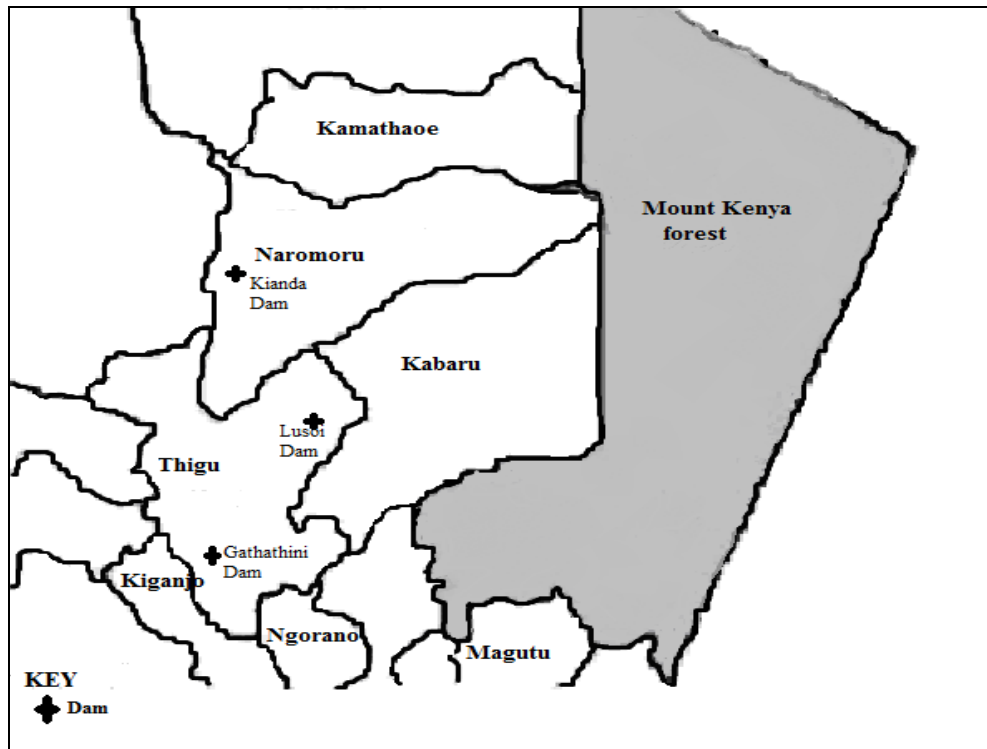


Figure 3.4: Map of Kenya showing the location of the study area and the three reservoirs

3.2. Sampling

Research was carried out in September 2008, October 2008 and January/February 2009. The reservoirs were selected based on availability of fish, accessibility, and different habitat and ecoclimatic conditions of the reservoirs. Systematic sampling technique was used in collecting water quality samples. Samples were collected from the inlet zone, the middle zone and the outlet zone of the reservoir. The points at which the samples were collected were marked by the Geographical Positioning System (GPS) in order to ensure that samples were collected from the same point every time sampling was done.

3.3 Water Quality Assessment

3.3.1 Physical and chemical Characteristics

Measurements of physical and chemical water parameters were taken at mid-day from the centre, inlet, outlet and sides of each reservoir. Water temperature was determined using ordinary mercury thermometer. The thermometer was dipped into the water and left for about three minutes before being withdrawn and the reading taken. Transparency was estimated using a 20cm diameter secchi disc. The secchi disc was dipped into the water and points of disappearance and re-appearance noted. The mean secchi disc depth was then computed by averaging the depths at which the secchi disk just disappears and re-appears upon raising after being lowered beyond visibility (Wetzel, 1983). Maximum depth of each reservoir was measured using a long straight pole and a tape measure.

The pH, conductivity and Total dissolved solutes (TDS) were measured using a calibrated portable pH/Conductivity/TDS probe meter (model PCT: 40). A sample of water was collected in a plastic container and the different probes placed in the sample each at a time. The meter was allowed to equilibrate before the readings were made. Dissolved oxygen (DO) on the other hand was measured using Winkler's method and a calibrated sensitive electrode probe meter. Water sample was collected in a container and the probe placed in the sample. The meter was allowed to equilibrate and the DO concentration read.

3.3.2 Major cations, anions, heavy and nutrients

Duplicate samples of water each measuring 1 litre were collected from the inlet, the sides, the centre, and the outlet of the reservoirs. The major cations, anions, heavy metals and nutrients were analysed from the Department of Geology and Mines laboratory based on procedures described by APHA (1998).

Concentration of calcium, magnesium, potassium, sodium, copper and lead ions were analyzed by flame atomic absorption spectrometry. A known volume of each sample was aspirated into a flame corresponding to its absorption wavelength and atomized. The amount of energy for each sample at a characteristic wavelength absorbed in the flame was considered to be proportional to the concentration of that element (APHA, 1998).

Ions of the nitrates, phosphates, sulphates, chlorides and bicarbonates were analyzed by ion chromatography method with chemical suppression of effluent

conductivity according to APHA (1998). The concentration of each ion was calculated in mg l^{-1} by referring to the appropriate calibration curves. In cases of linear response, anion concentration was calculated as;

$$C=H \times F \times D$$

Where $C=\text{mg l}^{-1}$ of anion, H =peak height or area, F =Response factor or concentration of the standard and D =dilution factor.

3.4 Assessment of natural fish food availability

3.4.1 Phytoplankton

Plankton's samples were collected by filtering 15 litres of water through a 0.14m diameter, 0.063 μm mesh plankton net. Samples were put in two small plastic bottles and immediately fixed using Lugol's iodide. Phytoplankton cells in the samples were later identified to the lowest possible taxonomic unit and counted with the aid of a compound microscope. Their densities were expressed as individuals per field under magnification of $\times 200$ (Wetzel and Likens, 1991).

Primary productivity of the dams was measured using Winkler's dissolved oxygen method according to APHA (1998). Six dissolved oxygen bottles (2 initial, 2 light and 2 dark bottles) of 300 ml volume were used. The dark bottles were wrapped in aluminium foil and all bottles carefully filled with dam water. Oxygen in the initial bottles was immediately fixed using the Winkler's reagent for measurement in the laboratory in order to determine the initial amount of oxygen prior to incubation. The remaining bottles were incubated in situ for

three hours, after which, the bottles were removed and immediately oxygen fixed. Analysis was done later in the laboratory and calculations done as follows;

$$GPP(mgC^{-2}h^{-1}) = \frac{DO(LB) - DO(DB)}{T(h)} \times PQ(1.2) \times \frac{12}{32}$$

$$NPP(mgC^{-2}h^{-1}) = \frac{DO(LB) - DO(IB)}{T(h)} \times PQ(1.2) \times \frac{12}{32}$$

where, DO(LB) = DO in light bottle, DO(DB) = DO in dark bottle, DO(IB) = DO in initial bottle, PQ = photosynthetic quotient (1.2) and T(h) = time in hours.

Species diversity of phytoplankton at each dam was calculated using Simpson's diversity index (Rosenzweig, 1995), as;

$$D = \frac{1}{\sum_i^s p_i^2}$$

where D=Simpson's diversity index, S=total number of species of phytoplankton present in the sample and Pi=proportion of S made up of ith species of phytoplankton.

3.4.2 Zooplankton

Zooplankton samples were collected in duplicates from each dam by filtering 10 litres of water through 100µm zooplankton net. The samples were put in small plastic containers and immediately fixed in 4% formalin solution. Zooplankton cells were later identified to the lowest possible taxonomic unit and counted using a compound microscope under magnification of ×100 (Wetzel and Likens, 1991). Species composition, relative abundance and species diversity of

zooplankton community in each dam were determined. The species diversity was calculated according to Rosenzweig (1995) using Simpson's diversity index.

3.4.3 Benthic invertebrates

Samples were collected from four locations in each reservoir differing in vegetation cover using an Ekman grab sampler (area 0.0625 m²). Samples were washed using a 200 µm mesh sieve and the invertebrates preserved using 4-5% formaldehyde. In the laboratory, samples were washed thoroughly to remove formalin and sorted to the lowest taxonomic level using a dissecting microscope and enumerated. The macro-invertebrate densities were expressed as individuals per metres square (m²). Diversity index of invertebrate community in each reservoir was calculated based on Simpson's diversity index (Rosenzweig 1995).

3.5 Fish species composition and variability

Fish sampling was carried out using gill and seine nets according to Jumbe (2003). The gill nets used were made of fine nets each 30 m long and had mesh sizes of 2.5, 3, 3.5 and 4 inches joined together end to end. The nets were placed at randomly selected sites in the evening and hauled the following morning. The catch was then sorted to different species and all fish caught measured for total length to the nearest 0.1cm and weight determined to the nearest 0.1gm. A

sample of at least 10 fish, where available, was then preserved in 4-5% formaldehyde. The specimens were later identified and curated at ichthyology department, National Museums of Kenya (NMK).

At NMK, morphometric and meristic measurements were done using protocols described by Nyngi (2002) and Snoeks (2004). Morphometric measurements involved determination of standard length (SL), total length (TL), head length (HL), body depth (BD), mouth width (MW), caudal peduncle length (CPL), caudal peduncle depth (CPD), pre-dorsal length (PDL), dorsal fin base length (DFL), pre-anal length (PAL), anal base length (ABL), lower jaw length (LJL), inter-orbital width (IOW), cheek depth (ChD), eye diameter (ED), pre-pectoral length (PPL), pre-ventral length (PVL) and snout length (SnL). The measurements were made using vernier calipers and recorded to the nearest 0.1mm. Meristic variables that were counted included dorsal spines, dorsal rays, anal spines, anal rays, upper lateral line scales, lower lateral line scales, longitudinal lateral line scales, transverse scales, gill rakers (outer gill arch), cheek scales and teeth on the upper jaw (outer row).

Morphometric data was transformed into percentages of standard body length and head length respectively. Caudal peduncle length was expressed as a ratio of caudal peduncle depth. Log-transformed morphometric measurements and untransformed meristic measurements were subjected to Principal Component Analysis (PCA). Mann-Whitney test was performed to test whether there was significance difference between variables of the three fish populations.

3.6 Catch per unit effort

Fish CPUE was determined according to Gayguzuz *et al.* (2007) as follows;

$$CPUE = (CN \times AS / AN) / t$$

where CN= nominal catch, AS=area of standard net (100m²), AN= area of net used, and t = time of exposure (hours).

3.7 Length-weight relationships and relative condition factor

3.7.1 Length-weight relationship

Length-weight relationships of fish caught from each dam was calculated using the least squares regression on transformation of the equation

$$W = a.L^b$$

according to Abdallah and El-Haweet (2000), where W=total weight (g), a & b=constants and L=total length (mm)

3.7.2 Fish condition

Length and weight data was used in determining the fish relative condition factors (fatness index) using Fulton's condition factor (K) method as;

$$K = W/L^3 \times 100,000$$

where L is total length in mm, W is weight in grams and K is the condition factor (Lagler, 1956).

3.5 Data analysis

The data was entered in excel spreadsheet and summarised before being imported to Past programme for analysis. Significant differences between the reservoirs were determined using Kruskal-Wallis statistic, and morphometric and meristic variations using principal component analysis and Mann-Whitney U test.

Chapter 4: Results

4.1 Water quality characteristics

A total of 15 observations (n=14) of each of the physical and chemical variables were used in analysis by Kruskal-Wallis test to determine significant differences among the reservoirs.

4.1.1 Physico-chemical characteristics

a) Temperature

Water temperature was higher at Gathathini Dam ($21.9 \pm 0.52^\circ\text{C}$) than at Lusoi and Kianda Dams where pulled mean temperatures were $20.3 \pm 0.43^\circ\text{C}$ and $20.8 \pm 0.49^\circ\text{C}$ respectively (Fig. 4.1). However, the differences were not significant ($K=3.638$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test). The water temperature remained fairly stable at Gathathini Dam, ranging from 21.0°C to 24.3°C , while at Lusoi Dam, water temperature showed greater fluctuation ranging from 19.3 to 21.3°C (Fig. 4.1).

Changes in water temperature with depth showed a minor thermal stratification at Gathathini Dam, with a thermo-cline at 1.5m (Fig. 4.2). At Lusoi Dam, however, water temperatures were almost constant from top to bottom, suggesting lack of stratification. Kianda Dam depicted similar observations as Lusoi Dam, although there was a slight stabilization at 1m depth.

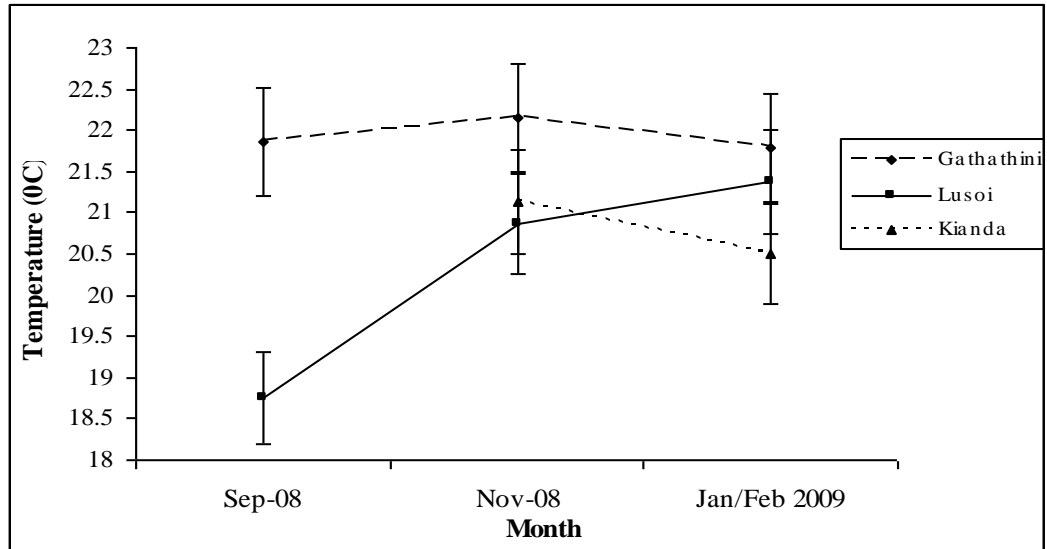


Figure 4.1: Temporal mean water temperature changes at three Naromoru Undrainable water reservoirs, Kenya.

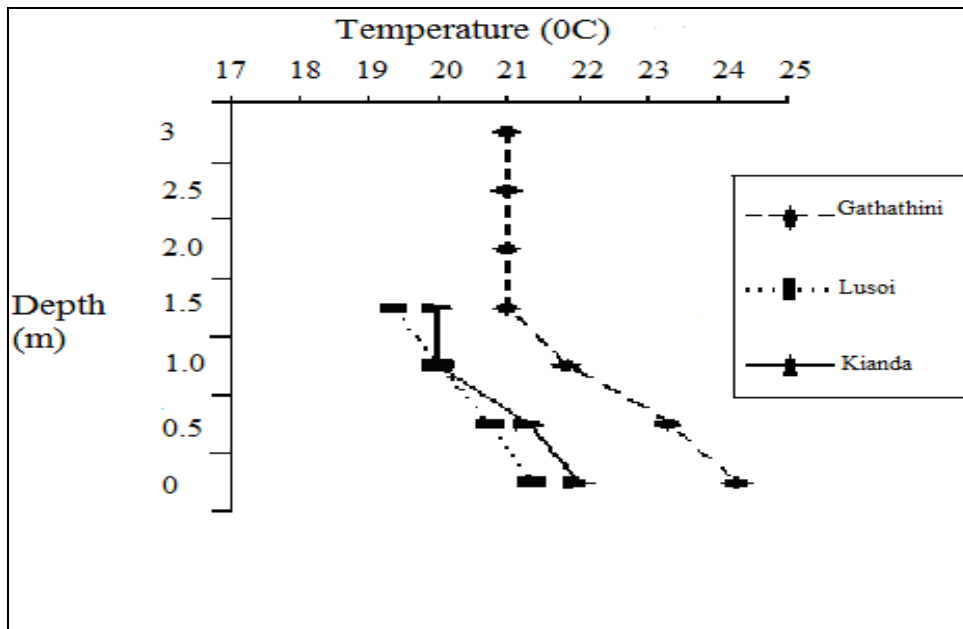


Figure 4.2: Temperature changes with water depth in the three dams of Naromoru

b) Transparency

Water transparency was lower at Kianda Dam as compared to Lusoi and Gathathini Dams (Fig. 4.3), although again these differences were not significant ($K=4.028$, $d.f.=2$, $P>0.05$, Kruskal-Wallis). Low water transparency at Kianda Dam was attributed to algal blooms (Plate 4.1) and siltation.

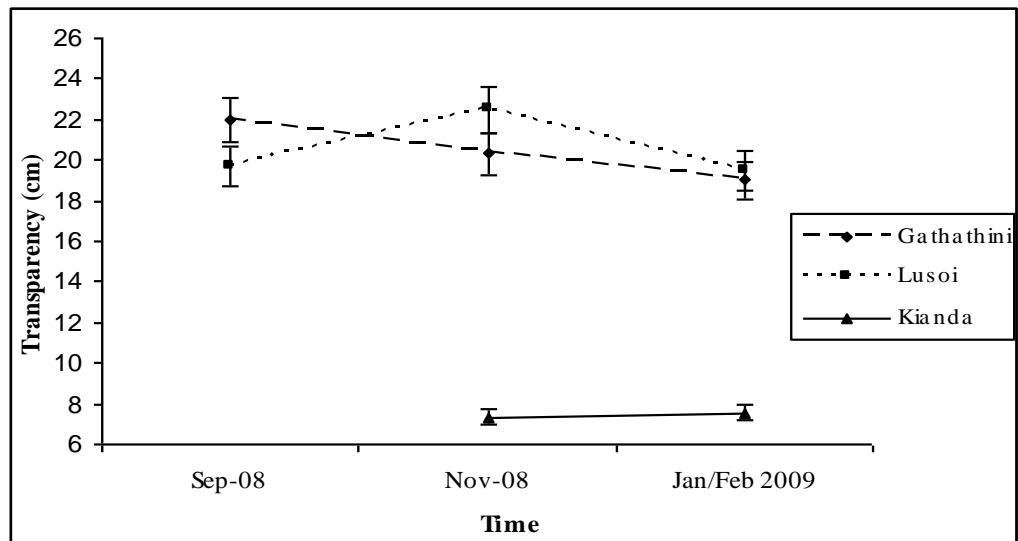


Figure 4.3: Water transparencies in the three dams during the sampling period



Plate 4.1: Picture showing the algal blooms (green) on the shore of Kianda dam

c) Water depth

Gathathini Dam was significantly deeper ($K=6.25$, $d.f.=2$, $P<0.05$, Kruskal-Wallis) than Lusoi and Kianda Dams, with an average depth of $1.7\pm 0.38\text{m}$ (Fig. 4.4). The greater depth was due to the fact that Gathathini dam underwent reconstruction after the 1997-98 El Nino rains. Kianda dam was the shallowest, with depths averaging $0.8\pm 0.08\text{m}$, due to extensive siltations arising from massive erosion of the banks and catchment areas. Depth at Lusoi Dam averaged $0.9\pm 0.003\text{m}$. Water depth at Gathathini Dam experienced high fluctuations ranging from 1.21m to 4.91m, while Lusoi and Kianda Dams had relatively stable water depths.

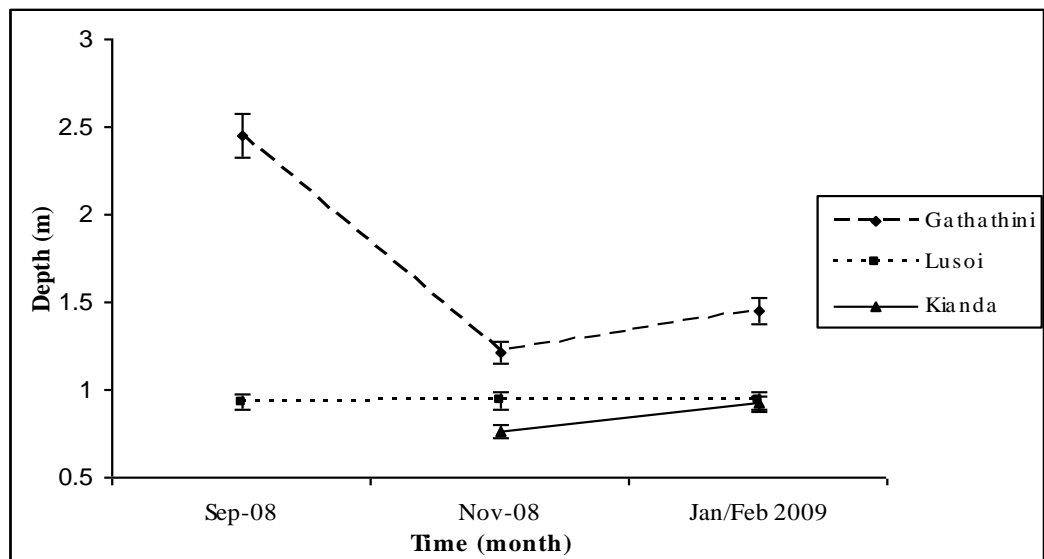


Figure 4.4: Mean water depth in the three dams of Naromoru at different times

d) Water pH

Lusoi Dam had higher water pH averaging 9.6 ± 0.05 , than Gathathini and Kianda dams whose pH averaged 8.3 ± 0.11 and 8.6 ± 0.05 , respectively (Fig. 4.5).

However, the differences were not significant ($K=5.139$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test). Gathathini Dam recorded high fluctuations in water pH ranging from 7.53 to 8.64. Lusoi and Kianda Dams had stable water pH that ranged from 9.46 to 9.73 and 8.5 to 8.69, respectively.

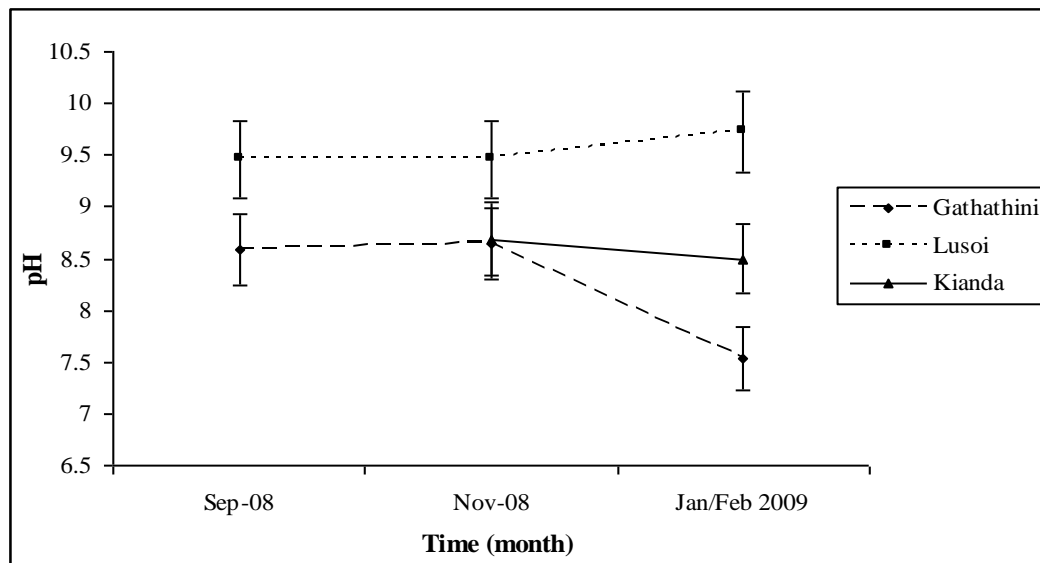


Figure 4.5: Changes in pH in the three dams of Naromoru at different times of sampling period

e) Total dissolved solutes (TDS)

Lusoi Dam had significantly higher TDS ($K=6.25$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test) than Gathathini and Kianda Dams (Fig. 4.6). TDS at Gathathini Dam was low and fairly constant throughout the study period, probably because of low entry of solutes as it is largely dependent on rain water. Its banks were similarly well protected. Lusoi and Kianda Dams, however, received stream inflows from extensive agricultural catchments.

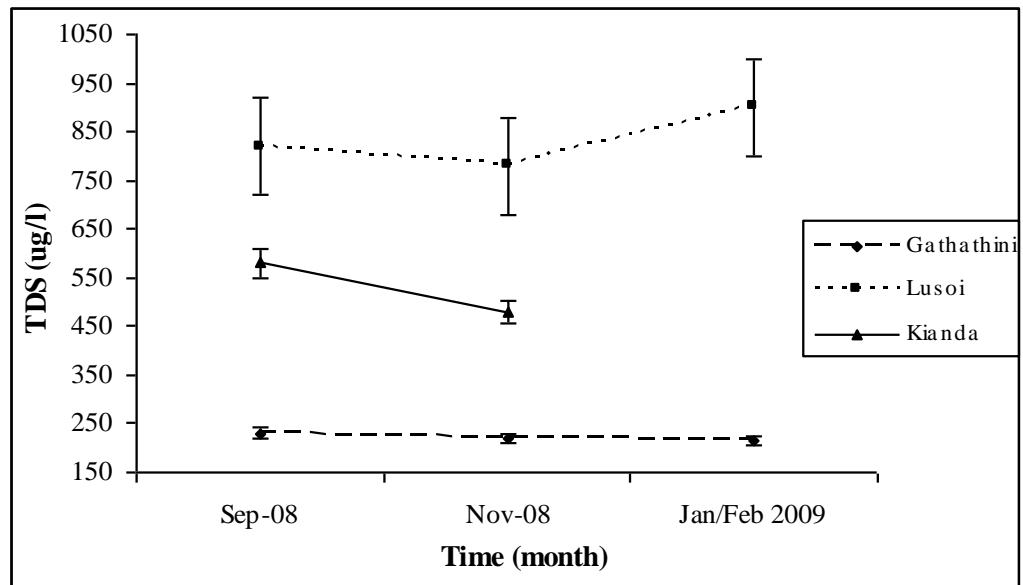


Figure 4.6: Changes in total dissolved solutes in the three dams of Naromoru with time

f) Water conductivity

Water conductivity was significantly higher at Lusoi Dam ($K=6.25$, $d.f.=2$, $P<0.05$, Kruskal-Wallis), averaging $1283\pm 48.1\mu\text{Scm}^{-1}$, with a range of 1190 to $1350\mu\text{Scm}^{-1}$, probably because of ionic concentration due to its long period of existence as it was constructed in 1960's. At Gathathini and Kianda Dams, conductivity was low averaging $312\pm 1.11\mu\text{Scm}^{-1}$ and $730\pm 10\mu\text{Scm}^{-1}$, respectively, probably because the dams were newly constructed and hence low ionic concentration.

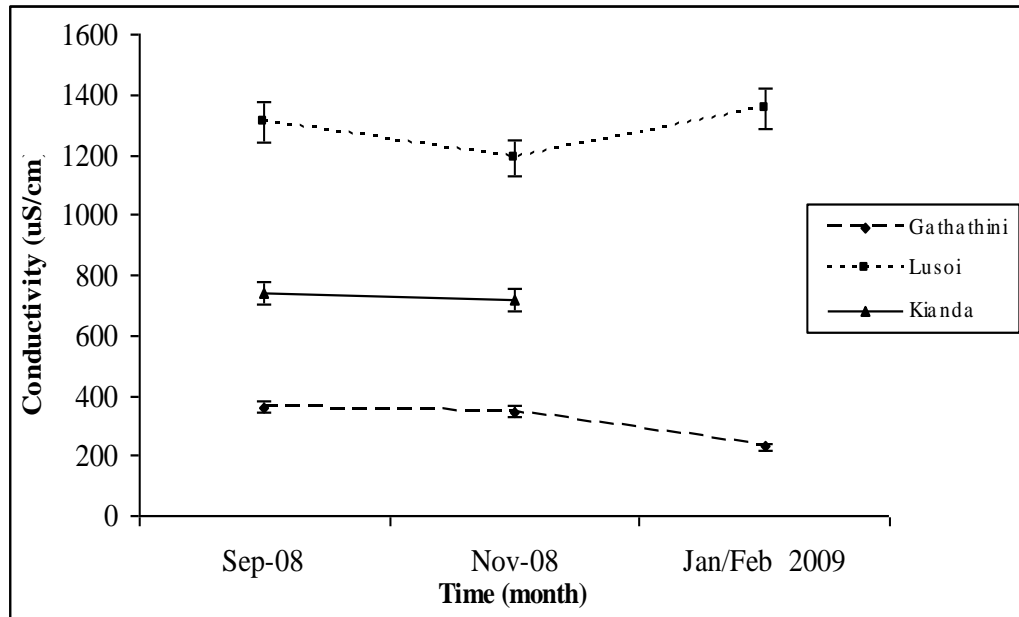


Figure 4.7: Changes in conductivity of the three dams of Naromoru at different times

g) Dissolved oxygen concentration (DO)

Dissolved oxygen was generally high in the three dams and did not differ significantly ($K=1.111$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test) between the dams (Fig. 4.8). Lusoi Dam had the highest DO concentration averaging $6.7\pm 0.06\text{mg l}^{-1}$, but highly fluctuating between 5.13 to 8.31mg l^{-1} . The high level of oxygen concentration is attributed to the low water temperatures and the location of the Dam at high altitude. Gathathini and Kianda dams located at lower altitudes, with high water temperatures recorded lower DO concentrations averaging $5.3\pm 0.01\text{mg l}^{-1}$ and $5.9\pm 0.06\text{mg l}^{-1}$, with ranges of 4.91 - 5.50mg l^{-1} and 5.15 to 6.67mg l^{-1} , respectively.

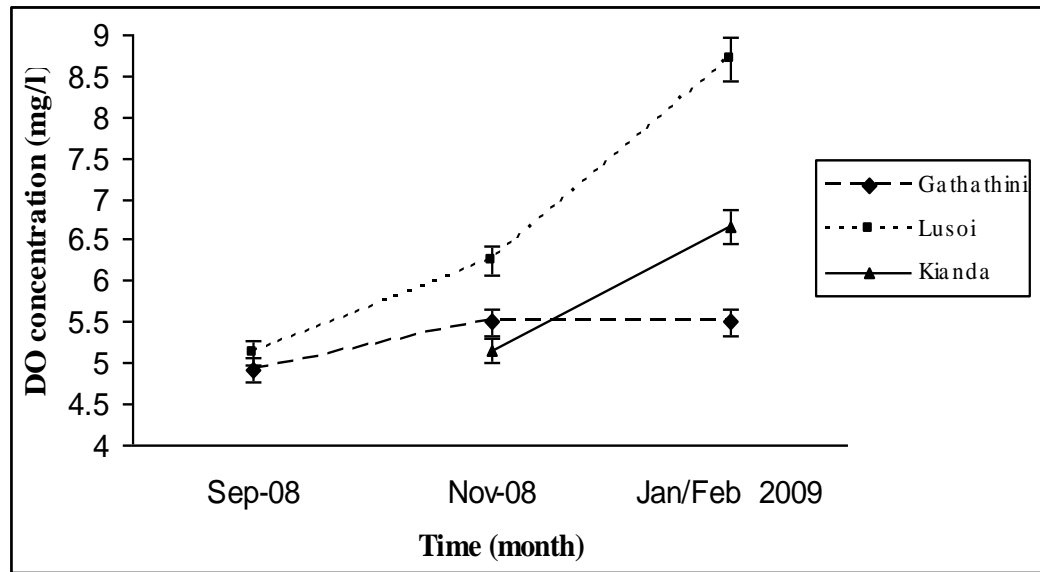


Figure 4.8: Changes in dissolved oxygen in the three dams of Naromoru over time

4.1.2 Major cations and anions

a) Concentrations of potassium, calcium, magnesium and sodium

Mean concentration of calcium ions ($123.9 \pm 41.71 \text{ mg l}^{-1}$) was significantly higher at Kianda Dam ($K=6.14$, $d.f.=2$, $P<0.05$, Kruskal-Wallis test), with Gathathini and Lusoi Dams having means of $18.2 \pm 0.79 \text{ mg l}^{-1}$ and $77.4 \pm 14.99 \text{ mg l}^{-1}$, respectively (Fig. 4.9). Unlike calcium, however, sodium ion concentration was significantly higher in Lusoi Dam ($K=19.65$, $d.f.=2$, $P<0.05$, Kruskal-Wallis test), averaging $202.2 \pm 9.86 \text{ mg l}^{-1}$ than at Kianda ($105.9 \pm 8.25 \text{ mg l}^{-1}$) and Gathathini ($21.2 \pm 0.89 \text{ mg l}^{-1}$).

Potassium ion concentration at Kianda Dams was significantly higher ($K=12.75$, $d.f.=2$, $P<0.05$, Krukall-Wallis test) than the concentrations at Gathathini and Lusoi Dams (Fig. 4.9). Their mean concentrations were; $44.3 \pm 4.72 \text{ mg l}^{-1}$ at Kianda Dam, $21.5 \pm 0.79 \text{ mg l}^{-1}$ at Lusoi Dam and $11.2 \pm 0.47 \text{ mg l}^{-1}$ at Gathathini

Dam. However, magnesium ions did not show significant differences ($K=3.119$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test) between the three Dams. Gathathini and Kianda Dams had relatively same concentration of magnesium ions, with means being $4.3\pm 0.3\text{mg l}^{-1}$ and $4.4\pm 0.37\text{mg l}^{-1}$ respectively. Lusoi Dam had the lowest concentration of magnesium ions, averaging $3.2\pm 0.16\text{mg l}^{-1}$ (Fig. 4.9).

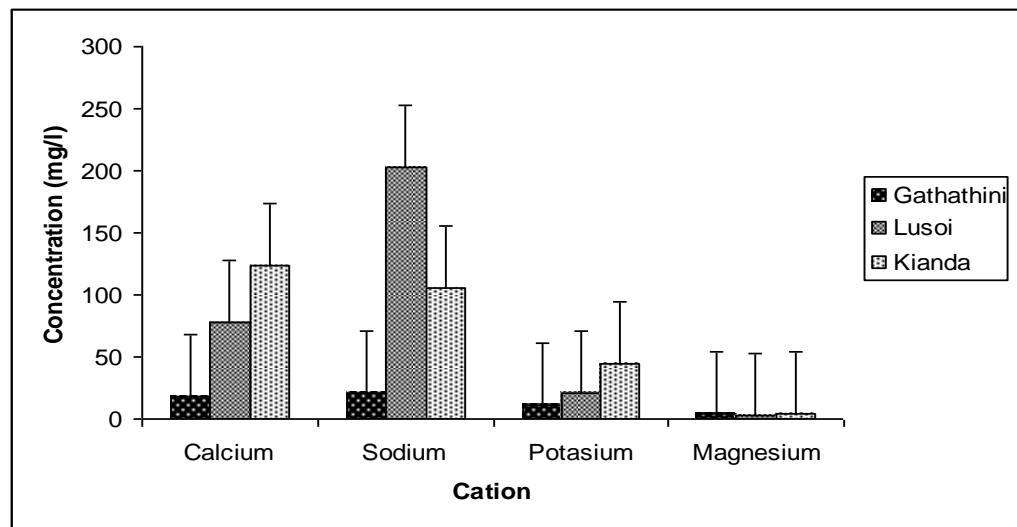


Figure 4.9: Mean concentration of the major cations in the three undrainable reservoirs of Naromoru

b) Concentrations of bicarbonates, sulphates and chlorine

The concentration of major anions was higher in Lusoi Dam, though not significant ($K=5.683$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test) except for sulphate ions, whose concentration was higher at Kianda Dam ($25.3\pm 3.62\text{mg l}^{-1}$) and Lusoi ($24.9\pm 4.10\text{mg l}^{-1}$) compared to Gathathini with 0.013mg l^{-1} (Fig. 4.10). Bicarbonate ions averaged $265.6\pm 8.04\text{mg l}^{-1}$, $99.4\pm 36.57\text{mg l}^{-1}$ and $79.9\pm 13.16\text{mg l}^{-1}$ at Lusoi, Kianda and Gathathini Dams, respectively. Similarly,

the concentration of chloride ions averaged $94.5 \pm 5.39 \text{mg l}^{-1}$, $19.8 \pm 8.52 \text{mg l}^{-1}$ and $16.68 \pm 1.63 \text{mg l}^{-1}$ at Lusoi, Kianda and Gathathini Dams, respectively.

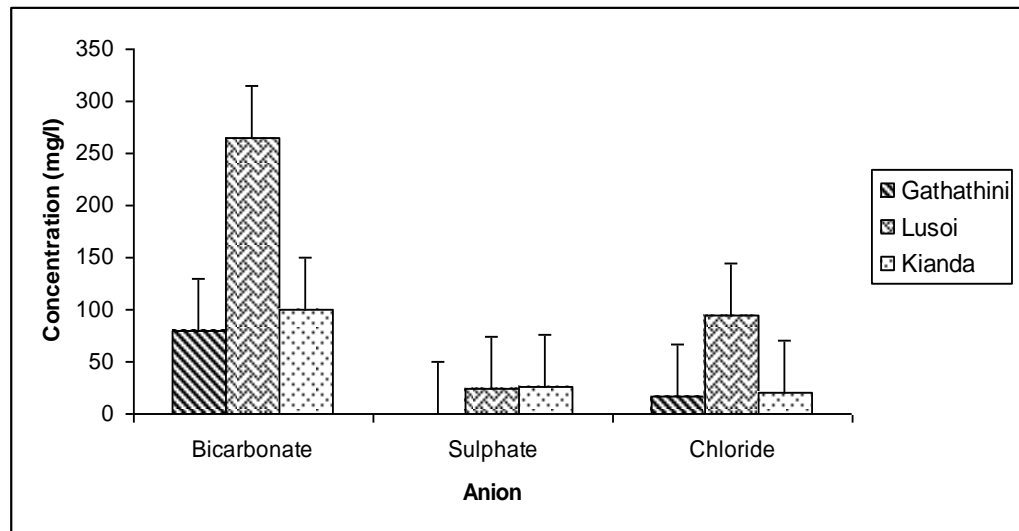


Figure 4.10: Variation in concentrations of the major anions in the three undrainable reservoirs of Naromoru

4.1.3 Heavy metals

Heavy metal (copper and lead) occurred generally in very low concentrations in all the three dams, ranging from 0.001 to 0.134mg l^{-1} (Fig. 4.11). Like the major cations, however, Lusoi Dam had significantly higher concentrations (K=10.66, d.f.=2, $P < 0.05$, Kruskal-Wallis test), averaging $0.01 \pm 0.002 \text{mg l}^{-1}$, $0.007 \pm 0.002 \text{mg l}^{-1}$ and $0.003 \pm 0.002 \text{mg l}^{-1}$ of copper at Lusoi, Kianda and Gathathini Dams, respectively. Similarly, lead concentration averaged $0.048 \pm 0.05 \text{mg l}^{-1}$, $0.02 \pm 0.003 \text{mg l}^{-1}$ and $0.04 \pm 0.009 \text{mg l}^{-1}$ at Lusoi, Gathathini and Kianda Dams, respectively.

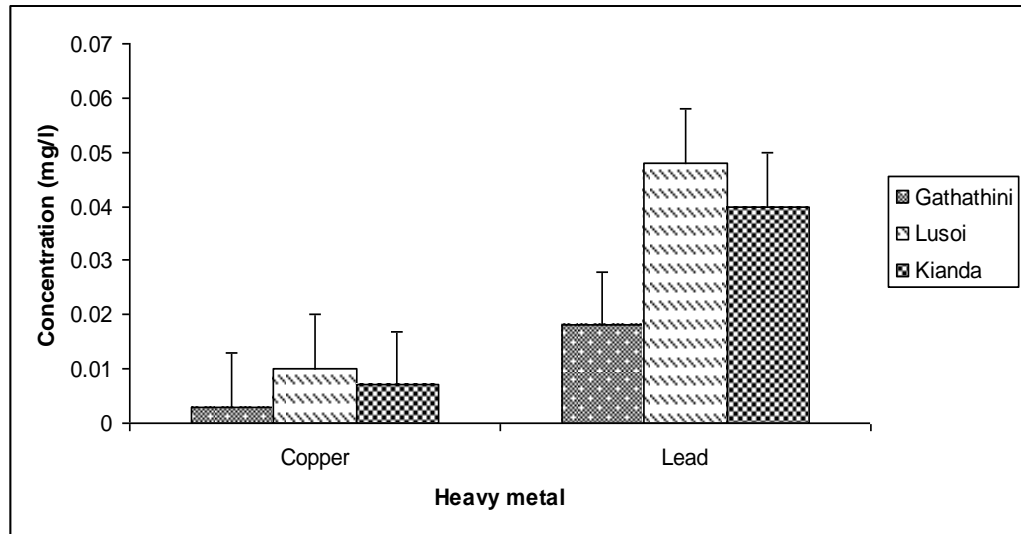


Figure 4.11: Variations in concentration of heavy metals in the three reservoirs of Naromoru

4.1.4 Nutrients

All the three dams were generally rich in nutrients, particularly phosphates which ranged from 1.2 to 6.0mg^l⁻¹ (Fig. 4.12). Nitrate levels were significantly higher at Gathathini Dam ($K=14.17$, $d.f.=2$, $P<0.05$, Kruskal-Wallis test), averaging $2.0\pm 1.66\text{mg}^{\text{l}^{-1}}$, $1.3\pm 0.27\text{mg}^{\text{l}^{-1}}$ and $0.07\pm 0.01\text{mg}^{\text{l}^{-1}}$ at Gathathini, Lusoi and Kianda Dams, respectively. The concentrations of phosphate ions however had no significant differences ($K=3.362$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test) between the three dams, with averages being $6.0\pm 2.75\text{mg}^{\text{l}^{-1}}$, $4.7\pm 1.42\text{mg}^{\text{l}^{-1}}$ and $1.2\pm 0.81\text{mg}^{\text{l}^{-1}}$ at Kianda, Lusoi and Gathathini Dams, respectively.

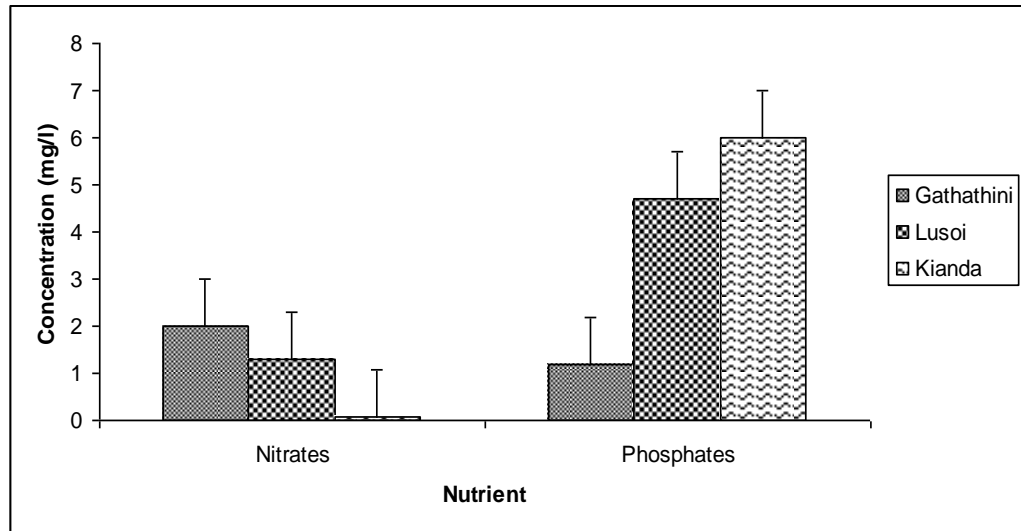


Figure 4.12: Variation of the major nutrients in the three dams of Naromoru

4.2 Natural fish food availability

4.2.1 Phytoplankton

a) Phytoplankton species composition

The species composition of phytoplankton identified from the three Dams is shown in table 4.1. The highest number of species was recorded at Gathathini Dam (22 genera), which had the highest concentration of nitrate ions concentration compared to phosphates. Lusoi and Kianda Dams, which had relatively high phosphate ions concentrations than nitrate ions had 15 and 13 genera, respectively. Some of species of phytoplankton found in the undrainable reservoirs are shown in Plate 4.2.

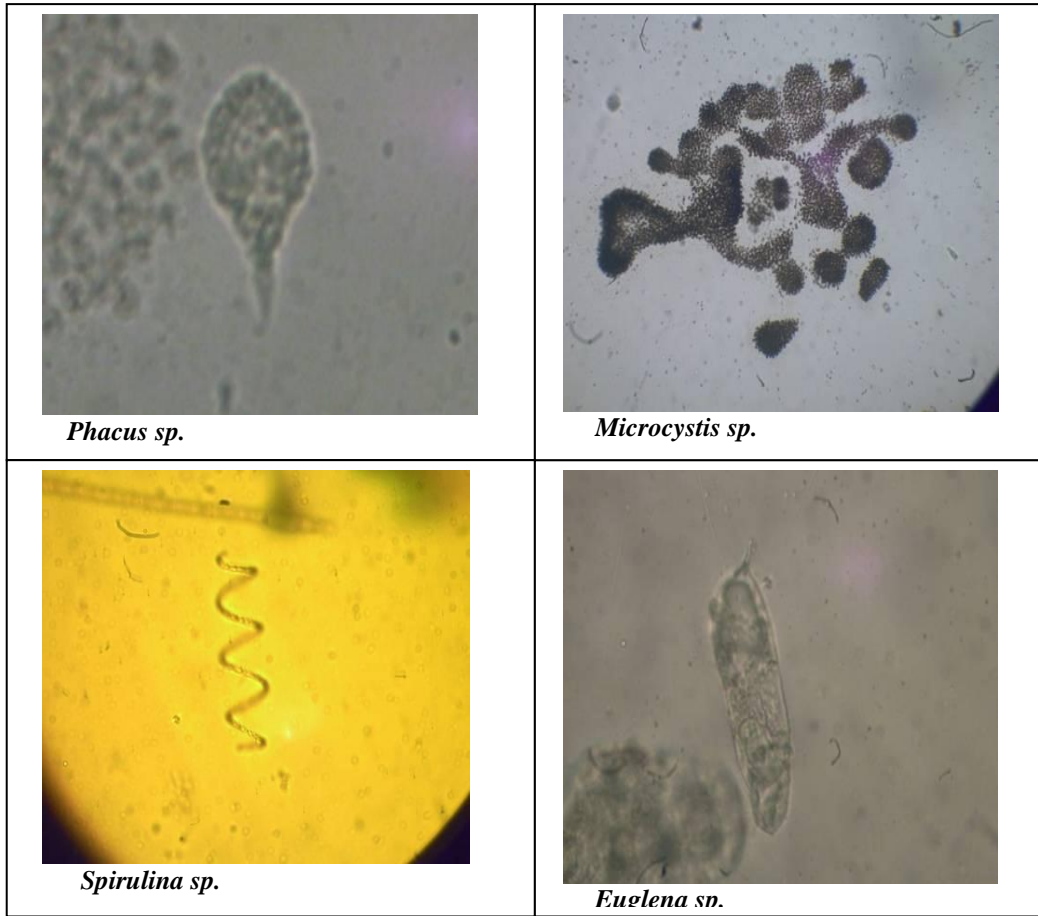


Plate 4.2: Some of the phytoplankton from undrainable reservoirs of Naro Moru

Table 4.1: Species composition of phytoplankton identified in the three undrainable reservoirs of Naromoru (Presence=+, absence= -)

SPECIES	SPECIES ABSENCE (-) OR PRESENCE (+)		
	Gathathini Dam	Lusoi Dam	Kianda Dam
Green algae			
<i>Scenedesmus</i>	+	+	+
<i>Ankistrodesmus</i>	+	+	-
<i>Pediastrum</i>	+	-	-
<i>Schroederia</i>	+	-	-
<i>Monoraphidium</i>	+	-	+
<i>Chlorogloea</i>	+	-	-
<i>Oocystis</i>	+	-	-
<i>Selenastrum</i>	+	-	-
<i>Eresmopedia</i>	-	+	-
<i>Kirchneriella</i>	-	+	-
<i>Spyrogyra</i>	-	+	-
<i>Trentepohlia</i>	-	-	+
Blue green algae			
<i>Microcystis</i>	+	+	+
<i>Phormidium</i>	+	-	-
<i>Synechocystis</i>	+	-	-
<i>Merismopedia</i>	+	+	-
<i>Oscillatoria</i>	-	+	-
<i>Spirulina</i>	-	+	-
<i>Eucarpisia</i>	-	+	-
<i>Scytonema</i>	-	-	+
Dinoflagellates			
<i>Trachelomonas</i>	+	+	+
<i>Euglena</i>	-	+	+
<i>Phacus</i>	-	-	+
<i>Dinobryon</i>	-	-	+
Diatoms			
<i>Navicula</i>	+	+	+
<i>Surirella</i>	+	+	-
<i>Cyclostela</i>	+	-	+
<i>Closterium</i>	+	-	-
<i>Chrysococcus</i>	+	-	-
<i>Stephanodiscus</i>	+	-	+
<i>Nitzschia</i>	+	-	-
<i>Synedra</i>	+	-	-
<i>Cocconeis</i>	+	-	-
<i>Diploneis</i>	-	+	-
Desmids			
<i>Cosmarium</i>	-	-	-
<i>Mougeotia</i>	-	-	-
<i>Cosmacladium</i>	-	-	+

Total genera	22	15	13
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b) Phytoplankton relative abundance

The relative abundance of the four orders of algae that occurred at Gathathini Dam did not show significant differences ($K=6.282$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test). Diatoms had the highest relative abundance averaging $32.4\pm 6.71\%$. Green algae and blue green algae followed closely with mean abundances of $29.7\pm 5.80\%$ and $26.7\pm 2.91\%$ respectively, while dinoflagellates had the lowest abundance averaging $6.6\pm 1.06\%$ (Fig. 4.13).

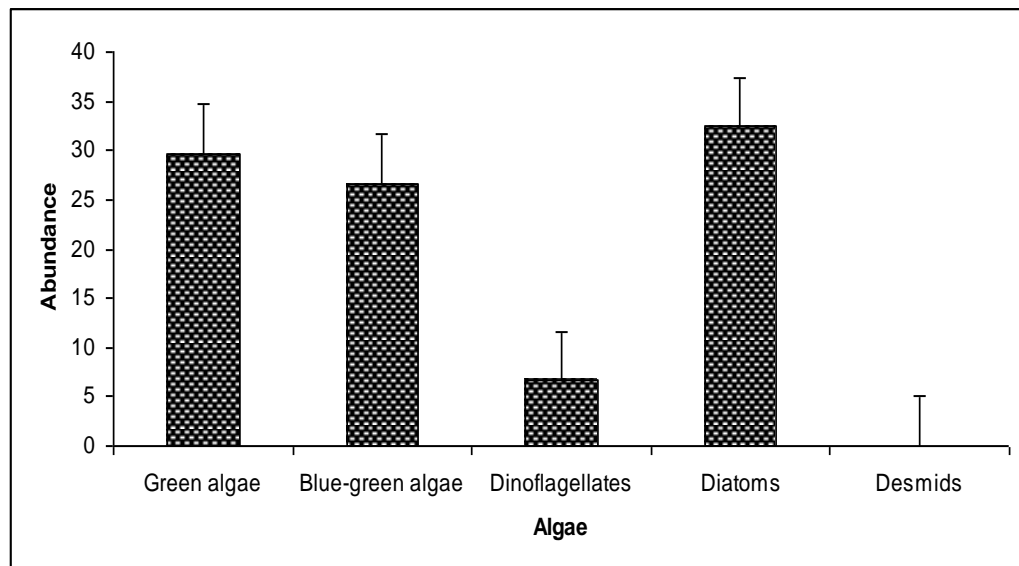


Figure 4.13: Relative abundance in % of various orders of algae at Gathathini Dam

Blue green algae were significantly more abundant ($K=12.1$, $d.f.=2$, $P<0.05$, Kruskal-Wallis test), than the other four groups of phytoplankton at Lusoi Dam

(Fig. 4.14). The blue green algae had a mean relative abundance of $71.9 \pm 6.24\%$. Green algae, diatoms, dianoflagellates and desmids followed with mean abundances of $12.5 \pm 2.19\%$, $7.2 \pm 2.78\%$, $5.2 \pm 0.87\%$ and $2.2 \pm 0.71\%$, respectively.

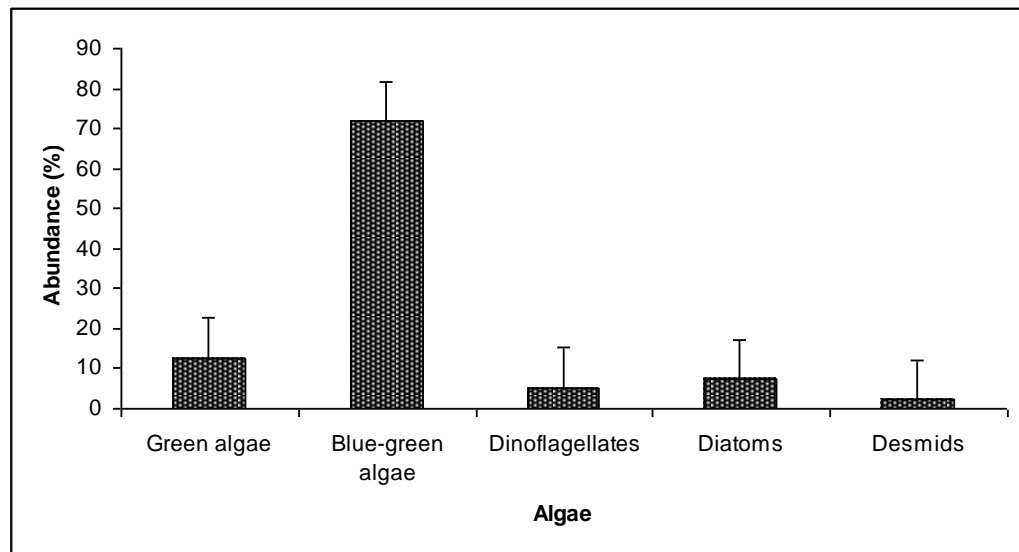


Figure 4.14: Relative abundance (%) of various orders of algae at Lusoi Dam

Comparison between the relative abundances of various groups of algae at Kianda Dam did not show significant differences ($K=7.418$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test). However, blue green algae had the highest relative abundance averaging $70.1 \pm 12.85\%$, compared to the other four groups (Fig. 4.15). Diatoms, dianoflagellates, green algae and desmids had low relative abundances averaging $8.8 \pm 0.70\%$, $3.8 \pm 3.10\%$, $1.4 \pm 1.10\%$ and $0.9 \pm 0.90\%$, respectively.

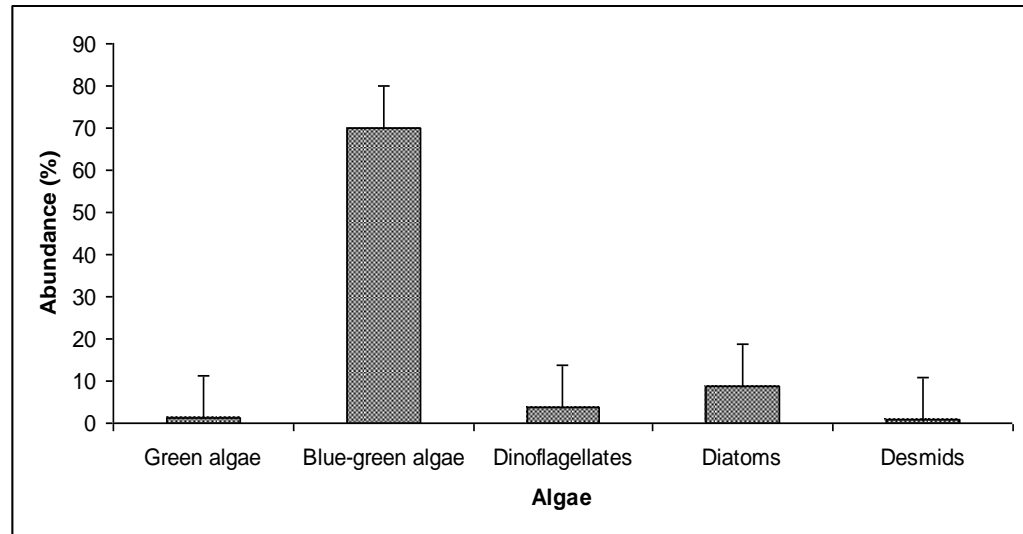


Figure 4.15: Relative abundance of various orders of algae at Kianda Dam

c) Primary productivity

Primary productivity was generally low in September 2008 at Gathathini and Lusoi Dams measuring 250g/hr/l and 200g/hr/l respectively (Fig. 4.16). This occurrence was as a result of cold and cloudy weather experienced in the area during the study. However, high productivity was recorded in the three Dams in January and February 2009 as a consequence of increased sunny conditions with the onset of the dry season and higher water volumes experienced at the time.

Generally, Lusoi Dam had the highest primary productivity of 587.14g/hr/l probably due to high water transparency at the site resulting in higher abundance of algae. Gathathini Dam had the second highest primary productivity measuring 461.25g/hr/l, while Kianda Dam had the lowest productivity measuring 401.25g/hr/l (Fig.4.16). The low primary productivity at Kianda Dam may be associated with low water transparency in the dam.

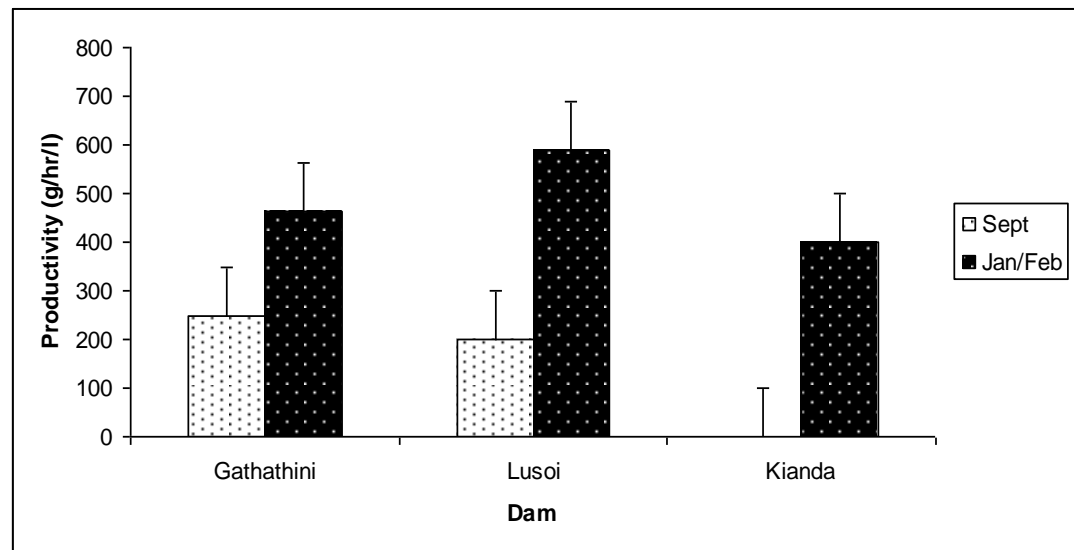


Figure 4.16: Primary productivity of the three reservoirs of Naromoru in September 2008 and January/February 2009.

d) Phytoplankton species diversity

Phytoplankton community at Gathathini Dam was more diverse than the other two reservoirs (Table 4.2). Lusoi Dam had relatively high phytoplankton diversity, while Kianda Dam community recorded the lowest diversity (Table 4.2).

Table 4.2: Diversity indices of phytoplankton communities of the three dams of Naromoru at different sampling periods

Dam	Gathathini	Lusoi	Kianda
Time	Simpson	Simpson	Simpson
Sep 2008	0.090	0.297	-
Oct 2008	0.144	0.303	0.682
Jan/Feb 2009	0.158	0.309	0.667
Mean	0.13±0.021	0.3±0.003	0.67±0.008

4.2.2 Zooplanktons

a) Zooplankton species composition

Zooplankton community comprised of 6 genera of Rotifera, while Cladocera and Copepoda had 1 genus each (Table 4.3). Species composition of the rotifers in the three Dams was similar with an exception of *Asplanchna* and *Polyratha* which were absent at Gathathini Dam and Kianda Dam respectively, while *Daphnia* occurred only in Kianda Dam. Some of the zooplanktons identified at the three undrainable reservoirs of Naromoru are shown in Plate. 4.3.

Table 4.3: Species composition of zooplanktons identified in the three undrainable reservoirs of Naromoru (presence and absence indicated by + and -, respectively)

SPECIES	SPECIES PRESENCE OR ABSENCE		
	Gathathini Dam	Lusoi Dam	Kianda Dam
Rotifera			
<i>Branchionus</i>	+	+	+
<i>Fillinia</i>	+	+	+
<i>Keratella</i>	+	+	+
<i>Trichocerca</i>	+	+	+
<i>Polyratha</i>	+	+	-
<i>Asplanchna</i>	-	+	+
Cladocera			
<i>Daphnia pulex</i>	-	-	+
Copepoda			
<i>Cyclops</i>	+	+	+

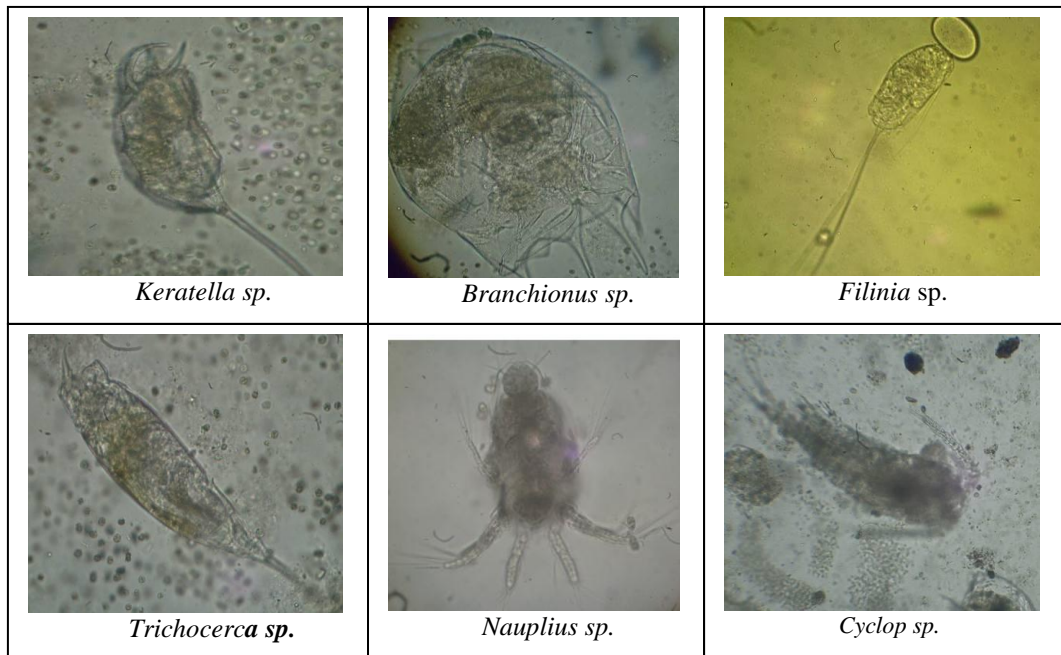


Plate 4.3: Some of the zooplanktons identified from Gathathini, Lusoi and Kianda Dams, Naromoru area, Kenya

b) Abundance of zooplanktons

The order *Rotifera* dominated the zooplankton community at Gathathini and Lusoi Dams, and accounted for more than 50% of the total abundance of each community. However, Lusoi Dam recorded higher relative abundance than Gathathini and Kianda Dams with the latter recording the least abundance (Fig. 4.17). Order *Copepoda* also occurred in the three Dams with Gathathini Dam population being more abundant than Lusoi and Kianda populations, whose abundances were less than half the abundance at Gathathini Dam (Fig. 4.17). Order *Cladocera* only occurred in Kianda Dam, and was more abundant than orders *Rotifera* and *Copepoda* in the Dam (Fig. 4.17).

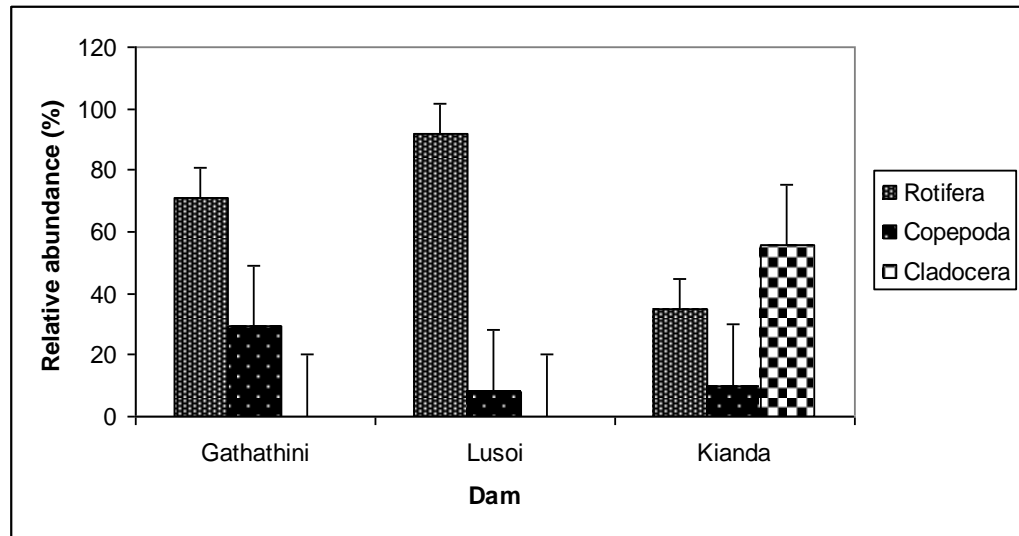


Figure 4.17: Relative abundance of different orders of zooplanktons in the three undrainable reservoirs of Naromoru

c) Zooplankton diversity

Simpson's diversity index showed slight variations between the zooplankton communities of the three reservoirs. Kianda Dam, however, had the highest species diversity and was closely followed by Lusoi and Kianda Dams, respectively (Table 4.4).

Table 4.4: Diversity indices of the zooplanktons at the three undrainable reservoirs of Naromoru at different sampling times

Dam	Gathathini	Lusoi	Kianda
Time	Simpson	Simpson	Simpson
Sep 2008	0.3892	0.5115	-
Oct 2008	0.4425	0.2971	0.5432
Jan/Feb 2009	0.5521	0.4688	0.271
Mean	0.46±0.048	0.43±0.066	0.407±0.136

4.2.3 Benthic invertebrates

a) Benthic invertebrate species composition

Benthic invertebrates in the three Naro Moru undrainable reservoirs were represented by the Diptera, Odonata, Ephemeroptera and Oligochaeta. The dipterans were dominated by the larvae of *Chironomus sp.* Plate 4.4 shows some of the benthic invertebrates found in the reservoirs.

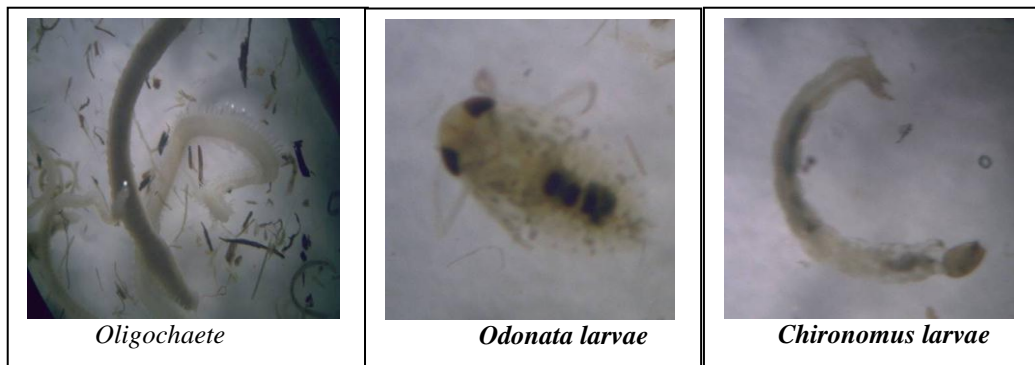


Plate 4.4 Some of the benthic organisms identified from Gathathini, Lusoi and Kianda Dams, Naromoru area, Kenya

b) Abundance of benthic invertebrates

The invertebrates at Gathathini and Lusoi Dams ($63.3 \pm 0.15\%$ and $87.2 \pm 4.78\%$) were dominated by the order Diptera (Chironomids), while the order Oligochaeta ($94.4 \pm 1.2\%$) was more dominant at Kianda dam (Fig. 4.18). However, comparison between the relative abundances of the various orders of invertebrates in the dams did not show significant differences ($K=0.8401$, d.f.=2, $P>0.05$, Kruskal-Wallis test). Order Odonata occurred in the three dams at relatively low abundances, while order Ephemeroptera occurred in very low abundances ($<0.5\%$) at Gathathini and Lusoi dams and absent at Kianda dam.

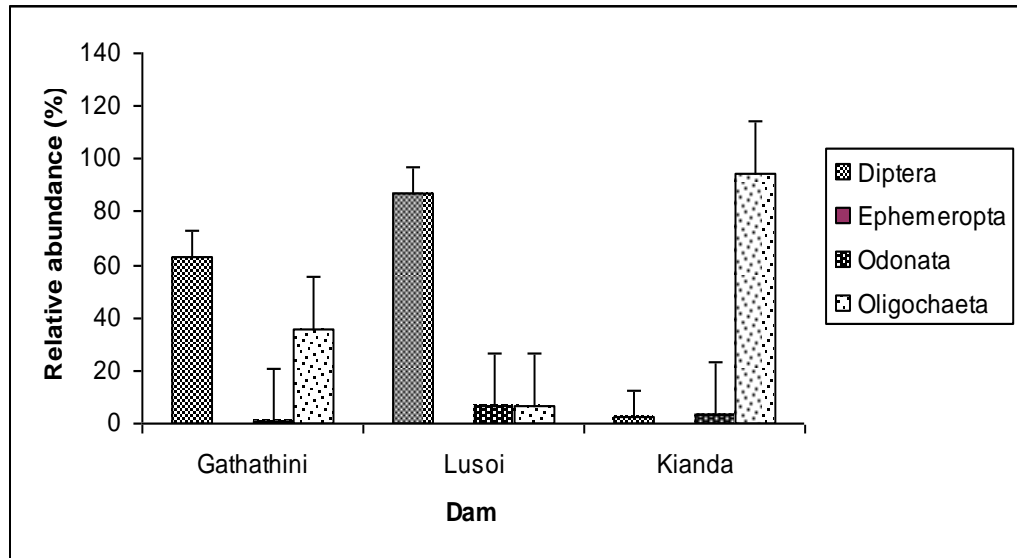


Figure 4.18: Relative abundance of various orders of benthic organisms found in Kianda dam

c) Benthic invertebrate species diversity

Benthic invertebrate species diversity was generally low in the three reservoirs as shown by Table 4.5. Comparison of the diversity indices between the three reservoirs showed no significant differences ($K=0.1561$, $d.f.=2$, $P>0.05$, Kruskal-Wallis test).

Table 4.5: Diversity indices of benthic organisms in the three undrainable reservoirs of Naromoru at different times

Dam	Gathathini	Lusoi	Kianda
Time	Simpson	Simpson	Simpson
Sep 2008	-	0.5662	-
Oct 2008	0.6948	0.9835	0.4877
Jan/Feb 2009	0.6087	0.7402	0.6004
Mean	0.65±0.04	0.76±0.12	0.54±0.06

4.3 Fish species composition and variability

4.3.1 Fish species composition

The main fish species occurring in the reservoirs was the tilapia *Oreochromis spirulus spirulus*, although it occurred in different varieties, probably due to hybridization. Genetical analysis of the specimens collected is ongoing to confirm the role of hybridization in the occurrence of the different varieties. A few Catfish (*Clarias gariepinus*) had been stocked in Kianda Dam for control of the tilapia population. This study mainly focused on *Oreochromis spirulus spirulus* since they had been purposely cultured to provide proteins to the locals. Plate 4.4 shows the two species of fish that occurred in the reservoirs.

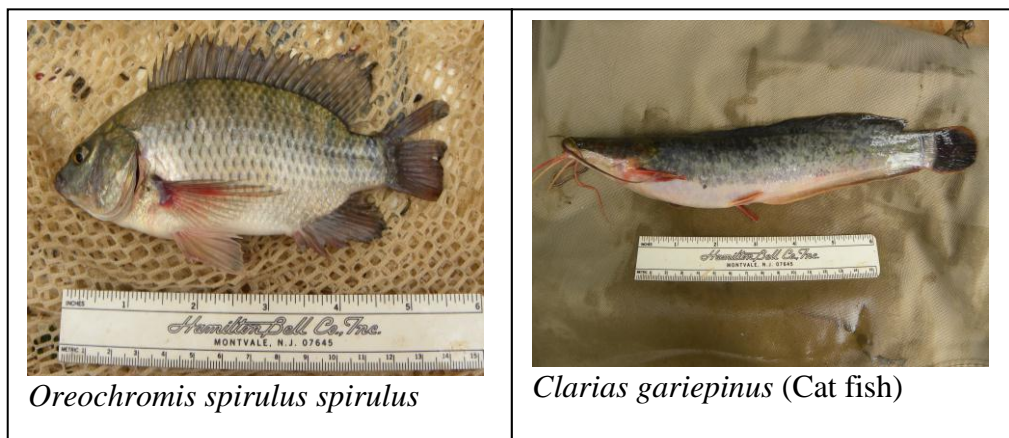


Plate 4.5: Two species of fish cultured in undrainable reservoirs of Naromoru

4.3.2 Fish variability

(a) Meristics

Principal component analysis performed on 12 meristic variables showed no difference between the three populations on component 1 (Fig. 4.19a). However, there was total separation of Gathathini and Lusoi populations, and partial

overlap between Gathathini and Kianda populations with reference to component 2 (Fig. 4.19a). Complete overlap was observed between Lusoi and Kianda populations. The variables responsible for separations observed in component two were gill rakers and teeth counts (Fig. 4.19b & 4.19c).

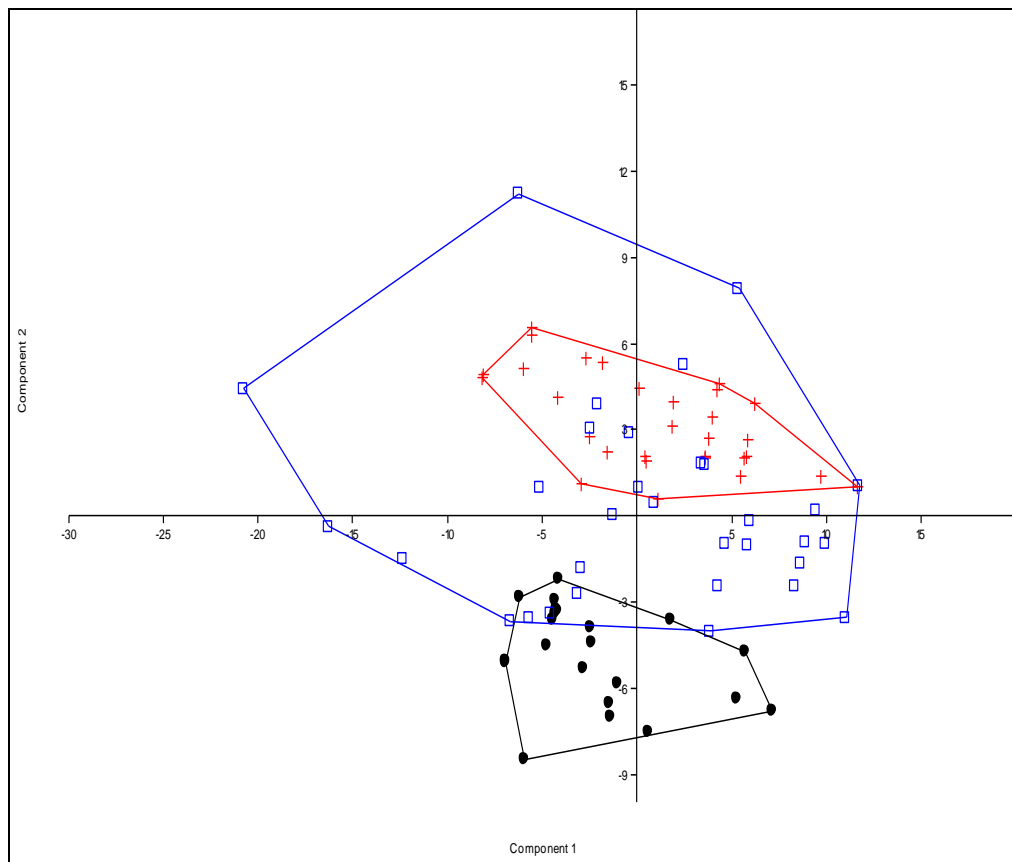


Figure 4.19a: Scatter plot of meristic characteristics of the fish population (Gathathini●, Lusoi+, Kianda □)

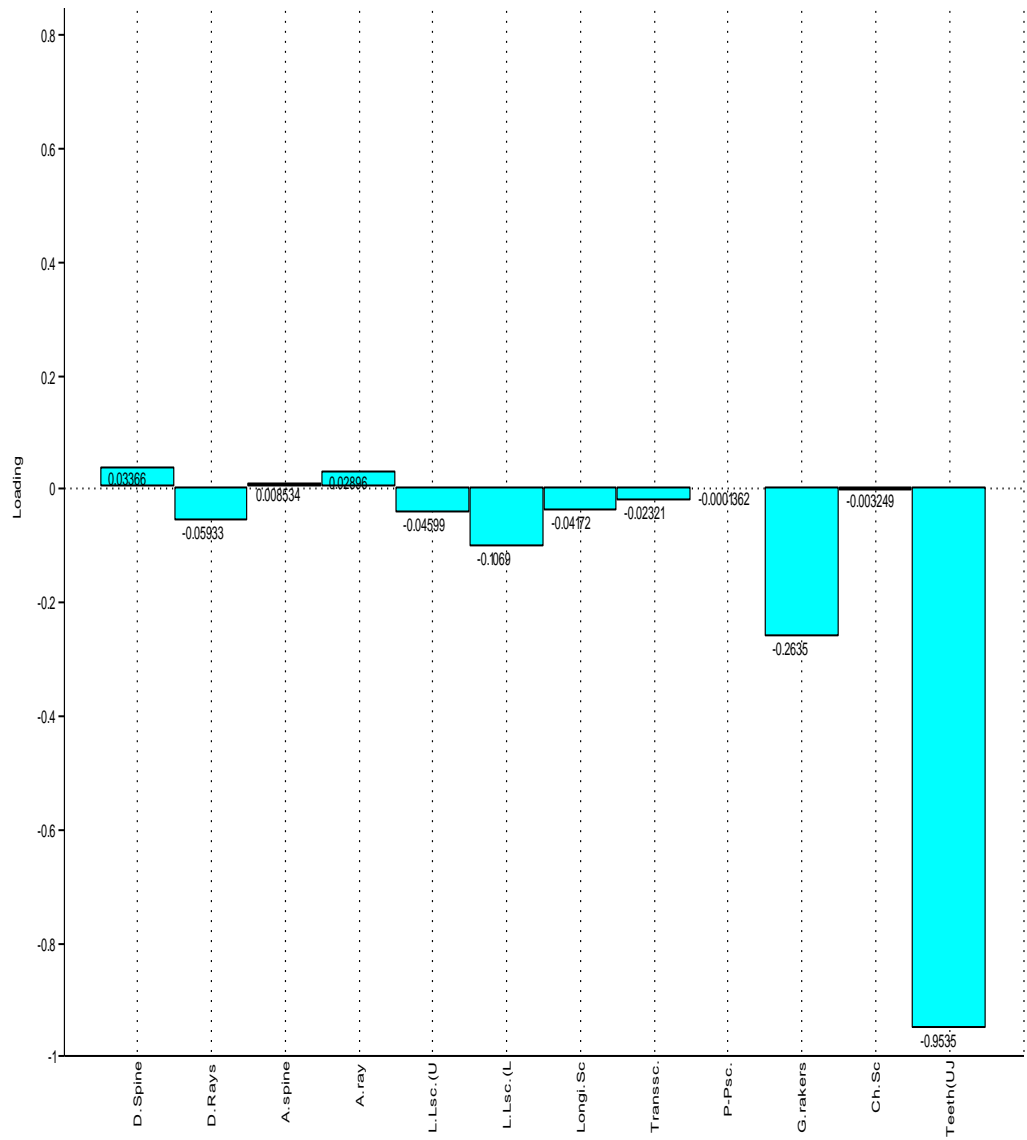


Figure 4.19b: Loadings for principal component 1 (PC 1) comparing variability of various meristic parameters

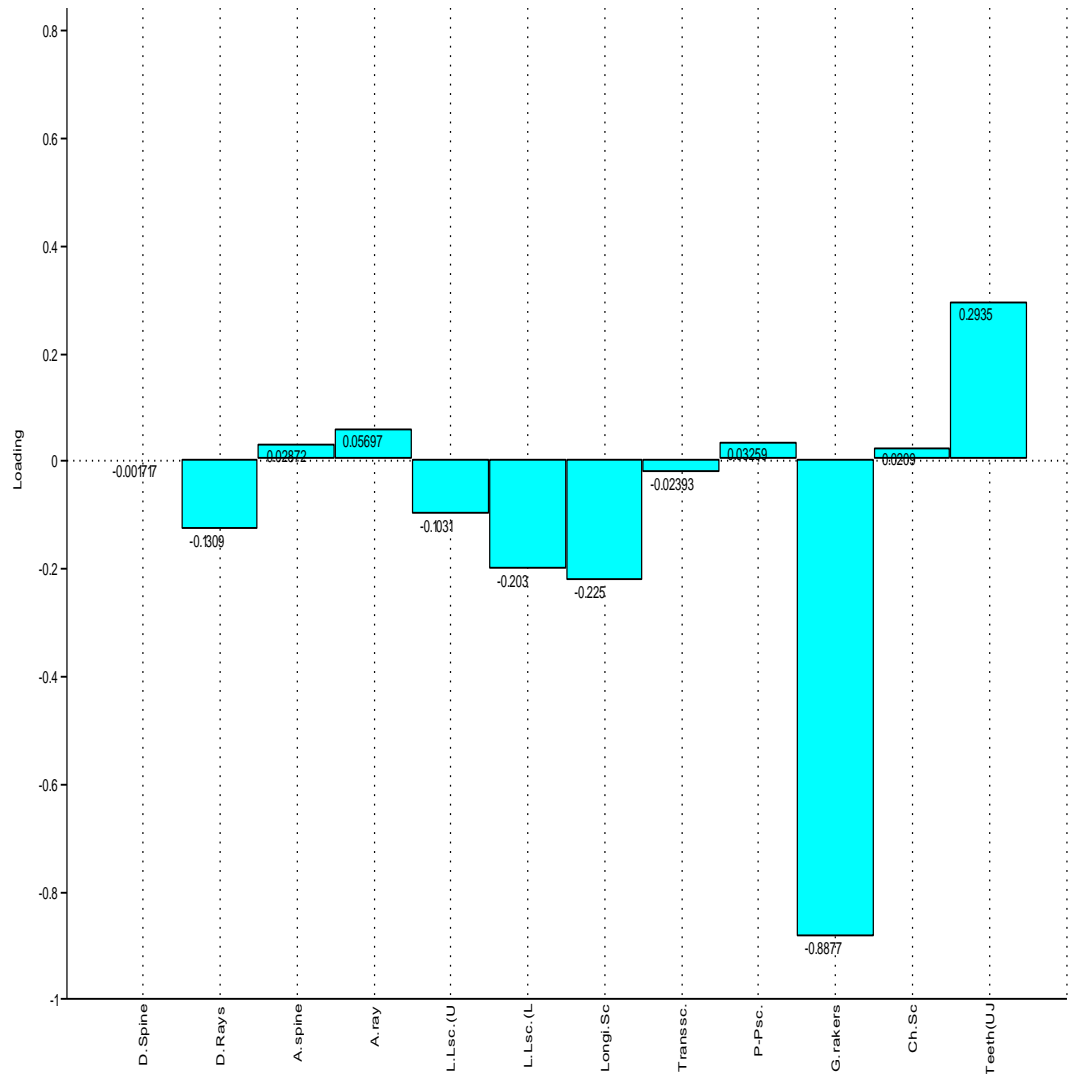


Figure 4.19c: Loadings for principal component 2 (PC 2) showing variability of different meristic parameters

Further analysis using Mann-Whitney test revealed no significant differences between the specimens from the various Dams for teeth counts ($n_g=22$, $n_l=30$, $U=290$, $P>0.05$ for Gathathini-Lusoi; $n_g=22$, $n_k=33$, $U=284$, $P>0.05$ for Gathathini-Kianda; $n_l=30$, $n_k=33$, $U=433$, $P>0.05$ for Lusoi-Kianda), and significant difference for gill raker counts ($n_g=22$, $n_l=30$, $U=0$, $P<0.05$ for Gathathini-Lusoi, $U=41.5$, $P<0.05$ for Gathathini-Kianda; $n_l=30$, $n_k=33$, $U=187$, $P<0.05$ for Lusoi-Kianda). Specimens from Gathathini Dam had teeth counts

ranging from 36–50 (mean 45.45; mode 48), Lusoi Dam 34–54 (mean 44.8; mode 42) and Kianda Dam 33–60 (mean 44.31; mode 36) as shown in table 4.6. Gill raker counts of specimens from Gathathini Dam had the highest number of gill rakers in their outer arch row ranging from 22–27 (mean 24.59; mode 25), Lusoi Dam 14–20 (mean 16.53; mode 16) and Kianda Dam 11–25 (mean 19.22; mode 18) (Table 4.6).

Table 4.6: Number of gill raker counts and teeth counts of fish samples from the three undrainable reservoirs of Naromoru

Reservoir	Gathathini Dam		Lusoi Dam		Kianda Dam	
	Gill rakers	Teeth	Gill rakers	Teeth	Gill rakers	Teeth
Minimum	22	36	14	34	11	33
Maximum	27	50	20	54	25	60
Mean	24.59	45.45	16.53	44.8	19.22	44.31
Mode	25	48	16	42	18	36

Principal component analysis excluding teeth and gill raker counts showed no difference in the three populations with respect to component 2 (Fig. 4.20a). However, component 1 showed partial differences within the three populations, and a linear relationship with reference to lateral line scales (Fig. 4.20a). High variability occurred in upper lateral line scales, lower lateral line scales and longitudinal lateral line scales (Fig. 4.20b, Fig. 4.20c).

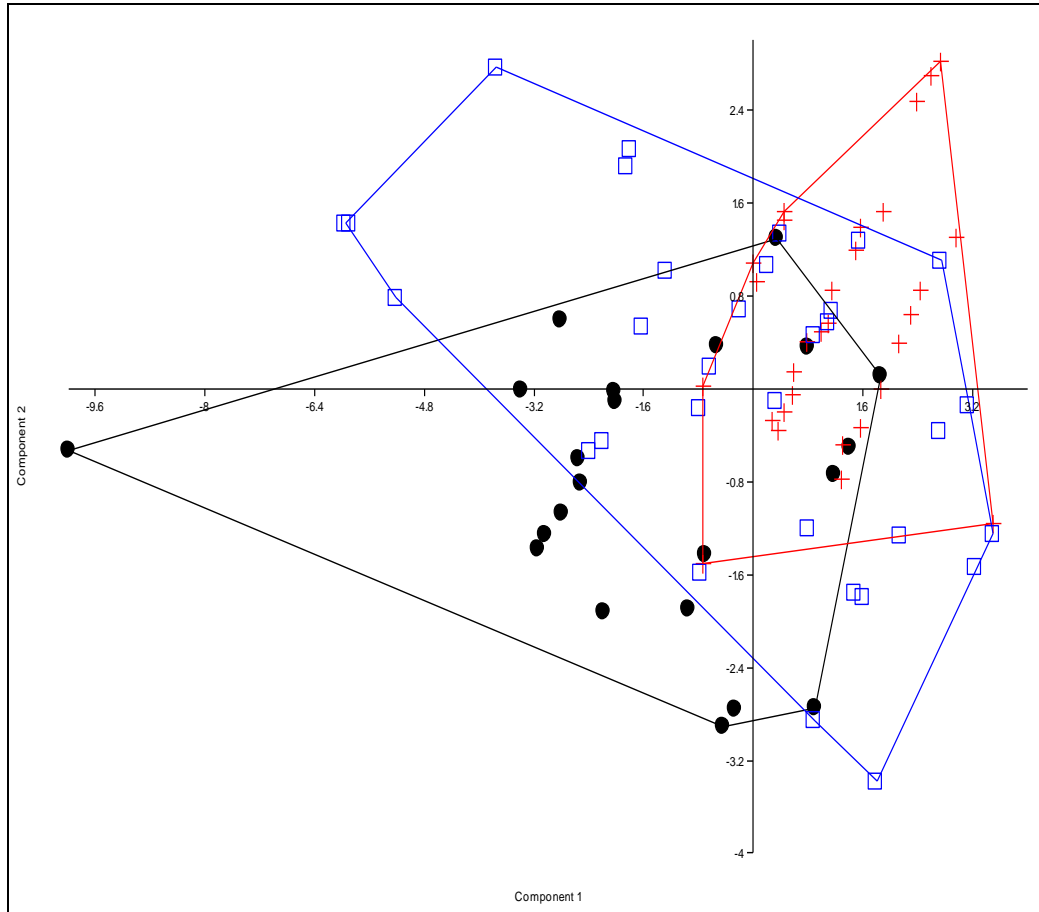


Figure 4.20a: PCA scatter plot of the fish populations with gill rakers and teeth number variables excluded (Gathathini●, Lusoi+, and Kianda □).

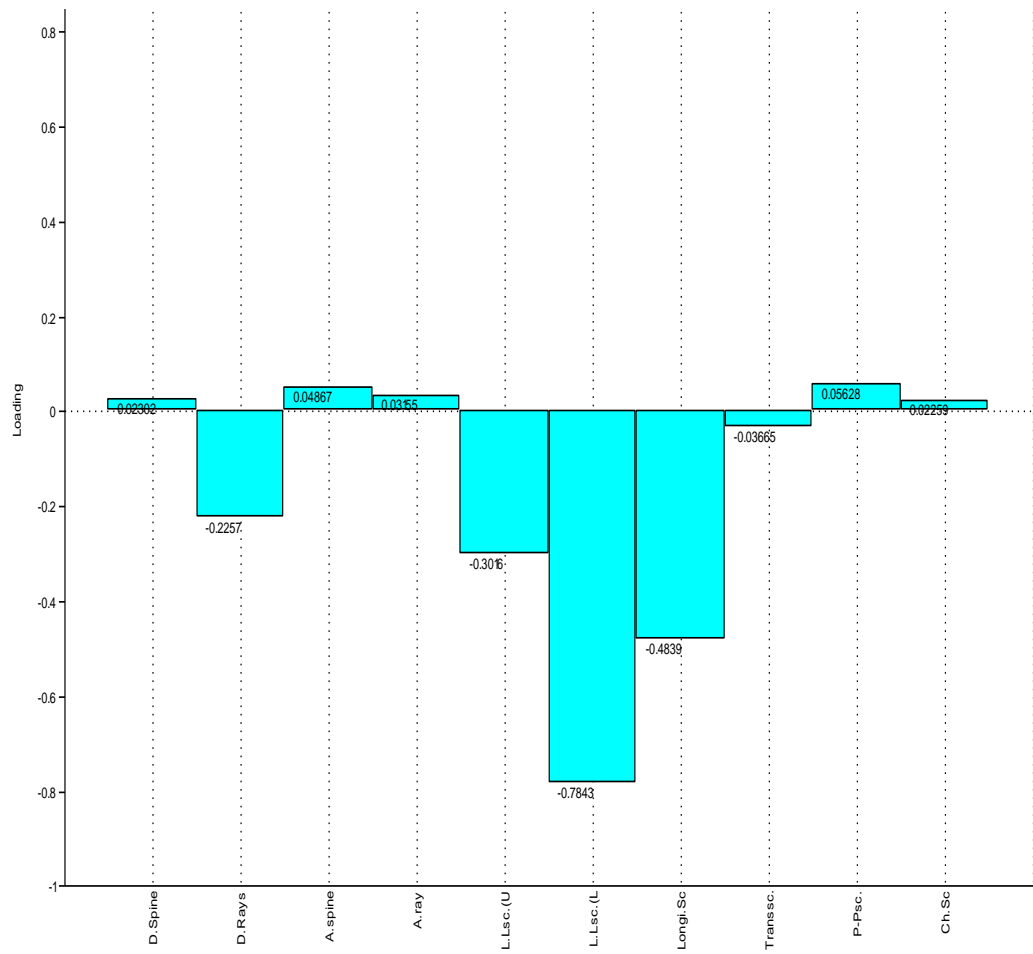


Figure 4.20b: Loadings for principal component 1 (PC 1) showing variability of different meristic parameters

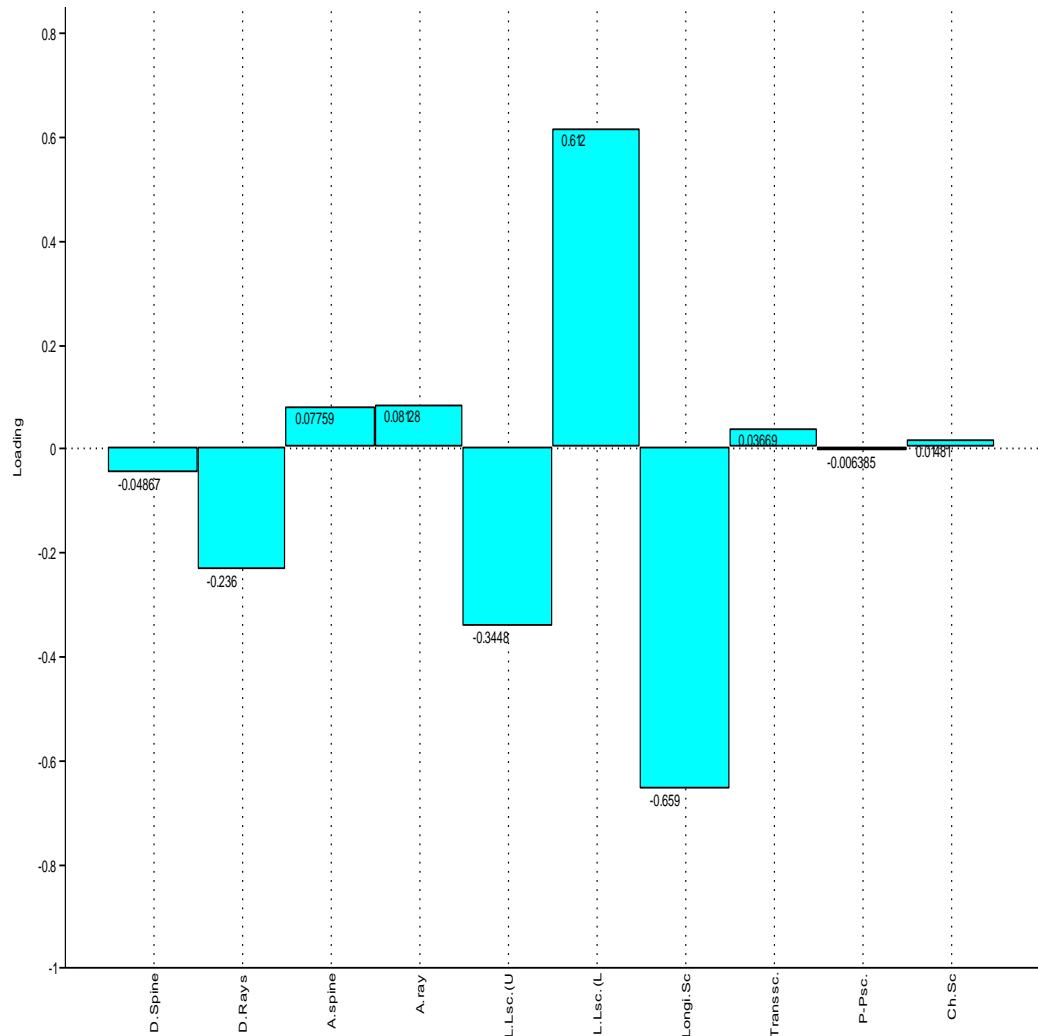


Figure 4.20c: Loadings for principal component 2 (PC 2) showing variability of different meristic parameters

Further analysis using Mann-Whitney U test on specimens from Gathathini-Lusoi Dams showed significant differences ($n_g=22$, $n_l=30$, $U=208$, $P<0.05$) in upper lateral line scales, and lack of significant difference between Lusoi-Kianda Dams ($n_l=30$, $n_k=33$, $U=356.5$, $P>0.05$) and Gathathini-Kianda Dams ($n_g=22$, $n_k=33$, $U=315.5$, $P>0.05$) populations. Lower lateral line scales revealed significant difference ($n_g=22$, $n_l=30$, $U=200.5$, $P<0.05$) for Gathathini-Lusoi populations, and no significant difference ($n_l=30$, $n_k=33$, $U=403$, $P>0.05$; $n_g=22$,

$n_k=33$, $U=293.5$, $P>0.05$) between Lusoi-Kianda and Gathathini-Kianda populations, respectively. Comparison of longitudinal lateral line scales showed significant difference between Gathathini-Lusoi ($n_g=22$, $n_l=30$, $U=76.5$, $P<0.05$), Gathathini-Kianda ($n_g=22$, $n_k=33$, $U=186.5$, $P<0.05$) and Lusoi-Kianda ($U=300$, $P<0.05$) populations. Upper lateral line scales showed highest range of 18–23 (mean 20.27; mode 20) at Gathathini Dam, Lusoi Dam closely followed with a range of 17–21 (mean 19.43; mode 20), and Kianda Dam had the lowest range of 19–22 (mean 20.06; mode 19) (Table 4.7). Lower lateral line scales had a high range of 11–21 (mean 14.09; mode 15) at Gathathini Dam, closely followed by Kianda Dam with a range of 10–19 (mean 13.56; mode 11), while Lusoi Dam had the lowest range of 10–14 (mean 12.8; mode 13) as (Table 4.7). Longitudinal scales of specimens from Gathathini Dam had a range of 29–33 (mean 31.73; mode 32), Lusoi Dam 28–32 (mean 29.87; mode 30), while Kianda Dam population had a range of 29–33 (mean 30.75; mode 30) (Table 4.7).

Table 4.7: Number of upper lateral line, lower lateral line and longitudinal line scale counts of fish samples from the three undrainable reservoirs of Naromoru

Dam	Scale location	Min	Max	Mean	Mode
Gathathini	Upper lateral line scales	18	23	20.27	20
	Lower lateral line scales	11	21	14.09	15
	Lateral line scales	29	33	31.73	32
Lusoi	Upper lateral line scales	17	21	19.43	20
	Lower lateral line scales	10	14	12.8	13
	Lateral line scales	28	32	29.87	30
Kianda	Upper lateral line scales	19	22	20.06	19
	Lower lateral line scales	10	19	13.56	11
	Lateral line scales	29	33	30.75	30

Studies on dorsal spines and rays showed that Gathathini Dam fish population had dorsal fin formula of XV–XVII 11–14. The spines averaged 16.2 and had a mode of 16, while the rays had a mean of 12.5 and a mode of 12. Kianda Dam specimens on the other hand had a dorsal formula of XV–XVII 9–13, with spines having a mean and mode of 16.2 and 16 respectively, while the rays averaged 11.44 and had a mode of 11. Lusoi Dam specimens had a dorsal fin formula of XV–XVIII 10–12, with means and modes of spines and rays being 16.5 and 16, and 10.9 and 11 respectively. Studies on anal spines and rays showed that specimens from Gathathini Dam had anal fin formula of III 8–10, with the mean and mode of spines being 3 and 8.82, and the rays 9 (mean and mode). Lusoi Dam specimens had anal formula of III–IV 9–11, and spines had a

mean and mode of 3.4 and 3, while the rays averaged 9.6 with a mode of 10. Kianda Dam population had anal formula of III–IV 8–10, with spines averaging 3.09 with a mode of 3, and rays averaging 9.09 with a mode of 9.

(b) Morphometrics

Body proportions of specimens from the three undrainable reservoirs expressed as percentages of standard length (SL) and head length (HL) did not show marked differences between the three populations in most parameters measured. However, fish from Lusoi Dam had a lower range of body depth (BD) compared to those from Gathathini and Kianda Dams, which had relatively high proportions (tables 4.8, 4.9 & 4.10).

Table 4.8: Showing proportions of various variables expressed as % of head length (HL) or standard length (SL) of the specimen from Gathathini Dam

PARAMETER	CLASS		
	70-79	80-89	90-99
BD/SL%	38.81-41.60	33.71-41.51	35.87
HL/SL%	33.46-36.66	30.90-35.35	33.62
Sn.L/HL%	29.46-34.10	28.32-36.53	32.76
ED/HL%	24.48-28.40	24.47-27.11	25
IOW/HL%	27.20-32.95	26.94-35.17	35.56
LJL/HL%	28.28-54.26	27.97-54.44	34.48
MW/HL%	31.03-35.61	30.63-34.83	39.44

Table 4.9: Proportions of various variables expressed as % of head length (HL) or standard length (SL) of the specimen from Lusoi Dam

PARAMETER	CLASS			
	60-69	70-79	80-89	90-99
BD/SL%	33.88-34.49	33.47-38.62	35.85-39.49	34.80-38.43
HL/SL%	34.47-36.23	33.29-35.81	32.81-37.50	32.42-33.92
Sn.L/HL%	30.80-31.76	28.93-35.46	31.05-37.11	32.19-38.82
ED/HL%	24.00-25.75	20.72-28.00	21.24-24.50	22.62-26.75
IOW/HL%	26.80-27.90	29.17-32.86	26.14-33.68	29.79-35.76
LJL/HL%	30.80-35.19	29.29-32.00	29.41-36.43	27.38-35.76
MW/HL%	24.80-34.76	26.07-35.20	35.94-38.35	31.25-39.21

Table 4.10: Proportions of various variables expressed as % of head length (HL) or standard length (SL) of the specimen from Kianda Dam

PARAMETER	CLASS						
	50-59	60-69	70-79	80-89	90-99	100-109	110-above
BD/SL%	37.80-39.61	36.43-39.87	36.94-40.77	35.96-39.27	37.97-40.19	38.56-39.82	40.00-43.83
HL/SL%	32.88-36.27	33.73-35.88	34.32-36.80	33.15-38.14	32.79-36.47	34.15-35.23	28.02-34.46
Sn.L/HL%	28.73-30.93	26.96-32.44	28.69-34.24	30.48-34.97	32.52-41.16	33.33-36.41	31.58-46.26
ED/HL%	27.84-28.64	25.56-29.49	23.66-27.05	21.90-24.14	20.92-25.66	21.01-22.78	18.73-22.11
IOW/HL%	25.97-32.99	28.89-32.89	29.01-30.74	29.52-38.64	26.77-34.20	31.13-32.22	30.79-42.73
LJL/HL%	30.93-36.46	31.39-37.61	32.44-34.84	29.02-35.25	29.18-37.23	34.17-36.09	31.58-37.80
MW/HL%	24.27-35.57	29.33-36.00	30.18-35.41	28.28-37.06	33.85-40.87	37.22-38.57	38.11-46.05

Principal component analysis carried out on 17 morphometric characteristics of the three populations showed partial differences for both components 2 and 3 (Fig. 4.21a). Variables that showed high variations were caudal peduncle length (CPL) for component 2 (Fig. 4.21b), and inter-orbital width (IOW) and anal basal length (ABL) for component 3 (Fig. 21c).

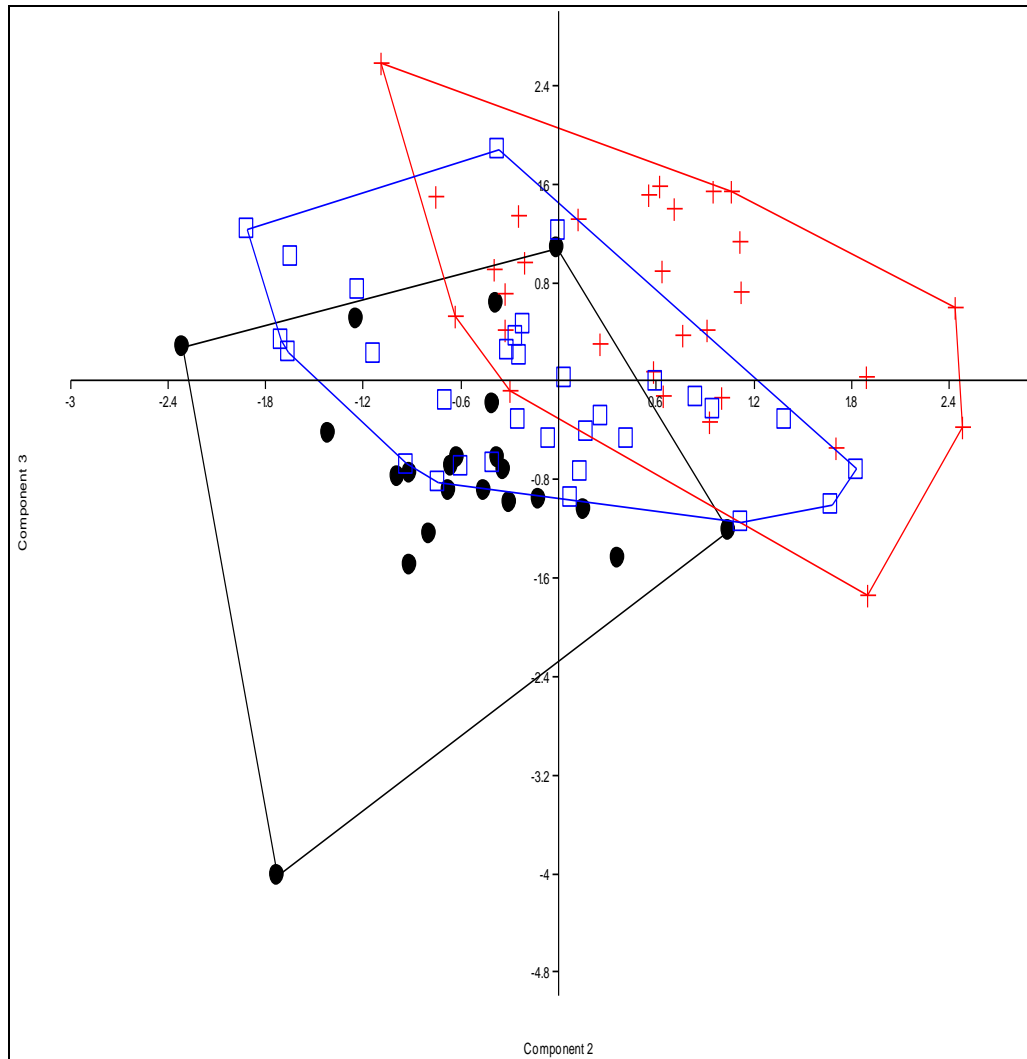


Figure 4.21a: Scatter plot of PC2 and PC3 of fish populations from three undrainable reservoirs of Naromoru reservoirs (Gathathini●, Lusoi+, Kianda □)

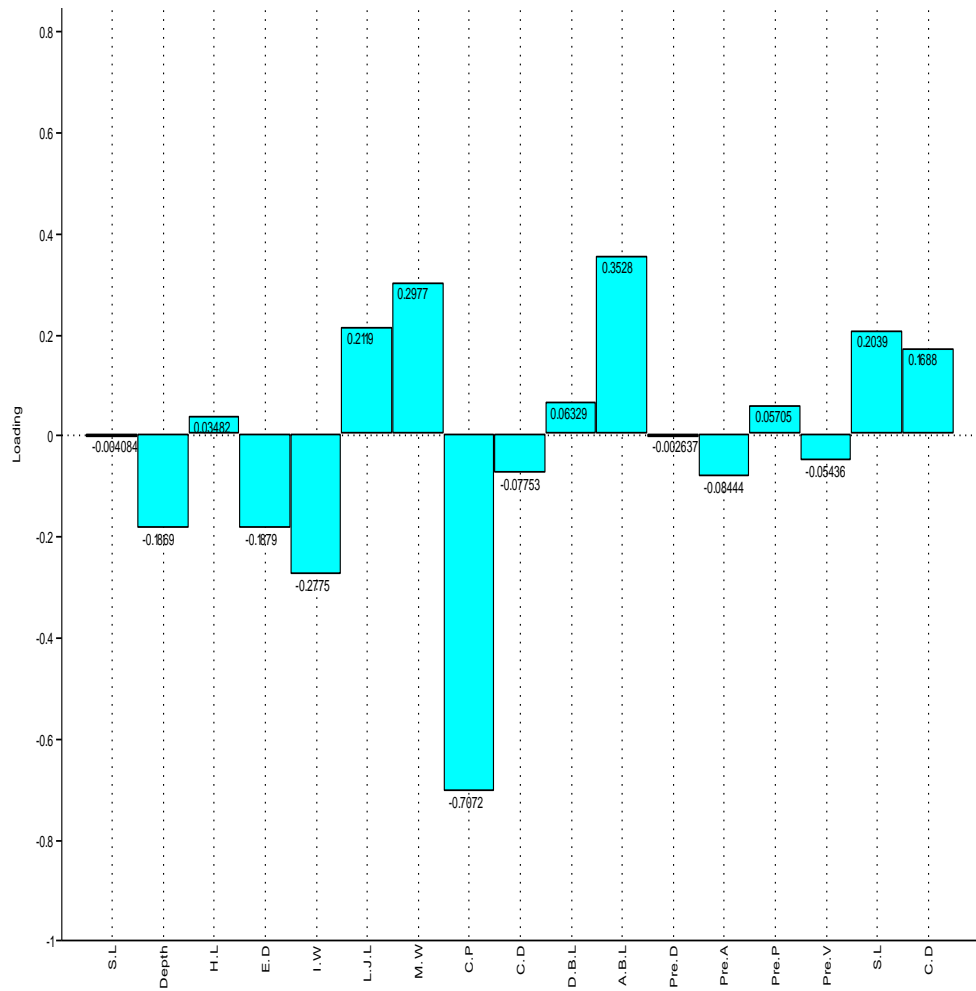


Figure 4.21b: Loadings of PC 2 showing variability of different measured morphometric parameters

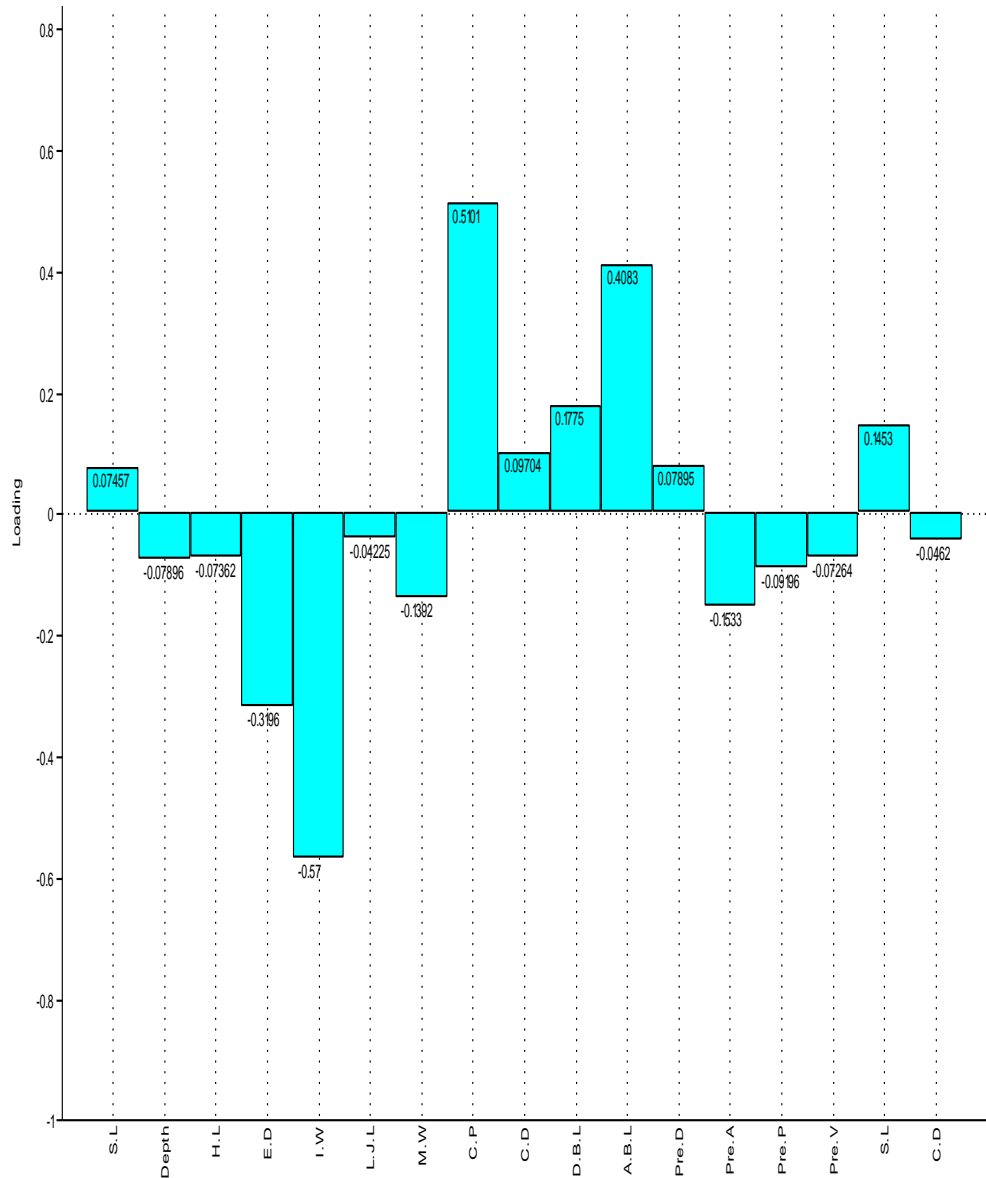


Figure 4.21c: Loadings of PC 3 showing variability of the measured morphometric parameters

Caudal peduncle length showed significant difference between Gathathini-Lusoi populations ($n_g=22$, $n_l=30$, $U=150.5$, $P<0.05$, Mann-Whitney U test) and lack of significant differences between Lusoi-Kianda ($n_l=30$, $n_k=33$, $U=398.5$, $P>0.05$, Mann-Whitney U test) and Gathathini-Kianda ($n_g=22$, $n_k=33$, $U=272.5$, $P>0.05$, Mann-Whitney U test) populations. Percentage ratios of caudal peduncle length

to standard length ranged from 10.0-14.38 with a mean of 12.38 at Gathathini Dam, 9.32-15.65 with a mean of 11.77 at Lusoi Dam and 9.96-16.50 with a mean of 12.52 at Kianda Dam. Inter-orbital width differed significantly between Gathathini-Lusoi populations ($n_g=22$, $n_l=30$, $U=176$, $P=0.05$, Mann-Whitney U test), while comparisons between Lusoi-Kianda and Gathathini-Kianda populations showed no significant differences ($n_l=30$, $n_k=33$, $U=407$, $P=0.05$ and $n_g=22$, $n_k=33$, $U=312.5$, $P=0.05$, Mann-Whitney U test), respectively. The ratios of inter-orbital width to head length expressed as percentages ranged from 26.94–57.11 with a mean of 32.56mm for Gathathini Dam population, 26.14–35.76 with a mean of 30.89mm for Lusoi Dam population, and 25.97–42.73mm with a mean of 32.36mm for Kianda Dam population. Comparisons between the three populations with respect to anal basal length showed significant differences ($n_g=22$, $n_l=30$, $U=45.5$, $P<0.05$; $n_l=30$, $n_k=33$, $U=279.5$, $P<0.05$, Mann-Whitney U test) between Gathathini-Lusoi and Lusoi-Kianda populations respectively, and no significant differences ($n_g=22$, $n_k=33$, $U=261.5$, $P>0.05$, Mann-Whitney U test) between Gathathini-Kianda populations. The percentage variations and means of anal basal length to standard length were; 16.07-19.87% and 18.27mm at Gathathini Dam, 19.01-23.77% and 21.42mm at Lusoi Dam, and 17.22-22.03% and 19.40mm at Kianda Dam.

Further analysis on morphometric characteristics after exclusion of caudal peduncle length, inter-orbital width and anal basal length showed small partial difference with respect to component 2 and no differences in component 3 (Fig.

4.22a). The most variable parameters were cheek depth for components 2 and mouth width for component 3 (Fig. 4.22b and 4.22c).

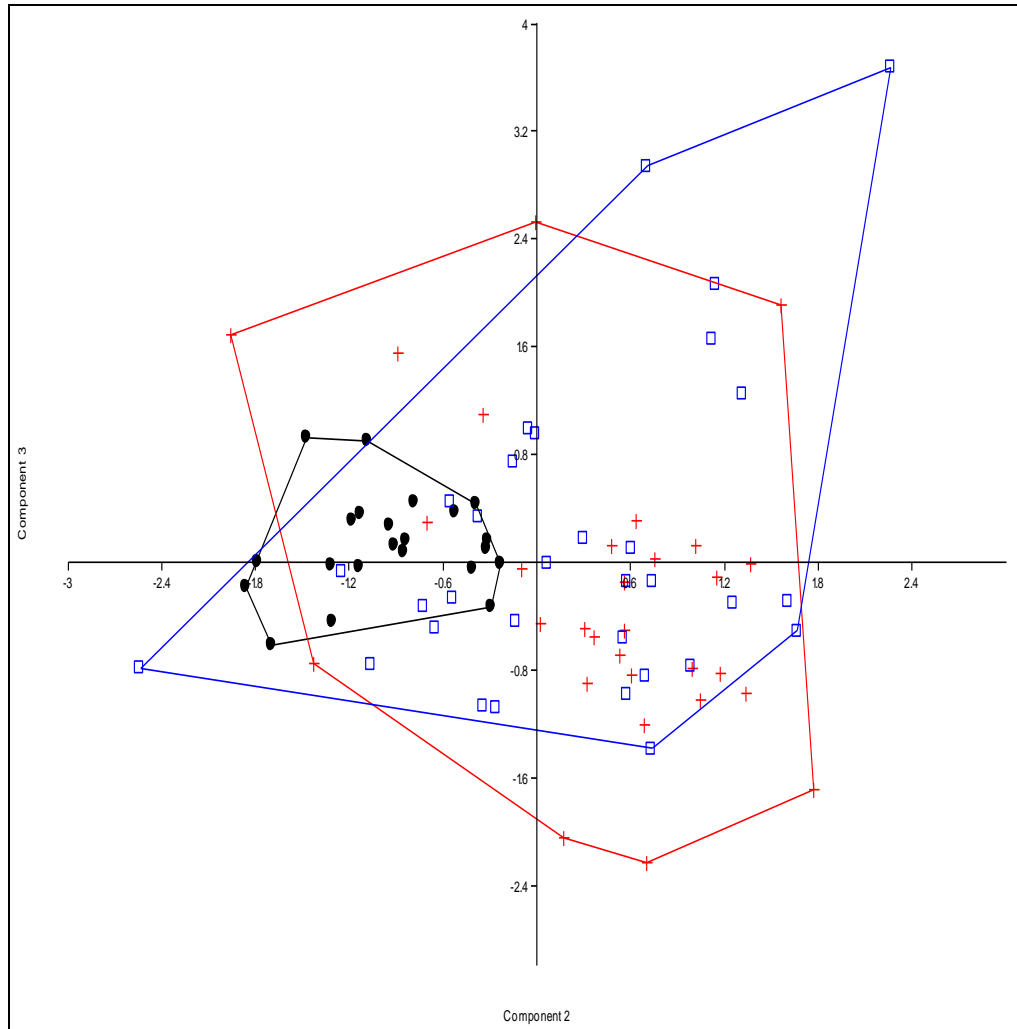


Figure 4.22a: Scatter plot of morphometric variables of fish populations after exclusion of caudal peduncle length, inter-orbital length and anal basal length (Gathathini●, Lusoi+, Kianda □).

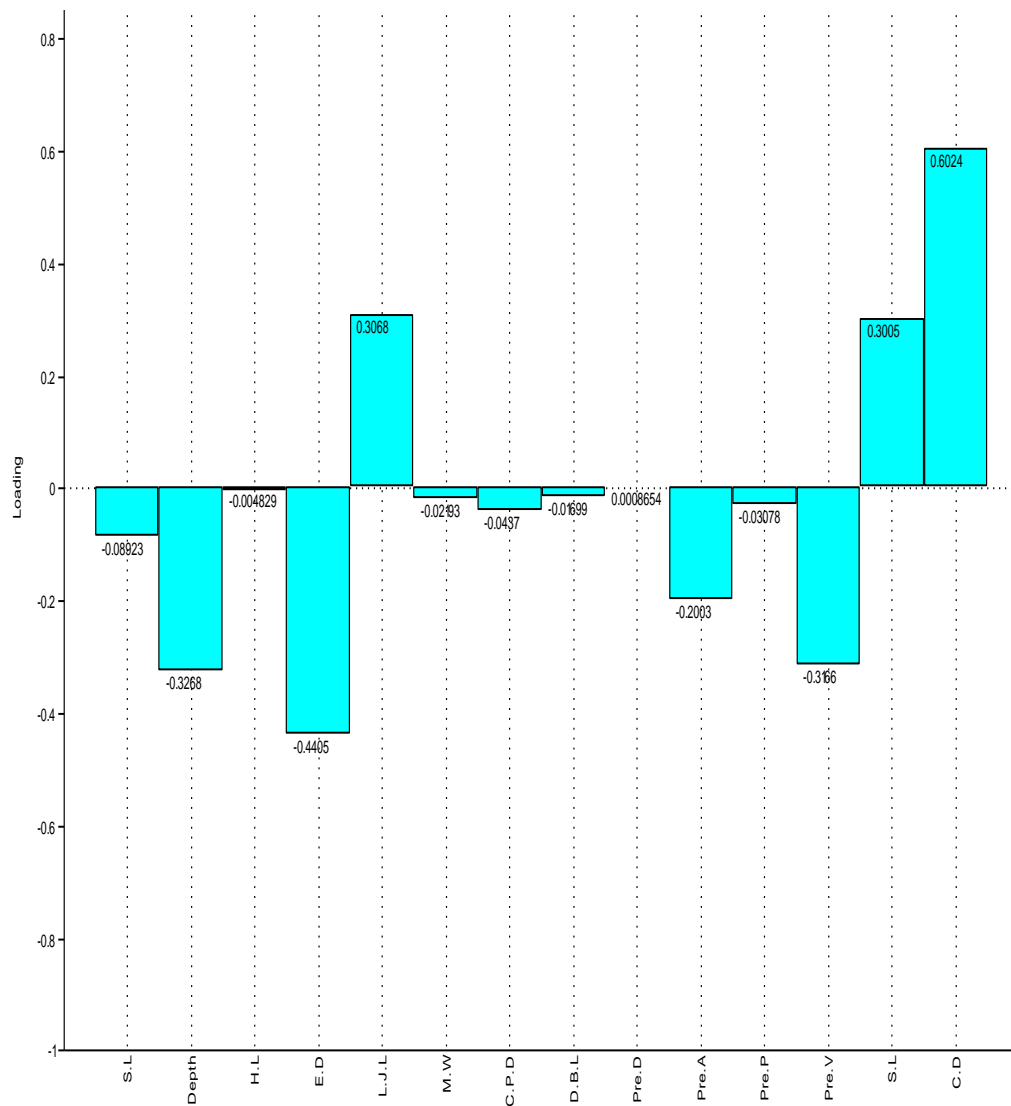


Figure 4.22b: Loadings of PC 2 showing variability of morphometric parameters after exclusion of caudal peduncle length, inter-orbital length and anal basal length

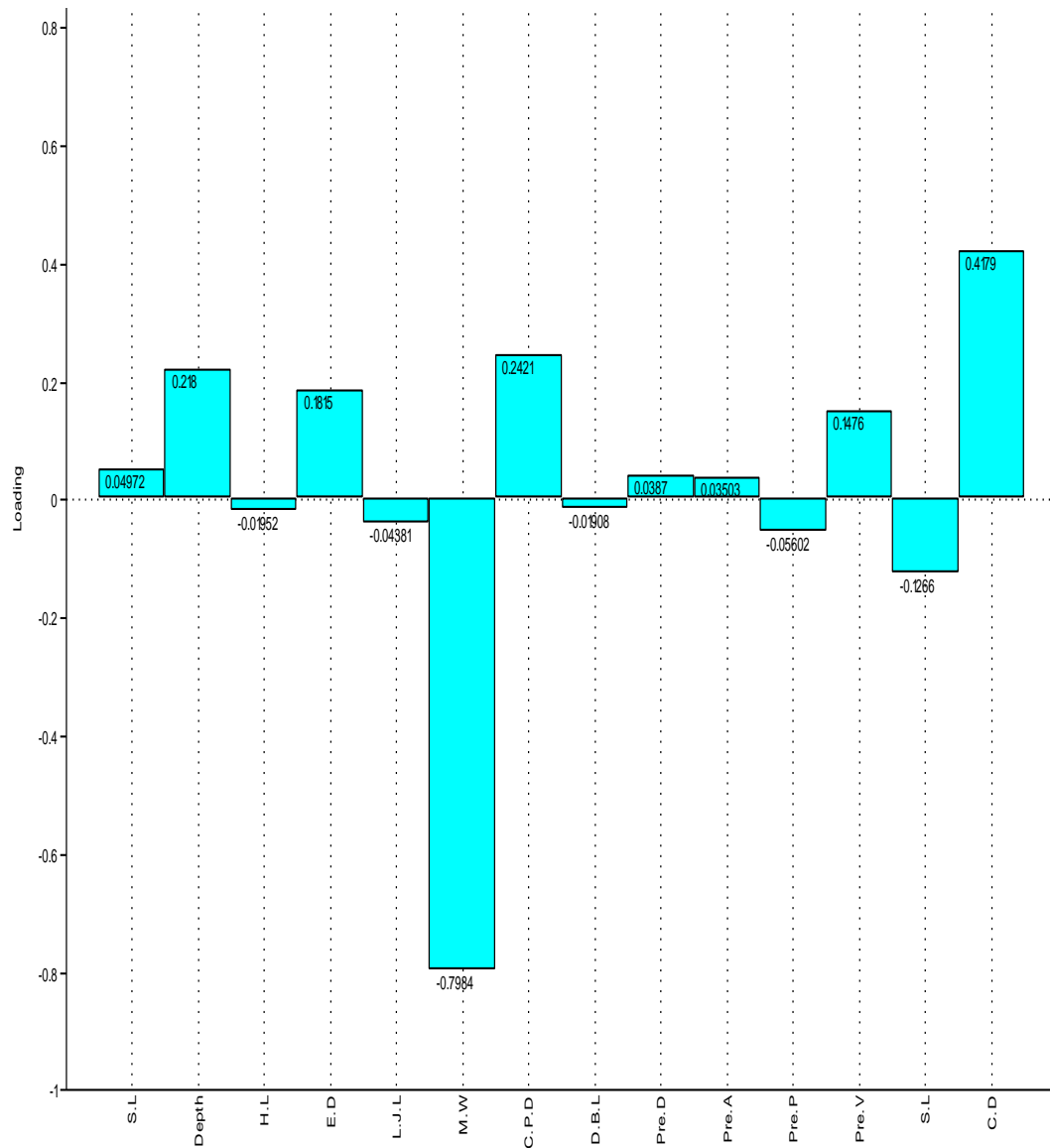


Figure 4.22c: Loadings of PC 3 showing variability of morphometric parameters after exclusion of caudal peduncle length, inter-orbital length and anal basal length

Significant difference ($n_g=22$, $n_l=30$, $n_g=22$, $n_l=30$, $U=121.5$, $P<0.05$, Mann-Whitney U test) was recorded between Gathathini-Lusoi populations, and no significant differences were found between Lusoi-Kianda ($n_l=30$, $n_k=33$, $U=384.5$, $P<0.05$ Mann-Whitney U test) and Gathathini-Kianda ($n_g=22$, $n_k=33$, $U=252$, $P<0.05$, Mann-Whitney U test) populations with respect to cheek depth.

The populations had ranges and mean percentage ratios of cheek depth to standard length of 9.21-11.19 and 10.39 at Gathathini Dam, 8.85-12.94 and 11.10 at Lusoi Dam, and 9.04-15.49 and 11.39 at Kianda Dam. Likewise, mouth width comparison showed significant differences between Gathathini-Lusoi populations ($n_g=22$, $n_l=30$, $U=$, $P<0.05$, Mann-Whitney U test), and no significant differences between Lusoi-Kianda ($n_l=30$, $n_k=33$, $U=$, $P>0.05$, Mann-Whitney test) and Gathathini-Kianda ($n_g=22$, $n_k=33$, $U=$, $P>0.05$, Mann-Whitney U test) populations. Percentage ratio of mouth width to head length ranged from 30.63-39.44 with a mean of 33.13 at Gathathini dam, 24.8–48.72 with a mean of 36.68 at Lusoi and 24.27-46.05 with a mean of 35.47.

4.4 Catch per unit effort

Catch-Per-Unit effort was highest at Lusoi Dam, where it averaged $259\pm150.2\text{g/m}^2/\text{hr}$ as compared to $58\pm39.4\text{g/m}^2/\text{hr}$ at Gathathini and $47\pm29.6\text{g/m}^2/\text{hr}$ at Kianda Dams (Fig. 4.23). During fishing at Lusoi Dam, the CPUE of the fish caught overnight ranged from 73.0 to $556.4\text{g/m}^2/\text{hr}$. Gill net mesh size 2.5 inch captured the highest number of fish, while gill net mesh size of 4 inch did not capture any fish (table 4.11). Seining method yielded very poor results irrespective of the effort used (table 4.12). At Kianda Dam, very large tilapia fish weighing over 1.5kg were caught indicating that the reservoir has high potential for fish production. Fish in the Dam, however, were extensively exploited by the community members, which may account for the low catch per unit effort. Gathathini Dam was the poorest in fish production with seining yielding low results despite use of greater effort (table 4.11 & 4.12). Gill netting

similarly yielded low catches rarely exceeding $97.7\text{g/m}^2/\text{hr}$ per fishing effort despite claims by the community that the reservoir had been recently stocked. Other than being newly stocked, the yield may also have been accounted for by the fact that the reservoir had only been recently reconstructed and was generally going through a phase of stabilization. Additionally, large number of fish eating birds attracted to the reservoir by the newly stocked fish may have contributed to the low yields.

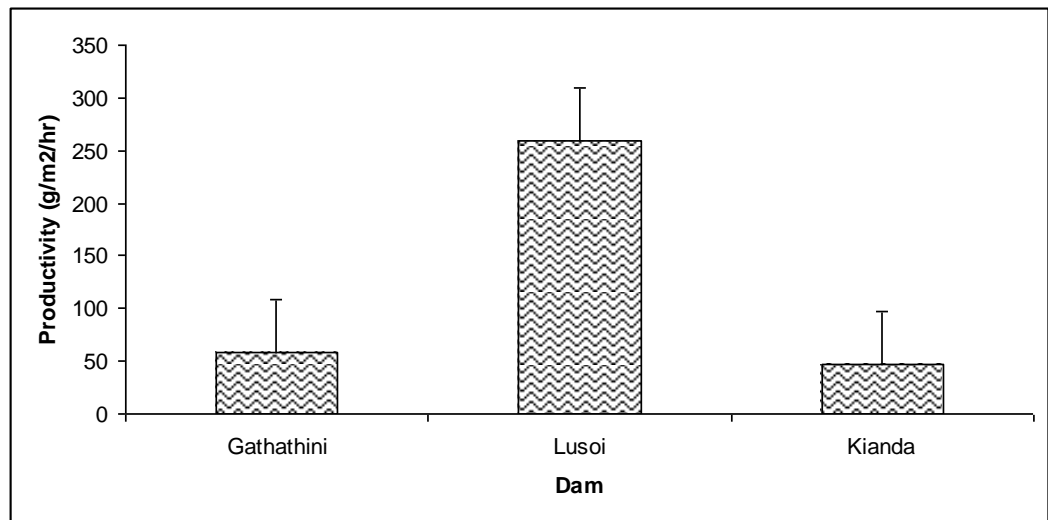


Figure 4.23: CPUE of fish in $\text{g/m}^2/\text{hr}$ in the three undrainable reservoirs of Naromoru

Table 4.11: Number of fish caught by different sizes of gill nets at different sampling periods

DAM	Time	2.5 inches	3.0 inches	3.5 inches	4.0 inches
Gathathini	Sept 2008	0	0	0	5
	Oct 2008	0	0	0	0
	Jan/Feb 2009	1	0	0	4
Lusoi	Sept 2008	0	4	0	0
	Oct 2008	59	10	0	0
	Jan/Feb 2009	52	16	4	0
Kianda	Oct 2008	6	2	0	1
	Jan/Feb 2009	4	4	1	0

Table 4.12: Number of fish caught by seine nets in the three undrainable reservoirs of Naromoru

DAM	Gathathini	Lusoi	Kianda
CATCH No.	32	50	63

Among the four different sizes of nets used, 2.5 inch mesh size captured the highest number of fish. However, most of the fish caught were small in size with their total lengths ranging from 6 to 22cm (Fig. 4.24). The 3 inch mesh net captured the second highest number of fish of relatively large size (19 - 27cm), while 3.5 and 4 inch mesh nets captured very few fish but of large sizes (Fig. 4.24).

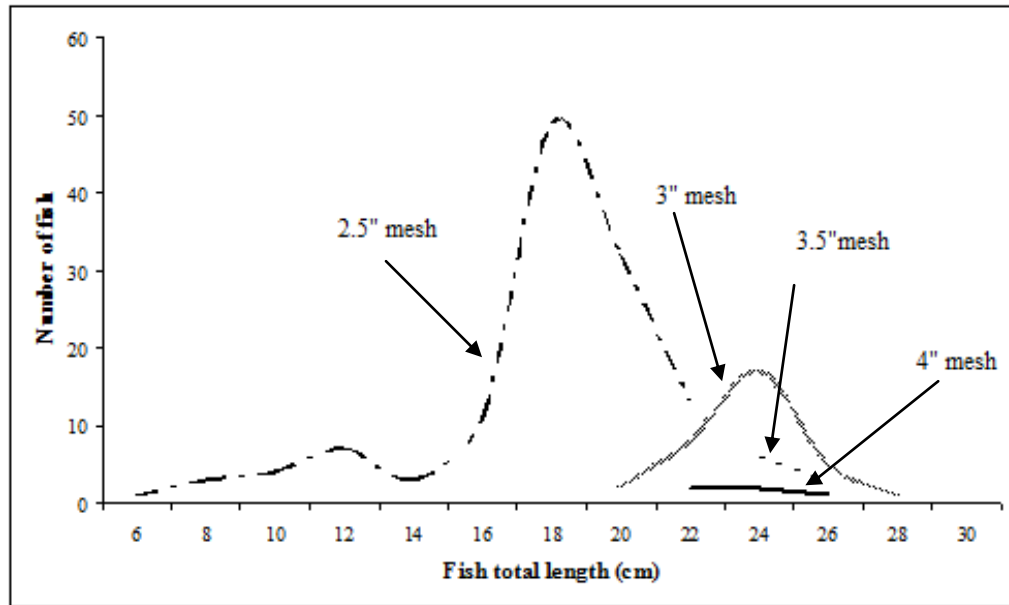


Figure 4.54: Gill net selectivity in the three undrainable reservoirs of Naromoru

4.5 Length weight relationships and relative condition factor

4.5.1 Length weight-relationship

Fish caught at Kianda Dam had length-weight relationship represented by formulae shown in figure 4.25 with R^2 value of 0.9495 indicating high positive correlation between length and weight and therefore normal growth. Length-weight relationship at Gathathini Dam yielded a formula shown in Fig. 4.26 with an R^2 value of 0.9908 indicating very close relationship between length and weight, hence normal growth. At Lusoi Dam, the length-weight regression equation was as shown in fig. 4.27. The R^2 value was 0.9708 suggesting high relationship between length and weight.

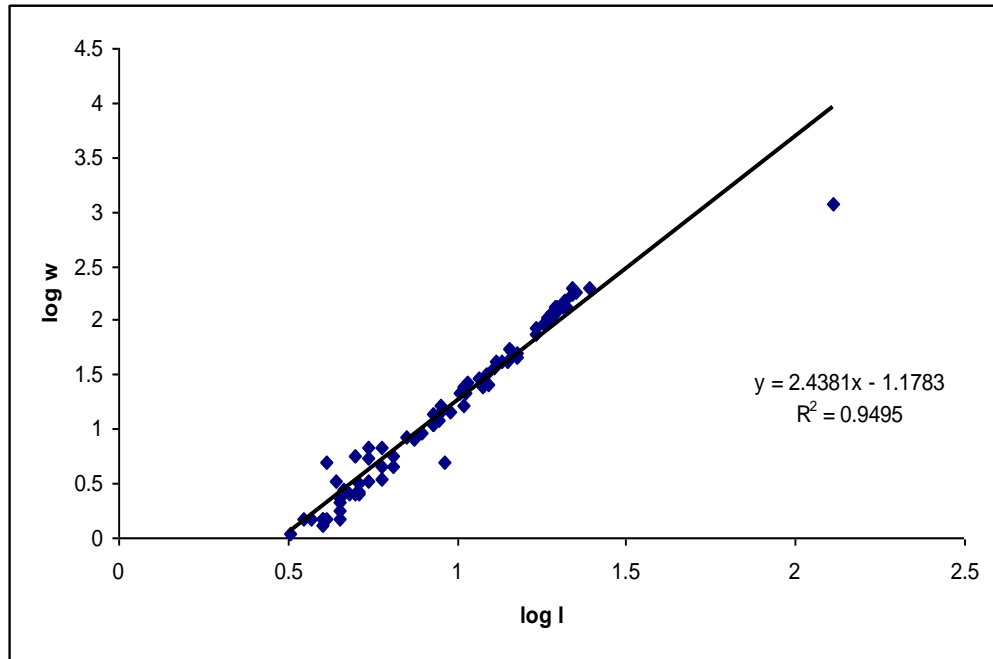


Figure 4.25: Length-weight relationship of fish caught at Kianda Dam

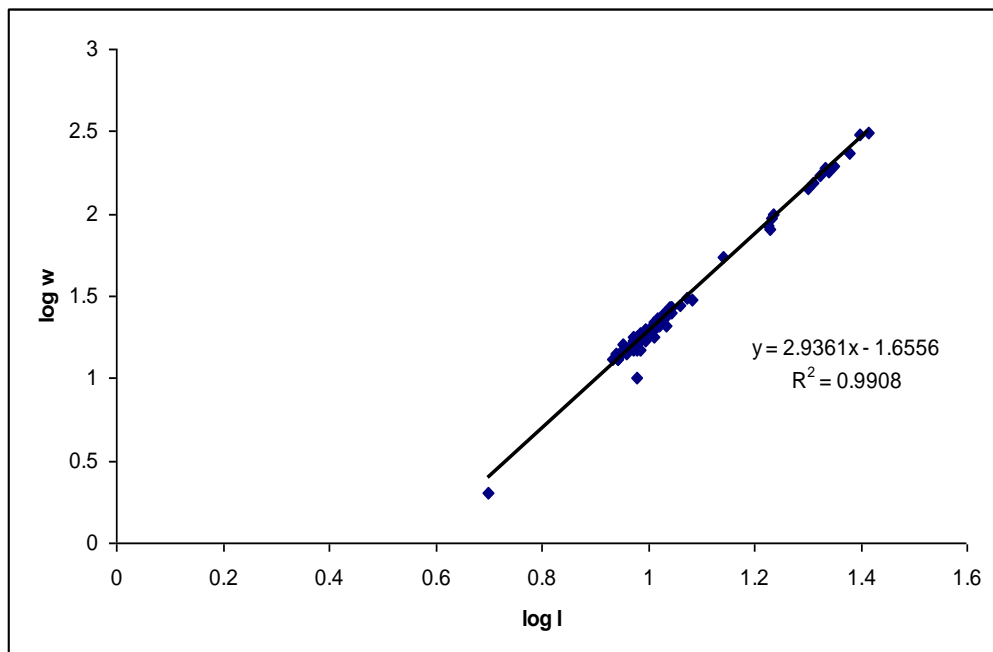


Figure 4.26: Length-weight relationship of fish caught at Gathathini Dam

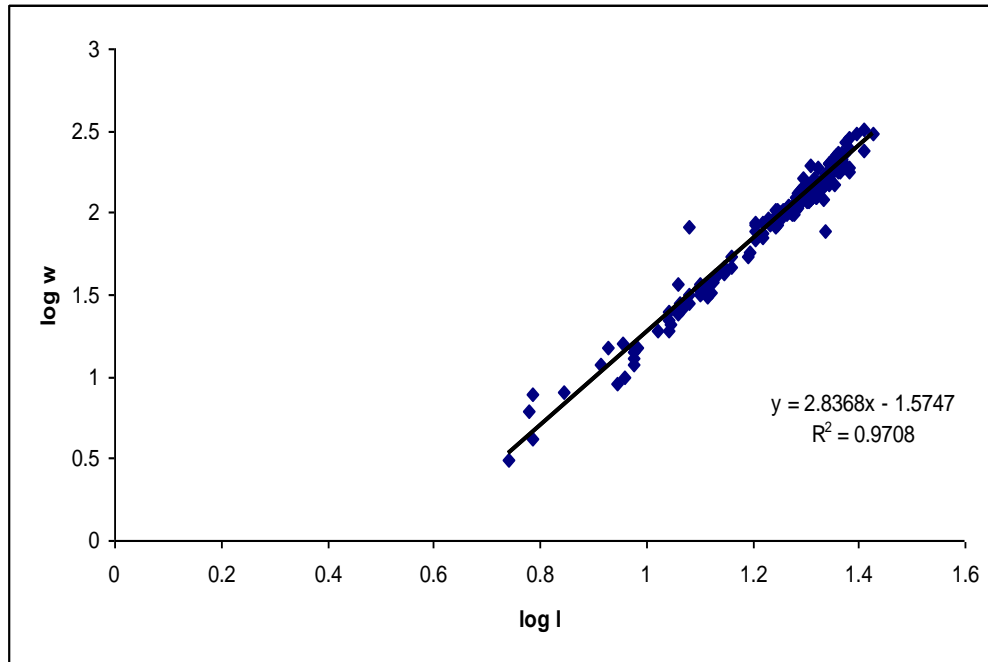


Figure 4.27: Length-weight relationship of fish caught at Lusoi Dam

4.5.2 Fish relative condition factor

Fish population from Gathathini Dam were in best condition with K values averaging 1.9 ± 0.09 and ranging from 1.84-2.02 (Fig. 4.28). Similarly, fish from Kianda Dam were equally healthy with mean relative condition of 1.86 ± 0.29 and a range of 1.57-2.15. Although Lusoi Dam yielded the highest catch per unit effort probably because of long existence and associated stability, fish condition was slightly lower, with mean K-factor of 1.7 ± 0.07 and a range of 1.61-1.82. Despite the low condition factor, however, the fish were still relatively healthy, suggesting that fish in these reservoirs are in good condition.

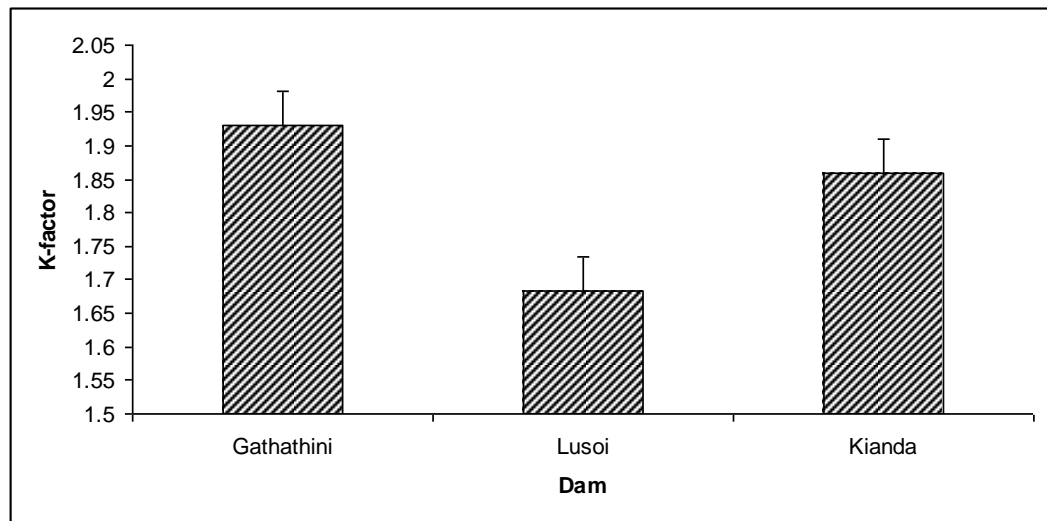


Figure 4.28: Comparison of fish condition factors of fish caught in the three undrainable reservoirs of Naromoru

Chapter 5: Discussion

5.1 Discussion

Undrainable reservoirs generally differ in their characteristics based on location, form and operations (Chapman, 1996). In the Naromoru area, the undrainable reservoirs differed markedly in their physical and chemical characteristics in relation to their location. Gathathini Dam, for example, located at 1756m asl, experienced in average higher temperatures than Lusoi and Kianda Dams, which were located on higher altitudes of 1960m and 1852m asl, respectively. Gathathini Dam also experienced a weak thermo-stratification at 1.5m depth possibly due to higher temperatures experienced at the site and greater water depths.

Water reservoirs in Naromoru were generally highly turbid, with turbidities ranging from 7.32cm at Kianda Dam to 22.5cm at Lusoi Dam, due to siltation caused by erosion from the farms and bare grounds surrounding the catchment areas. Among the three reservoirs, Kianda Dam had more turbid waters than Lusoi and Gathathini Dams, as it was open to extensive erosion by surface runoff and disturbance by catfish, *C. gariepinus*. The shores of the reservoir had extensively cleared shoreline, which had been subdivided by the local community for agricultural purposes. The catfish had been stocked in the reservoir for purposes of controlling tilapia population. Catfish are bottom dwellers, which extensively stir the bed sediments while searching for benthic invertebrates, which is their key food item (Koekemoer and Steyn, 2005). High turbidity prevents light penetration into the water thereby reducing primary

productivity (Bruckner, 2009). According to Datta (2010), transparencies ranging from 20 to 40cm are suitable for fish production. While Gathathini and Lusoi Dam were within this range, Kianda Dam fell below the range.

Measurements of primary productivity in the three reservoirs showed Kianda Dam to have the lowest as expected. This was majorly due to siltation that resulted to low transparency in the Dam. Low transparency reduced the rate of photosynthesis which in turn led to decline in primary productivity. Studies by Ampofo *et al.* (2001) in Ndaragwiti reservoir located in a semi-arid region of Kenya noted that lack of natural protection against detachment of soil due to sparse vegetation is responsible for accelerated rates of soil erosion leading to siltation. Lack of vegetation on the banks of Kianda Dam and farming are responsible for high rates of siltation.

The undrainable reservoirs of Naromoru were generally very shallow, possibly because they have been in existence over a long period and have therefore suffered from extensive siltation. Recently, however, the Government began renovating them and Gathathini Dam was reconstructed after the 1997/1998 El Nino rains. As such, Gathathini dam was the deepest of all the three. Kumar (1992) also reported that most undrainable reservoirs in India have shallow depths arising from siltation. Siltation rates of undrainable reservoirs in semi-arid areas are generally high as such areas potentially generate and transport large quantities of sediments during rainy seasons they are characterised by scanty vegetation cover (Ampofo *et al.*, 2001).

The three undrainable reservoirs of Naromoru had slightly alkaline waters with pH ranging from 7.53 at Gathathini Dam to 9.73 at Lusoi Dam, which was within the reported ranges of undrainable reservoirs (Chapman, 1996). Kumar (1992), for example, studying the undrainable reservoirs of India found their pH ranging from 7.0 to 9.0. The pH range recorded in all the three dams is within the tolerance levels of most aquatic organisms (Mukherjee *et al.*, 1992), with maximum fish production occurring with the pH ranges of 6.5 to 8.5 (Alabaster and Lloyd, 1980).

Measurements of total dissolved solutes showed Lusoi Dam to have significantly higher ionic concentration, indicating that the reservoir was much more fertile than the other two. Similarly, the reservoir also had significantly higher conductivity than the other two, again confirming the higher fertility status of the reservoir. TDS and conductivity have been shown to have a positive and significant correlation (Kutty, 1987), which supports the findings reported in this study. The high concentration of TDS and electrical conductivity at Lusoi Dam was attributed to accumulation of ions in the dam over a long period of time (since the creation of the dam in early 1960's). Gathathini and Kianda Dams, which were constructed later recorded lower TDS and electrical conductivities. Generally, undrainable reservoirs tend to have high salinities and conductivities due to lack or less outflow of water (UNEP, 2006), and high evaporation rates, which tend to concentrate dissolved minerals (Gordy, 2001).

The predominant ions in all the three reservoirs were sodium and calcium, although highest concentrations were recorded in Lusoi Dam. The observation is in agreement to the measurements of conductivity and TDS, which were also highest in Lusoi Dam. Studies by Purandara *et al.* (2004) along Malaprabha River in India reported that water bodies with high electrical conductivity values are predominant with sodium and chloride ions.

Unexpectedly, the reservoirs though occurring in intensively cultivated areas, had very low heavy metal concentrations, far below the recommended WHO guide for safe water levels (WHO, 2008). This result was surprising as most farmers around the area frequently use pesticides to spray their vegetables against pests. The results, however suggests that the fish in these reservoirs are fit for human consumption, although further studies may be necessary to confirm absence of the heavy metals from the fish tissues due to possible biomagnification.

Nitrate levels were significantly higher in Gathathini Dam as expected as the reservoir had been recently fertilized using farm manure. The reservoir was characterized by high abundance and diversity of green algae. This result agrees with the findings of Offem *et al.* (2010), who also found reservoirs having high nitrate concentrations being dominated by green algae. In contrast, Kianda and Lusoi Dams had higher phosphates concentrations. The reservoirs were dominated by the blue green algae, *Microcystis aeruginosa*, suggesting highly eutrophic status. Hoyos and Comin (1999) also found reservoirs dominated with

phosphates largely dominated by the blue green algae, *M. aeruginosa*. The findings of this study support that of Mwaura *et al.* (2002) on man made reservoirs of Rift Valley in Kenya who observed that most reservoirs are dominated by blue green algae with green algae being subdominant in dry season.

DO concentration in the three undrainable reservoirs of Naromoru ranged from 5.0mg^l⁻¹ at Gathathini Dam to 8.71mg^l⁻¹ at Lusoi Dam, which was greater than the minimum concentration of 5mg^l⁻¹ required for survival of aquatic organisms (Chapman, 1996). The low DO concentration at Gathathini Dam was attributed to the high water temperatures that were experienced in the dam, reducing DO solubility (Ebbert, 2003). Lusoi Dam on the other hand had high DO concentration, due to strong waves that occurred in the reservoir constantly aerating the water.

Primary productivity in the three reservoirs were generally high as expected due to high nutrient levels, which promoted dense growth of phytoplankton. This observation agrees with that of Kotut *et al.* (1999) who noted that primary productivity is positively correlated to concentration of nutrients (nitrates and phosphates). Lusoi Dam had the highest primary productivity followed by Kianda and Gathathini Dams, despite the higher nutrient levels at Kianda Dam. Lower primary productivity at Kianda Dam was probably a consequence of higher turbidity occurring at the site. Bruckner (2009) also noted that high turbidity often results in reduced primary production due to lower light

penetration. The higher primary productivity at Lusoi Dam also resulted in higher pH, as expected. Agarwal and Rajwar (2010) studying the physico-chemical characteristics of Tehri Dam in India, also noted similar relationship whereby high pH values were associated with increased rates of photosynthesis of algae. High rate of photosynthesis precipitates carbonates of calcium and magnesium from bicarbonates resulting to high alkalinity.

Zooplankton communities of the three undrainable reservoirs of Naromoru were mainly represented by rotifers and copepods that occurred in high relative abundance, while cladocerans occurred only at Kianda Dam. The high abundance of these zooplanktons was associated with high primary productivities experienced in the dams. This observation agrees with that of Lusweti (1992), who while working on Nairobi Dam noted a positive correlation between abundance of zooplankton and primary productivity. Kumar (1992), working on the undrainable reservoirs of India noted that they were dominated by copepods, cladocerans and rotifers. It's unclear why cladocerans were completely absent from Gathathini and Lusoi Dams. Benthic invertebrates were represented by a few species, dominated by *Chironomus spp.* and oligochaetes. The two groups occurred in high abundance, a reflection of the effects of high eutrophication, which resulted in low species diversity but high abundance of tolerant species (Osmond *et al.* 1995; Peckarsky *et al.* 1990). The benthos, however are an important food source for the fish, particularly the bottom feeding fishes. Capraz and Arslan (2005) noted that *Chironomus spp.*, and

Oligochaetes are a source of food to bottom feeding fish species such as *Clarias spp.* and *Carp spp.*

Morphometric and meristic studies showed that the three reservoirs had only one tilapia fish species, *Oreochromis spirulus* comprising several varieties that differed significantly in their number of gill rakers, longitudinal scales, dorsal rays and anal basal length. Trewavas (1983) noted that *O. spirulus* in Kenya occurs in three varieties; *O. spirulus spirulus*, *O. spirulus niger* and *O. spirulus percivali*. *O. spirulus niger* occurs in the upper Athi system, while *O. spirulus percivali* has been found in a pool on the northern Ewaso Nyiro (Trewavas, 1983). The varieties observed in Naromoru fitted *O. spirulus spirulus* and *O. spirulus niger*, although some specimens did not fit in to either of the three varieties.

Morphometric and meristic characteristics of the species obtained from Gathathini Dam suggested that they belong to *O. spirulus spirulus*. The specimens, for example had three anal spines with dorsal spines ranging from 15-17, which are key characteristics of *O. spirulus spirulus* (Trewavas, 1983; Nyingi, 2002). Despite these key characteristic of *O. spirulus spirulus*, the specimens also showed characteristics that deviated significantly from the species characteristics. For example, the specimens had gill rakers ranging from 22-27, which were higher than the recorded 16-19 for the species (Trewavas, 1983). Similarly, specimens had vertical stripes on the caudal fins instead of blotches, which Lowe-McConnel (1955) noted to be a key distinguishing

characteristic of *O. spirulus spirulus*. It is not clear at the moment what may be accounting for these differences although hybridization is highly suspected.

Fish samples from Lusoi Dam had most of their meristic characteristics within the range noted by Trewavas (1983) to be for *O. spirulus spirulus*. Despite this, a few samples had 18 dorsal spines, which is a key characteristic associated with *O. spirulus niger* (Trewavas, 1983). Kianda Dam had most of fish samples having gill rakers, dorsal spines and anal spines within the range associated by Trewavas (1983) to belong to *O. spirulus spirulus*. Despite this observation, a few samples had gill rakers and dorsal spines both below and above the recommended range of *O. spirulus spirulus* (Trewavas, 1983). Similarly, some of the fish samples had stripes on the caudal fin instead of blotches, a characteristic noted by Lowe-McConnell (1955) to deviate from that *O. spirulus spirulus*. This occurrence is also thought to be caused by hybridization. According to Elder (1971), hybridization provides the most likely explanation for instances where fishes show features that are intermediate between two well known species. The first hybrids of *O. spirulus* occurred at Sagana fish farm, when *O. spirulus niger* accidentally hybridized with *Tilapia zillii* (Whitehead, 1962). Similarly, Omondi *et al.* (2001) reported the presence of hybrids between *O. spirulus spirulus* and *O. niloticus* in Tana River system that originated from the Sagana fish farm. Sagana Fish Farm provided the fish stocked in the Naromoru reservoirs, a fact that may explain the presence of hybrids in those reservoirs.

Meristic comparisons between fish samples from the three Dams showed significant variation of gill rakers, longitudinal scales and dorsal rays. However, highest variations occurred between Gathathini-Lusoi populations, and Lusoi-Kianda populations. These variations were largely caused by upper lateral line scales and anal rays. On the other hand, Gathathini-Kianda populations had small variations mainly in gill rakers, longitudinal line scales and dorsal rays.

Morphometric comparisons between fish samples from the three dams showed a common significant variation in anal base length. Gathathini and Lusoi populations had more morphometric variations than Gathathini-Kianda and Lusoi-Kianda populations. Gathathini-Kianda population recorded significant variations in anal basal length and lower jaw length while Lusoi-Kianda populations had significant variation in anal basal length. The variations observed between the fish samples from the three undrainable reservoirs are thought to have been caused by physical and chemical parameters, which recorded significant variations between the dams. According to Omoniyi and Agbon (2008), some Morphometric characteristics (body depth, caudal peduncle depth) and meristic characteristics (gill rakers and lateral line scales) are caused by environmental changes especially water temperature and salinity. Specimens from Gathathini reservoir were also noted to have a large range of the number of teeth. This was largely influenced by the age differences between specimens. For example, mature fish samples were noted to have the highest number of teeth.

Catch per unit effort was highest at Lusoi Dam than Gathathini and Kianda Dam. The high CPUE at Lusoi Dam was associated with high rate of primary productivity recorded in the Dam. The observation is in agreement with studies by Garg and Bhatnagar (2001), which found a linear relationship between net primary productivity and fish biomass in reservoirs. The low CPUE at Gathathini Dam was attributed to both low primary productivity and high predation by birds of prey, while the low CPUE at Kianda dam was attributed to the low primary productivity of the dam and overfishing. These findings are consistent with observations of Mkare *et al.* (2010) working on Chepkanga Dam in Kenya who noted that fish population are remarkably sensitive to primary production at lower trophic levels.

The three undrainable reservoirs of Narom6oru recorded high positive relationship between length and weight of the fish, with correlation coefficients (r^2 values) ranging from 0.9495 to 0.9908, indicating allometric growth of fish (Olurin and Aderibigbe, 2006). However, the regression coefficient values were less than 3, which according to Guyanilo and Pauly (1997) imply allometric growth of fish. Jose *et al.* (2008) working in a shallow tropical lake of Mexico found *Oreochromis niloticus* species to have allometric growth thus supporting this study.

Fish from the three dams were found to be of good condition with their relative condition factors ranging from 1.7 at Lusoi Dam to 1.9 at Gathathini Dam, which according to Olurin and Aderibigbe (2006) is an indication of good

condition of fish. The condition factor values recorded by this study were higher than those reported for tilapiine fishes of Kamburu and Gakio reservoirs (Dadzie and Odero, 1989 and Jumbe, 2003). The results indicate good fish condition and nourishment.

5.2 Conclusion and recommendations

The results of this study showed that the three reservoirs of Naromoru reservoirs had most of their physical and chemical characteristics within the recommended guidelines for fish culture. In addition, natural fish food was found to be abundant in the Dams with some niches, such as the benthic invertebrates and detritus, not being utilised. The fish in the three reservoirs showed allometric growth and were of good condition. This is a clear indication that if well utilized, the reservoirs have the potential to generate income and protein food to the local communities through fish farming. The reservoirs, however, need proper management practices for this potential to be achieved. For example, Gathathini Dam produced fish with the best condition, but the dam requires protection from fish predating Birds. Similarly, Kianda Dam had fish with good condition, but its primary productivity was low due to high rates of siltation. Lusoi Dam on the other hand had fish whose conditions were affected by high pH, TDS and conductivity. This study therefore recommends the following actions for above mentioned vision to be realised:-

1. Introduce Catfish (*Clarias sp*) or Common carp species (*Cyprinus carpio*) which are benthic feeders to utilize the vacant niche inhabited by benthic invertebrates and detritus.

2. Buffer zones need to be maintained around the dams and along the feeding streams so as to reduce amount of salts and nutrient ions being carried into the reservoirs.
3. Lusoi Dam needs to be desilted in order to remove the silt and lower the levels of ions that have accumulated in the Dam over along period of time.
4. Rearing fish in cages to prevent birds of prey from predating on them.
5. Regular environmental monitoring studies should be carried out so as to advise the fish farmers on suitable interventions to be undertaken in order to increase fish productivity.
6. Suitable gill net to be used in harvesting of fish in the undrainable reservoirs 3 inch mesh size.

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