AN INVESTIGATION INTO SOME WATER QUALITY PROBLEMS OF LAKE KANYABOLI IN KENYA

BY

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DECLARATION

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

19/5/97

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This thesis has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

To my parents, Mr. John Anyona and Mrs. Jenifer Anyona, for their efforts that enabled me to attain my education.

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ABSTRACT

This study attempted an investigation into some water quality problems of lake Kanyaboli. The geographical location of lake Kanyaboli within the Yala swamp and its size of 10.5km² make it ideal for this investigation. Further the problem is complicated by the fact that the lake has no outlet and after the diversion of river Yala during the reclamation of the Yala swamp, there is no major inlet into this lake. On the whole it is assumed that the activities around the lake in addition to the hydro-technical measures that has taken place within the swamp have a direct impact on water quality of the lake.

This study therefore intended to assess the levels of various parameters in the lake water as well as their pathways. Because the lake lacks an outlet, a unified approach that integrates water quality parameters and that of interstitial water was preferred.

Both water samples and bottom sediments were collected and laboratory analysis performed on parameters for both surface water and interstitial water respectively.

Results show that the levels of ionic constituents are low, suggesting that this is due to the low solubility of the precambrian rocks within the catchment. On the other hand iron and manganese are reported in levels that are almost equal to or above the recommended levels. Most of the normal water characteristics reflect that lake Kanyaboli is a fresh (TDS), soft (hardness) and an alkaline lake (pH). However colour and turbidity are elevated.

Precipitation and runoff contribute significant amount of pollution parameters as shown by the results, implying that catchment activities have an important influence on the quality of the lake water. While phosphorus has not been detected in water, nitrates occurred only in trace amounts. The levels of nitrites, ammonium nitrogen, free ammonia and albuminoid ammonia (0.06mg/l, 0.12mg/l, 0.06mg/l and 0.06mg/l respectively) suggest organic contamination. Permanganate value (4.04mg/l) implies a large

amount of organic matter. The levels of the above nutrients are elevated in interstitial water and those of nitrates and phosphorus (0.12mg/l and 1.12mg/l respectively) suggest that the lake is eutrophic. Generally the levels of the parameters is higher in interstitial water than in overlying water (except pH and nitrites) suggesting that pollutants are accumulated in the bottom sediments. This therefore is a pointer to the fact that these pollutants have accumulated in the bottom sediments and thus sediments may act as source of these pollutants at certain periods of time and under certain prevailing conditions.

Prevention of further pollution appears as the only means of attaining the objective of managing the lake water. From the viewpoint of water quality management, Lake kanyaboli can be used as an experimental lake in the study of water quality and thus scientific knowledge of great value in controlling pollution may result. Above all, if proper management techniques can be achieved for this small lake, then the lake Kanyaboli example can be applied in other similar situation within the country as the nation faces the need for managing this aspect of its water resource.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

THE INTRODUCTION

This study attempts an investigation into some water quality problems of lake kanyaboli. Lake Kanyaboli with an area of $10.5km^2$ and a maximum depth of 3 metres is located in the Yala swamp in Western Kenya.

The water quality of lake Kanyaboli must be viewed as being controlled by factors such as climate, soils, geology as well as the anthropogenic activities in the catchment. The problems of water quality in lake Kanyaboli relates to the future and therefore to ensure good quality supplies from this lake, information is needed as to how good in quality the lake water will be at all times for long periods of years to come. Thus the main question to pose is "how can the sources, levels, and the effects of pollutants of the lake water be known? This can only be done through a study of water quality changes that have occurred assuming that this would continue at the same pace or possibly at greater magnitudes in future.

1.1 STATEMENT OF THE RESEARCH PROBLEM

Kenyan inland lakes form an important part of water resources. They contribute significantly to the water economy of Kenya. For along time they have been one of the main sources of food and water and favourable conditions along their shores has been one of the positive factors in the development of several activities.

Indeed, man's activities produce a whole series of much stronger and most profound influences on water bodies. Ohle (1975) noted that one of the most astonishable and nevertheless evident reactions of natural waters belongs to the field of water quality. In kenya some of the inland lakes have been identified to suffer from heavy pollution. There have been cases of fish kills as in the case of lakes Nakuru and Victoria while some have been choked by weeds as in the case of lake Naivasha as documented by Wandiga (1977a) and Muslim (1982).

There is evidence documented by Wandiga (1977b) that pollution of these lakes are as a result of human activities in the catchment areas of these lakes. Due to great demand of water resources both in terms of water supply and fisheries and to the fact that surface water accounts for a large proportion of water used for human needs, the deterioration of water quality in lakes and rivers has had decisive influence on the water policy developed for this country. Main tools on this work include legislation, administration and water quality monitoring. The goals of Kenya's water policy are to prevent further environmental deterioration and as far as possible to restore the already degraded areas of the environment.

Also nutrients and other pollutants have been transported in combination with rainfall and runoff water into such water bodies. Evidence of such effects are found in the upper layers of lake sediments. These increased accumulation of pollutants are also caused by direct influence from the surrounding areas.

Another human intervention of human civilization has changed the quality of water bodies profoundly. It has been an eager aim of hydrologists and agriculturalists to perform the so-called melioration of swamps, marshes and wetlands everywhere in order to gain farming land. However, Ohle (1975) notes that despite the fact that these operations have been successful in many cases, the drainage in such areas totally change and hence the water quality in general. The most important work in the case of lake Kanyaboli has been the reclamation of the Yala swamp. It will be relevant to note that before reclamation river Yala used to pass through the marshland before reaching lake Kanyaboli. However as a result of reclamation and river control engineering works a dyke was construction to replenish the lake. This dyke later broke down and to date there is no direct connection between river Yala and lake Kanyaboli(Okemwa,1981). Consequently Ochieng' (1987) and Okemwa (1981) reported that conductivity values have almost doubled after reclamation.

Lake Kanyaboli has a great importance as a source of water for domestic supply besides being a unique ecosystem whose value is encompassed in its fisheries. Once it was believed that lakes could not be affected by activities of man. But now especially near-shore areas, and in the shallow Lakes, the impacts of overuse are changing and are often reflected in the degrading of water quality. The rivers and other pathways that feed lakes bring excess nutrients and other toxic materials from the catchment area.

The land-use planning of the area of lake kanyaboli has not yet been finished. The reclamation of the Swamp is still under consideration. The impacts of these developments in terms of nutrients input into Lake Kanyaboli, with respect to eutrophication is one of the major aspects of this study.

Eutrophication is the process of enriching natural waters with nutrients such as phosphates and nitrates resulting in algal blooms. The causes of pollution and finally eutrophication of natural waters are many. In Urban catchments discharge from domestic and industrial sources are probably more significant causes. In rural catchments, the intensive use of fertilizers on farmland and a large number of animal population on farms can be the major cause of eutrophication as noted by Adams (1971). This study therefore intends to identify the potential pollutants and their possible sources.

The effect of pollution include deterioration of water quality, interferences with the rational use of water resources for domestic as well as other purposes, development constraints on fisheries which provide an important source of protein, enhancement of conditions which favour the spread of water related phases of diseases and aquatic vector parasites, and the excessive growth of aquatic plants which contribute to the accelerating rate of silting and sedimentation of water bodies. The study will further focus into the possible effects of Pollution on the lake water. Thus the study intends to reveal causes and sources of pollution. It may also reveal factors which can be controlled to reduce pollutants input into the Lake. The results obtained from this study may be applied to other similar situations in the country.

1.2 OBJECTIVES OF THE STUDY

In order to carry out the intended study, the following objectives have been formulated:

1. To determine the physical and the chemical characteristics of the lake water.
2. To examine the relationship between the water quality parameters of the lake water.
3. To asses the effects of rainfall and runoff on the quality of the lake water.
4. To determine the level of potential pollutants in the interstitial water.
5. To asses the suitability of the lake water for various uses.

1.3 LITERATURE REVIEW

Pollution studies are not of recent origin as several studies have been carried out in many different parts of the world by several scholars. Studies carried out by different scholars show that pollutants have got many origins. Most of these pollutants arise from human occupation, where mining, agriculture and poor factory practices stands high on the list. These release sediments and other pollutants which born upon flowing waters, are deposited into a lake. The above practices have also been shown to produce nutrients which inoculate lake water and thus may cause deterioration in water quality as has been pointed out by Johnes (1940); Hynes (1959); Morgan *et al* (1969); Glover (1975); and Butcher (1983).

Inorganic nutrients have achieved increasing prominence because of their role in stimulating the growth of algae in reservoirs and lakes. The natural ageing process in lakes and the associated increase in algal productivity was first described by Lindman (1942). Subsequent work by Allan and Kramer (1972) and Macan and Worthington (1968) has shown how this ageing process may be accelerated by increasing levels of nutrients. The principal nutrients are, according to Pearsall and Co-workers (1946), usually considered to be inorganic salts of nitrogen and phosphorus. For diatoms there is an additional requirements for silica The interest in nitrogen phosphorus has also been related to the possible role of fertilizers and detergents in causing increased levels. A great deal of literature have been published by several authors. Notable works include those by Rolich (1969), Ives and Jenkins (1962), Society of Water Treatment and Examination (1970), and Vollenweider (1968). Their more important findings show that the principle sources of nitrogen and phosphorus include domestic wastes, industrial wastes, and surface runoff.

Rodda (1976) pointed out that there is a daily excretion of about 9 grams nitrogen and 2 grams phosphorus per person. He further pointed out that nitrogen compounds are almost absent from rocks and the soils derived there from naturally contain very little. As a result some nitrogen is produced during storms but most nitrogen in the soil comes via bacterial fixation.

Phosphorus occurs naturally as apatite which is poorly soluble as stated by Sawyer and McCarty (1967). They claim that because of these low levels of nitrogen and phosphorus in soils, these nutrients tend to limit crop production and as a result necessitates the use of fertilizers to raise levels of agricultural production. Surface runoff therefore contain nutrients derived from fertilizers which are then washed into streams and lakes.

McGauhey (1968) stated that although the amount of nutrients is an influencing factor, there is no simple relationship between eutrophication process of a lake and the amount of nutrient present in its waters. Urban drainage has been considered as one of the most critical factors. The rate at which eutrophication occurs is governed by a combination of factors related in a complex fashion which is not fully understood. Rolich (1963) has pointed out that climatic, physical and biological factors have an influence on the eutrophication particularly as they relate to the distribution, availability, and utilization of nutrients required by algae in their metabolism. Rowson (1939) stresses the complexity of the relationship of environmental factors which lead to eutrophication of lakes. Geology, geometry of the lake, temperature, dissolved oxygen, pH, calcium, iron, nitrogen,phosphorus, silica, and organic material seem all to be involved in a complex fashion of unknown nature.

Sawyer and Lackey (1943), however stresses, the predominance of nitrogen compounds and phosphorus as determinants of algal blooms. In a report authored by Sawyer and Lacky (1943), nitrogen and phosphorus were identified as the culprits in the eutrophication of the Madison Lakes, the major source for Lake Mendota being the disposal plant for the city of Madison. The report further stated that "inorganic nitrogen and phosphorus were found to be critical factors in the productivity of the lakes, and that the inorganic nitrogen and phosphorus entering the lake were derived from nonagricultural activities. However, McGauhey (1968) maintained that there are other sufficient inputs from non Urban sources to produce algal blooms in the Lake when other factors are favourable.

Studies carried in UK by Roberts (1985) and Mitchell (1991) have shown that when the demand of nutrients by plants has been surpassed, excess nutrients can be lost to the ground and surface water through leaching or sediment loss, particularly during periods of high discharge.

There have been few studies of nutrient losses from rural catchments, but exceedances of water quality standards related to land use practices have been noted by Roberts *et al* (1983) and Kay and Stoner (1988). Elevated nutrient losses occur due to pre-afforestation drainage, phosphate application, scavenging of atmospheric nitrogen by mature trees, and from increased soil and vegetation decomposition following clear felling.

Mitchell (1991) contends that the historical pattern of nutrient loss in rural catchments is poorly recorded. However, the pattern of nutrient loss is associated with land use changes and nutrient levels in excess of WHO standards are increasingly evident. Water changes its quality as it passes through different phases of the hydrologic cycle. As a result high concentration of certain pollutants have been reported by Gorham (1964) and Powell (1964) to be poisonous to man, his livestock and aquatic organisms.

Bennet (1986), considered the contribution of nitrogenous and phosphate fertilizers to the eutrophication of surface waters. This is discussed with aid of published data concerning the quantities and rates of application of these fertilizers to cultivated crops in France and the concentration of nutrients in the runoff from farms as a function of fertilizer usage, rainfall and other factors. In addition, nutrients entering surface waters from the waste products of pigs, cattle and poultry rearing are discussed.

Prairie and Kalf (1986), investigated the effect of catchment size on phosphorus export. They tested the hypothesis that phosphorus export (in kilograms per year) was a linear function of the catchment size, and the constancy, or otherwise, of linearity among catchments undergoing different land uses. The collected data were then divided into two sets for afforestation or agricultural land use. The analysis of this data showed that the phosphorus export was a linear function of catchment size for forested catchment, non row crop areas and mixed agricultural areas.

OECD (1986) considered the problems of contamination of the aquatic environment by the application or misuse of fertilizers and pesticides. The adverse effects associated with the excessive nitrate leaching and contamination of surface runoff with nutrients are discussed including eutrophication of surface waters and possible health risk to humans and animals from excessive nitrate intake, followed by a discussion of methods for controlling fertilizer application rates.

Lang (1986) discussed the danger of accelerated eutrophication of lake Balaton due to the intensification of agricultural production and the development of food industry in its catchment area. The increasing sewage load was also contributing to the problem. International studies of the state and plans for remedial action are described. He concluded that although the enormous increase in the biogenic pollution which the lake had experienced over the last twenty years had created a situation which, the methods for the protection of the water resources had not been able to reverse, restoration of the lake was still possible.

Eutrophication has recently become a matter of urgency because although the limiting effect of production in natural water has seldom in the past regarded as of immediate practical importance, the artificial addition of nutrients usually leads to excess nutrients in the concerned water body as shown by a study carried out in USA. Jackson (1969) studied primary productivity of a highly polluted lake, the Onondaga, in relation to its organic and inorganic pollutants. The organically polluted part was found to be richer in total phosphorus, nitrates and algal individuals as compared to the inorganically polluted water. This organic zone was also found to contain very high concentrations of dissolved silicates and has shown that this is an important factor in influencing algal community especially diatoms.

Edwards **et al** (1983) and Balek (1983) found out that although artificial pollution of natural water resources is still comparatively rare, and limited to the vicinity of large urban centres and mining areas, the potable quality of water cannot be taken for granted, particularly in the rural areas since only a small percentage of population has access to treated water. In addition majority of rural populations frequently share the available water with their livestock and although the latter have a higher degree of tolerance to contamination, water quality should always be considered as one of the limiting factors in developing a water resource.

When considering the abstraction of water for various uses, an investigation of water quality in a lake should be carried out to establish changes that take place in the water quality in relation in relation to the rains and pollutants input. Several studies by Viner (1975) have shown that rain can cause an input of plant nutrients into a water body. The major factor influencing the formation of inorganic forms of nitrogen from the breakdown of organic materials in the soil is rainfall. The organic materials from Ugandan soils as for other parts of the world where this has been studied by Birch and Friend (1956), are strongly correlated to the mean quantity of rainfall. The amount of nutrients (especially from the breakdown of organic matter) that get leached out of the soil and into the water are related to the amount of rainfall in the catchment area of a water body.

Birch (1958; 1959; and 1960) carried out various experiments on a variety of Ugandan soils and found that ammonia and nitrate nitrogen released during wetting was markedly stimulated by previous drying. The amount released depend on the time allowed for decay and accumulation while still in the soil. Experiments on soil drying further show that the drying effect largely involves changes in organic materials rather than in the soil itself. The release of nutrients diminishes rapidly after each wetting, the longer the dry period the more the inorganic nitrogen produced. According to Birch (1960) the concentration of nutrients in the soil is, therefore, severely reduced by flushing out into the rivers and lakes.

In Kenya, the content, distribution and accumulation of pollutants in the inland waters are still inadequately known. Previous surveys as cited by Welch (1952) on Lakes Naivasha, Nakuru, and Victoria have been reported with doubts on reliability of the data, due to instrumental problems.

Water is the most important of all the natural resources, for it is indispensable not only to life but also for agricultural and industrial development. Grundy (1953) considered problems facing Kenyan water resources where he pointed out that pollution is one of the problems hindering their development. Wandiga (1977a and 1977b) pointed out that the major chemical pollutants includes oxides of sulphur, fluoride, copper, agricultural fertilizers, pesticides and insecticides and human wastes. He cited Lake Victoria, Lake Nakuru, and River Nzoia as the most affected. He maintained that the major sources of sulphur oxides are vehicle emissions and Webuye paper mill. He however decried lack of data on the effect of these pollutants on the inland lakes and rivers as the major drawback.

Muslim (1982) stressed the need to protect water resources against pollution. He noted that dense Population, lack of provision of sanitary facilities including proper sewerage, farming activities, and indiscriminate felling of vegetation are the major factors causing lake pollution especially lake Nakuru. This has lead to sudden death of fish which had been witnessed as early as 1971. However the control of such types of pollution has proved to be difficult indeed. This he attributed to a shortcoming in the water act since it does not apply in controlling chemical pollution emanating from areas where water is not extracted and to lack of trained manpower to monitor the quality of water in order to identify major sources of pollution.

Njuguna (1982) pointed out that lake evolution history, distribution, morphometry, chemistry, nutrients, biota and productivity are interwoven with the lakes geological, and climatic history. Studies on nutrients supply have been carried out in lake Naivasha by Njuguna (1978 and 1982) and Muthuri (1980). Their studies have shown that nutrient input into the inland lakes occur from various sources including atmospheric precipitation, river discharge, surface runoff, seepage inflows, nitrogen fixation and from drawdown areas.

A large amount of literature on water chemistry for rivers in the LBDA region has been published. Reports on the water chemistry of rivers Nzoia and Nyando has been published by MoWD (1976). Several studies have also been conducted on the conditions of sewage works from municipalities and towns in the LBDA region. UNEP (1982) carried out a survey on five sewage works where they collected samples from effluent and tested for BOD_5. Their results show that none of the treatment works is producing effluent which satisfies a BOD standard of 30 to 40 mg/l. The results further show that some of the treatment works studied were discharging high loads of inorganic pollutants of lead, and mercury both of which are highly toxic. The above results were attributed to poor maintenance of the sewage works in the region.

Chabeda (1983) carried out a survey on eutrophication and pollution load on four rivers of the northern region of LBDA. The study showed that tributaries draining agricultural areas have much higher nutrients levels than those draining forested areas. The results further indicated that tributaries draining wheat and maize belt sub-basins where fertilizers are applied produce high levels of nutrients than sugar cane sub-basins. Areas with high population density of livestock were also shown to have high nitrogen concentrations.

LBDA (1985) conducted a study on the water quality of Winam Gulf of lake Victoria. The results showed a maximum transparency of 2m, and BOD_5 of 55mg/l. The high BOD was attributed to high organic pollution while the low transparency was attributed to suspended sediment load from Nyando and Sondu Rivers.

Okun (1985) and MoWD (1985) conducted a study on some pollution parameters in the Winam Gulf. They analyzed the chlorophyll-a content, nutrients, and BOD_5. Their results of the analysis showed high content of chlorophyll-a, high nutrient levels and high BOD values. These high values were attributed to high incoming organic pollution as well as a high biological activity.

Nyamu (1986) carried out an investigation into the water quality in the Winam Gulf (lake Victoria) among other things she found out that nutrient levels are already elevated in this part of the lake. She attributed this to the leaching of fertilizers from the surrounding farms and runoff emanating from a treatment plant. She further discussed the effect of rainfall on the lakes water quality by Maintaining that rainfall affects the water quality either directly by falling into the lake causing dilution of ions or indirectly by washing wastes into the lake through surface runoff. However, she never took into account the fact that rainfall can supply pollutants directly into the lake given the fact that Kisumu is an Urban centre with intense industrial activities.

In lake Kanyaboli very little has been done as far as pollution studies are concerned. Okemwa (1981) carried out a survey on physical and chemical properties of lake Kanyaboli. From the results of the survey he observed that water quality of lake

Kanyaboli is deteriorating. He attributed this to the fertilizer application in the nearby farms and also to the hydro-technical measures that has been undertaken in the Yala Swamp.

Mavuti (1987) collected data on the limnology of rivers and lakes in the lake Victoria basin. The results showed that the level of dissolved oxygen does not change much due to sufficient mixing of the lake water. However, he pointed out that the high conductivity values (680 - 950 us/cm) indicated by the results suggests that the lake is becoming saline. He attributed this to human mismanagement of the Yala river water course.

Ochieng' (1987) studied limnological aspects and trace element analysis of some Kenyan inland waters. He observed that some Kenyan inland lakes are saline and lake Kanyaboli may become saline due to high conductivities reported during the study and attributed this to the influence of geochemistry and prevailing environmental conditions as well as lack of outlets.

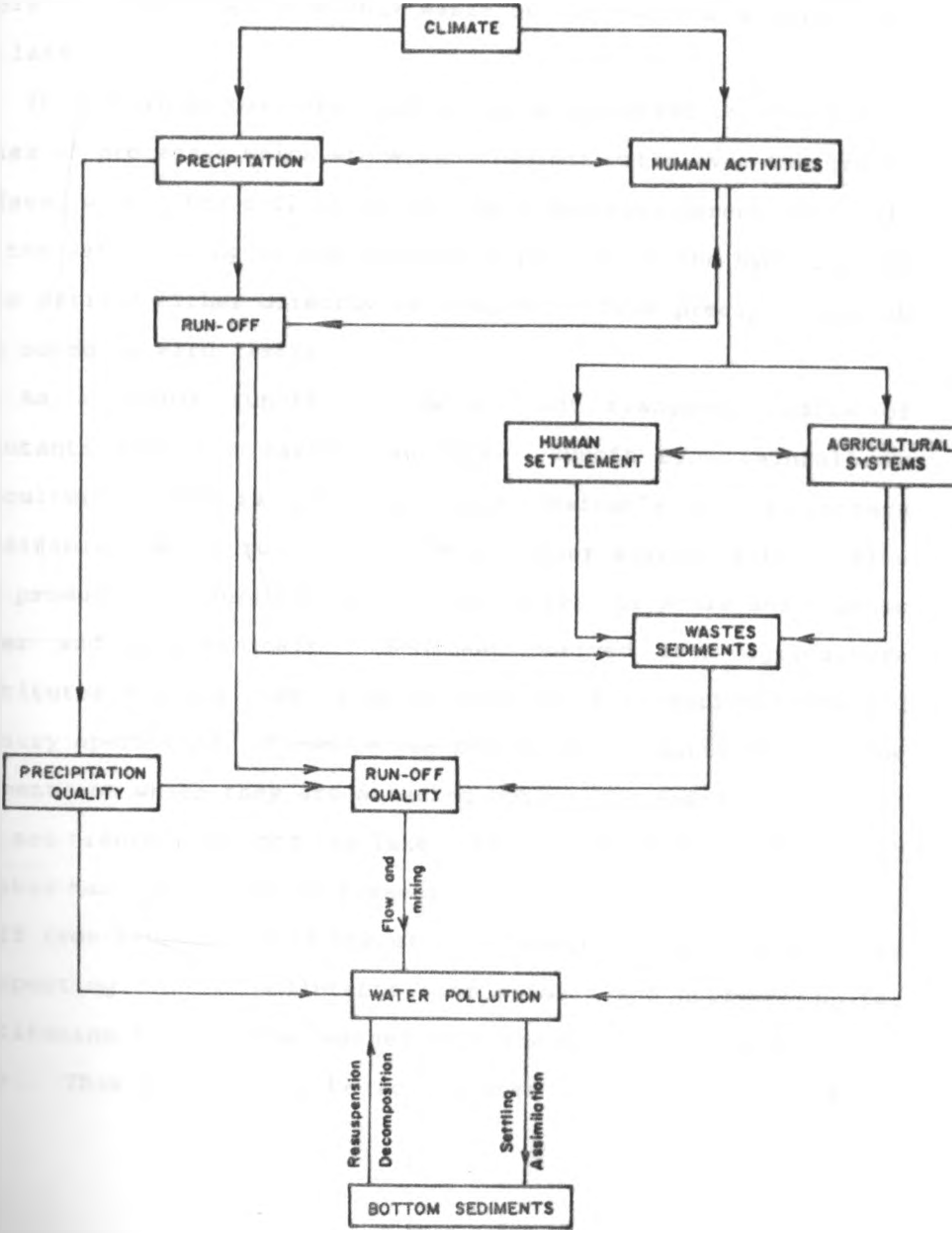
From the above literature review, it is clear that the studies that have been carried out in Kenya have mainly been concentrated on large lakes as opposed to small ones. Furthermore most of these studies have been concentrated in the Rift Valley lakes and lake Victoria. In lake Kanyaboli the studies carried out has either been surveys or part of studies encompassing a wide study area thus limiting the depth of the study. There has been no consistency in monitoring pollution. As a result much work is needed to achieve the broader, overall objectives of a wide range of water pollution problems.

1.4 CONCEPTUAL/THEORETICAL FRAMEWORK

According to Holdgate (1979), a lake is true "sink" in which materials tend to accumulate. However, in their natural state, the majority of inland lakes are low in pollutants so that they react readily on nutrients agents artificially introduced. In the case of lake Kanyaboli, inputs from natural sources, man-made sources, unless taken up by biological cycles, have only one further "sink" open to them (the lake). The study's conceptual framework is given in figure 1.

In this study the water quality of Lake Kanyaboli is considered as a function of several factors as well processes. Climate is very important as it influences most of these factors (including human activities) and processes. Precipitation affects the water quality in two ways: first it affect the lake water quality by directly falling on the lake surface. These depend on the quality of precipitation in that if the rainwater is polluted it will supply pollutants to the lake water but if rainwater is not polluted then this will dilute pollutant concentration in the lake water. The quality of precipitation is affected by human activities such as farming and grazing which generate a lot of dust especially during dry season. The pollutants normally get adsorbed onto these dust particles.

FIG 1 : FRAMEWORK FOR WATER POLLUTION OF LAKE KANYABOLI



Source : Researcher

On the other hand the quality of precipitation may be determined by other climatic factors such as long distance transport by wind. Secondly precipitation affect the lake water by generating runoff which washes waste on the earth's surface into the lake.

In a drainage basin precipitation is converted to runoff by a series of processes which store and transmit water over the ground surface, within the soil or within the underlying parent material. All the water moving in the land bound portion of the hydrological cycle derives either directly or indirectly from precipitation as also noted by Ward (1967).

As a result runoff act as a giant transport medium of pollutants from the earth's surface. Runoff from rainfall in agricultural land is in some cases desirable and in others undesirable. Water running off is no longer available for onsite crop production. Furthermore it removes fertile soils and organic matter and agrochemicals. Sediment derived from agriculture constitutes a large mass of waste material from agricultural and forestry operations. These become pollutants in water because the sediments on which they are attached become suspended in water as they are transported into the lake. As a result sediment deposited in lakes have been found to present a strong evidence of pollution. Runoff from agriculture is therefore a possible source, especially transporting organic pollutants from animals and nutrient salts, constituting fertilizers leached from the soil by the percolating water. This problem may be accelerated by the fact that water courses in agricultural areas are usually small.

Runoff from settled areas such as homesteads and cattle pens around the lake supply organic wastes which provide an extraneous source of nutrients. In the early years when the population was still rather scattered, population on average delivered less pollutants to the lake than can on empirical grounds be considered serious. At this time pollution from domestic sources has increased considerably due to the increase in the rural population, and low sanitary standards.

Human activities such as agriculture can also affect the water quality of the lake directly. Farming and grazing activities can result to wind erosion particularly during a dry season. In such a situation a lot of dust can be carried away by wind and deposited on the lake surface and since it is a known fact that certain pollutant are adsorbed on the surface of dust particles in the final analysis these will be deposited into the lake. Livestock at the time of watering will deposit their excreta directly into the lake thus introducing nutrient and organic pollutants.

The effect of pollutant in lake water (the lake environment) is that when pollutant load is introduced into fresh water the water quality is adversely affected and several processes take place depending both on the external factors (mainly on environmental variables). Some of the Pollutants get adsorbed onto the sediments which are deposited in the bottom of the lake through the processes of settling. The pollutant content in the sediment depends on various factors. Therefore the environmental assessment of lake Kanyaboli requires the analysis of not only water pollution but sediment pollution as well.

It is important to note that various environmental loads, process, and states are depicted (fig. 1). The effect of the environmental loads in the waters of the lake will produce changes in the state of the water by determining either the release of pollutants from the bottom sediments into the water or the removal of pollutants from the water into the bottom sediments. For instance sediments transported into phosphorus rich lakes, usually absorb some phosphorus thereby demonstrating a reversal of the pollution process providing the sediments settles in deep water and not later disturbed. Physical and chemical changes through the processes of advection, diffusion, settling will result in a state of different salinity, pH, temperature, etc, while biochemical changes through decomposition and assimilation will affect the concentration of BOD, total nitrogen and total phosphorus.

1.5 JUSTIFICATION OF THE STUDY

Although a very small lake at 10.5 km^2 of surface area, factors contributing to its deterioration are typical of any Kenyan inland water body. The catchment of this lake is an agricultural area, thus the quality of the water is important for local needs.

Lake Kanyaboli has been selected as an area of study because of its geographical location in relation to human activities and hence prone to nutrient loadings. Furthermore a detailed examination of the polluted lake might be rewarding since the concentration of pollutants there are less likely to fluctuate rapidly and thus sampling frequency can be reduced.

Water pollution in a semi-closed lake such as lake Kanyaboli is partly attributed to physical conditions such as little exchange of water place. As a result pollutant contained in the water is prone to accumulate, which in turn, cause deterioration of water quality. Social and economic activities are also important, since population concentration is common around the lake area.

Lake Kanyaboli falls within the yala swamp where a lot of hydro-technical measures has been undertaken. The degradation of the lake already witnessed have been attributed to the expansion of human activities, including the direct deposition of by-products into the lake. This nutrient pollution may become a problem which is expensive to control. A part from the degradation of the water quality of the lake, pollution would have adverse effects of destroying the habitat which the lake provides to fisheries and other aquatic life.

Before reclamation was done in the Yala Swamp no previous studies had been conducted in order to ascertain the water quality of lake Kanyaboli. Thus the effects of reclamation on the quality of lake Kanyaboli is not known. When this is coupled with the use of fertilizers in the surrounding farms, destruction of vegetation in the catchment due to indiscriminate felling of trees for charcoal burning, clearing forests to create room for human settlements as well as forest fires. Further with the increasing population, more of these nutrients now have the potential of finding their way into the lake. As a result the lake may be facing an eventual depletion and possible destruction altogether.

The ultimate physical and chemical effect of these nutrients is little understood. Because of the importance of the lake, however, an evaluation of their occurrence, their possible sources, and their concentration in the lake water is essential to an ultimate assessment of their significance as contaminants in the total environment. Thus despite the importance of water resources in this area, explicit assessment has not been made due to the paucity of pollution information.

1.6 SCOPE AND LIMITATIONS OF THE STUDY

1.6.1 Scope

The catchment of lake Kanyaboli is of major significance to the people around the lake. Due to the increasing demand likely to be placed on the water resources of this basin for various uses and fish and wildlife management and in the view of the deterioration of water quality and the disturbance of ecological balances in the basin the study will focus on the identification and analysis of these problems.

Consequently the study will include water quality studies as required to determine the present sources and levels of pollutants. In this regard therefore the following will be key points to be considered in this study:

1. Characteristics which are readily observed by the

+ 122

consumer but usually having little health significance such as colour and turbidity.

2. Natural physio-chemical parameters which are usually considered as normal characteristics of water. These include parameters such as pH, total dissolved solids, alkalinity, hardness, and Pv. A few of these parameters may have a little health significance but in general the aim is to prevent the supply of excessively balanced waters.

3. Substances undesirable in excessive amounts. This group include a variety of substances, some of which may be directly harmful in high concentration, others which may produce taste and colour problems and others may not be directly troublesome in themselves but are indicators of pollution. These include nitrate, ammonia, phosphorus, iron, manganese chloride, fluoride, calcium, and magnesium.

4. Nutrients mainly nitrogen forms and phosphorus (in 3 above). This is due to the role they play in eutrophication.

1.6.2 Limitations

The main limitations of this study were:

1. Lack of time - The four months allocated for field work did not cover different seasons and therefore, the effect seasonal variations can not be evaluated.

2. The money allocated for research was inadequate.
3. Lack of certain equipments (mainly the "core sampler") and some chemicals presented problems during the period of the study.

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1 LOCATION

Lake Kanyaboli is situated in western Kenya and lies near the equator at Latitude 0° 05′ N to 0° 02′ N, and longitude 34° 09′ E to 34° 11′ E and at an altitude of about 1140 m above sea level with an area of about 10.5 km^2 (figures 2 and 4). It has a maximum depth of 3m and gradual reduction is observed as one moves on either side to the shoreline. Lake Kanyaboli is on the North Eastern extremity of the Yala Swamp.

2.2 DRAINAGE

Lake Kanyaboli owes its existence mainly to the immediate catchment area West of Siaya town and to the Yala River through the Yala Swamp which act as the main source of water. This river originates from Uasin Gishu Highlands traversing through Nandi, Kakamega, and Siaya districts before entering the swamp. The river has a catchment area of about 300 km^2 and a length of about 200 km at the point of entry into the swamp. Gibb (1956) gives the average annual discharge into the swamp to be in the order of 500 million cubic meters of water. Before the diversion of the river in 1970, the Yala river used to flow through the eastern section into and through Lake Kanyaboli before it disperses into the main swamp in area I and area II (figure 4). After 1970, the lake was separated from the swamp by a silt-clay dyke but still partly connected to the swamp by drain canal. With the diversion of the Yala River in 1971, a feeder canal was constructed to replenish the waters of Lake Kanyaboli (figure 3). To date little or no water reaches the lake by way of the canal because the canal has been blocked and damaged by livestock, thus the water reaches the lake by back seepage-in from the Swamp waters through the broken dyke. This was noted by Okemwa (1981). The other river which also contribute to the swamp at this point is Hwiro river which is a seasonal stream and enters the swamp to the west of Lake Kanyaboli. A part from the above two rivers, river Rapudo contributes its water into Lake Kanyaboli mainly during the high flows. Otherwise the natural hydrology of the area includes both overland flow from various parts of the catchment through the forests, pasture lands, farms and marshes. This also include subsurface flow as well as direct precipitation into the lake. However the direct precipitation is almost equalled by evaporation over the lake surface. Thus it is important to note that the area has been heavily influenced by the construction of canals especially in the Yala swamp. Other impacts are wetland reclamation for agricultural expansion. These activities have altered the hydrology of the area in two ways, namely:

a) canals may lead to the eutrophication of surface water bodies; and

b) spoil banks associated with canals may inhibit sheet-flow and mineral sediment input from flood waters.

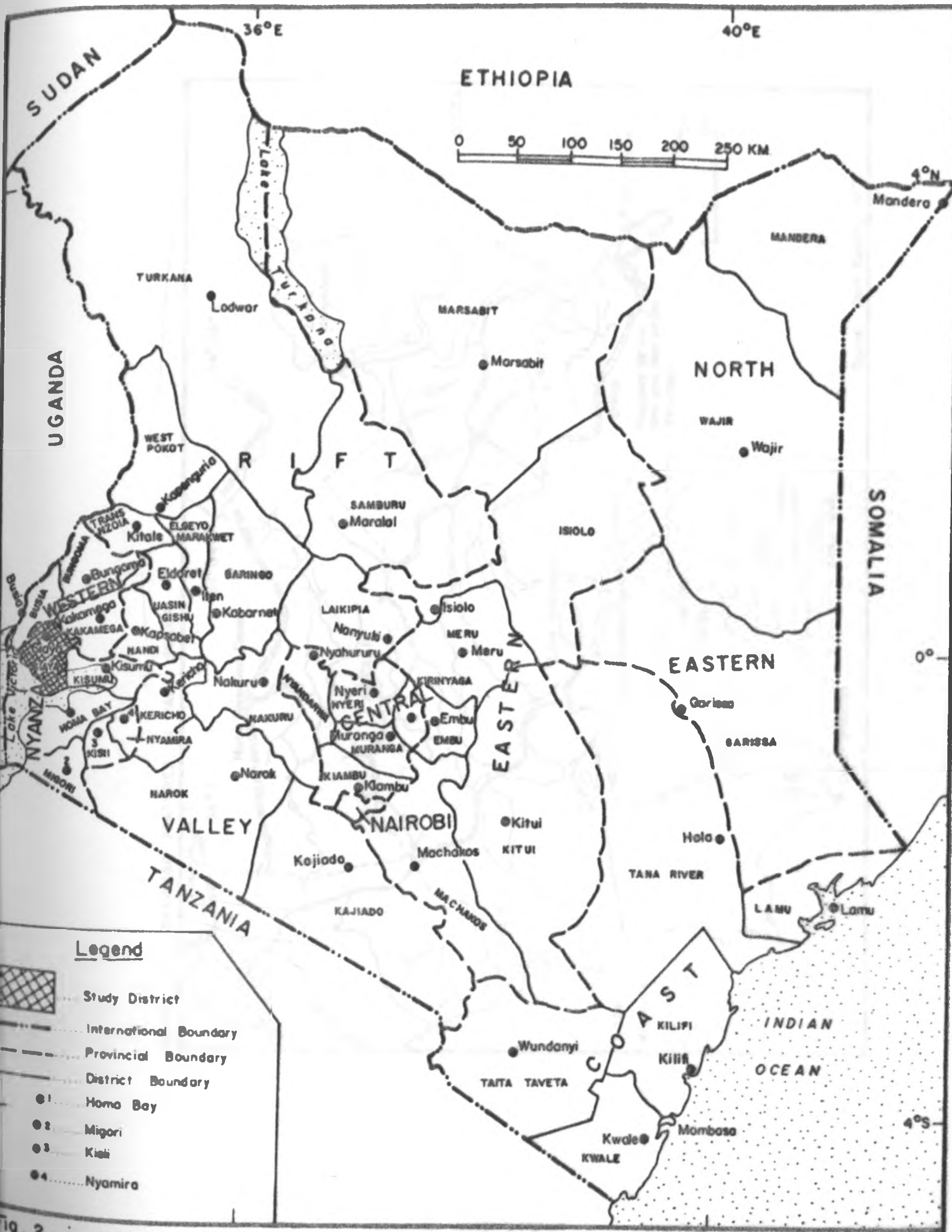
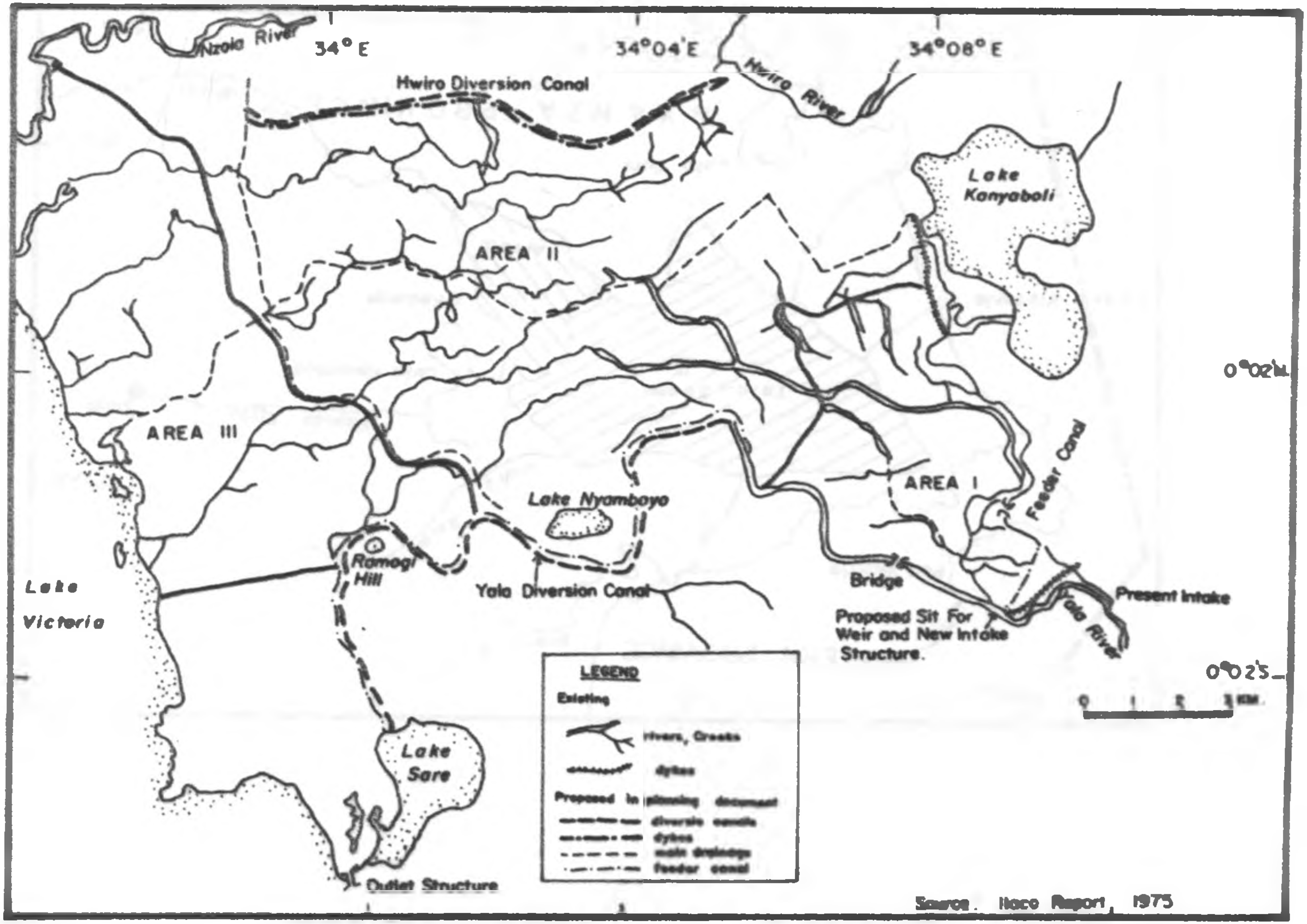


Fig. 2 : LOCATION OF SIAYA DISTRICT IN KENYA.

Source : Survey of Kenya.

FIGURE 3: DRAINAGE FEATURES IN YALA SWAMP



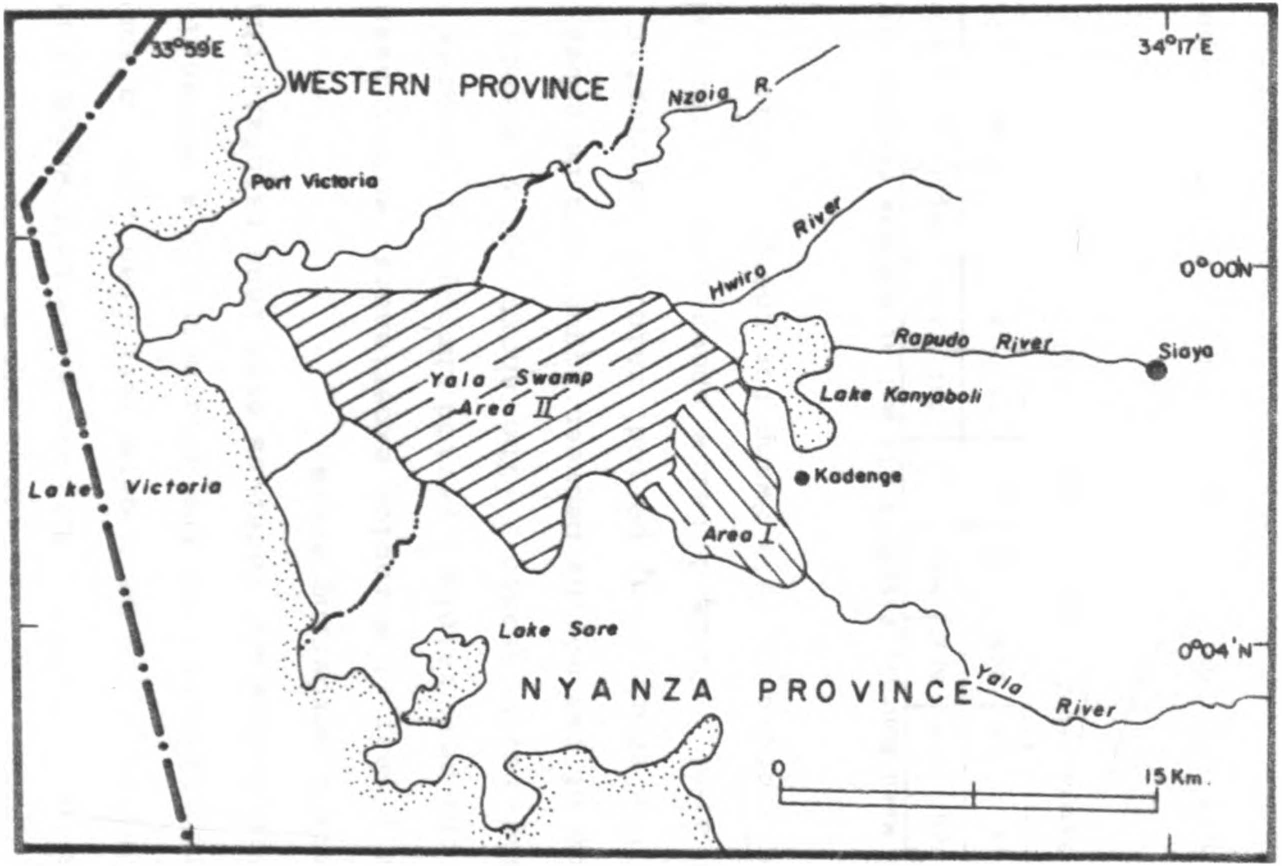


Fig. 4 : Location of Lakes Kanyaboli, Sare and Yala Swamp reclamation works.

2.3 CLIMATE

The climate of the area is mainly influenced by movements of the inter-tropical zone and the proximity of Lake Victoria. The climate of the area is mild with small variation in monthly average air temperature between 18°C and 25°C throughout the year. The lake is located within the lake-shore belt which generally receives low rainfall. This belt gets less than 1300 mm annually (fig 5). More important is that the area being in a depression seems to lie in a rain shadow and receives even less rainfall than the Northern and Western bordering areas.

In a year, the region experiences two wet seasons. March to May is the peak rainfall period throughout the area and is known as the long rainy season. The short rainy season occurs with a duration of two months between August and December. Particularly during the short rainy period, rainfall is erratic and unreliable in the area. Table 1 below shows average rainfall measured at Kadenge station in Yala Swamp for the period 1972 to 1980.

Table 1: Mean Monthly Rainfall (in mm) at Kadenge Station (1972-1980)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
66	59	133	218	152	48	58	65	87	86	110	75	1157

Source: Kenya Meteorological Department, 1984

LBDA (1986) identified this area to be more susceptible to erosion hazard. Problems in this area were observed to be mainly caused by extended dry period followed by intense rainfall, which washes away soils on the slope areas by sheet-wash and rill erosion. Thus the climate has an impact on the water quality of the lake water interms of evaporation as influenced by high temperature, dilution of the lake water during the rainy season as well as washing of pollutants directly into the lake by surface runoff.

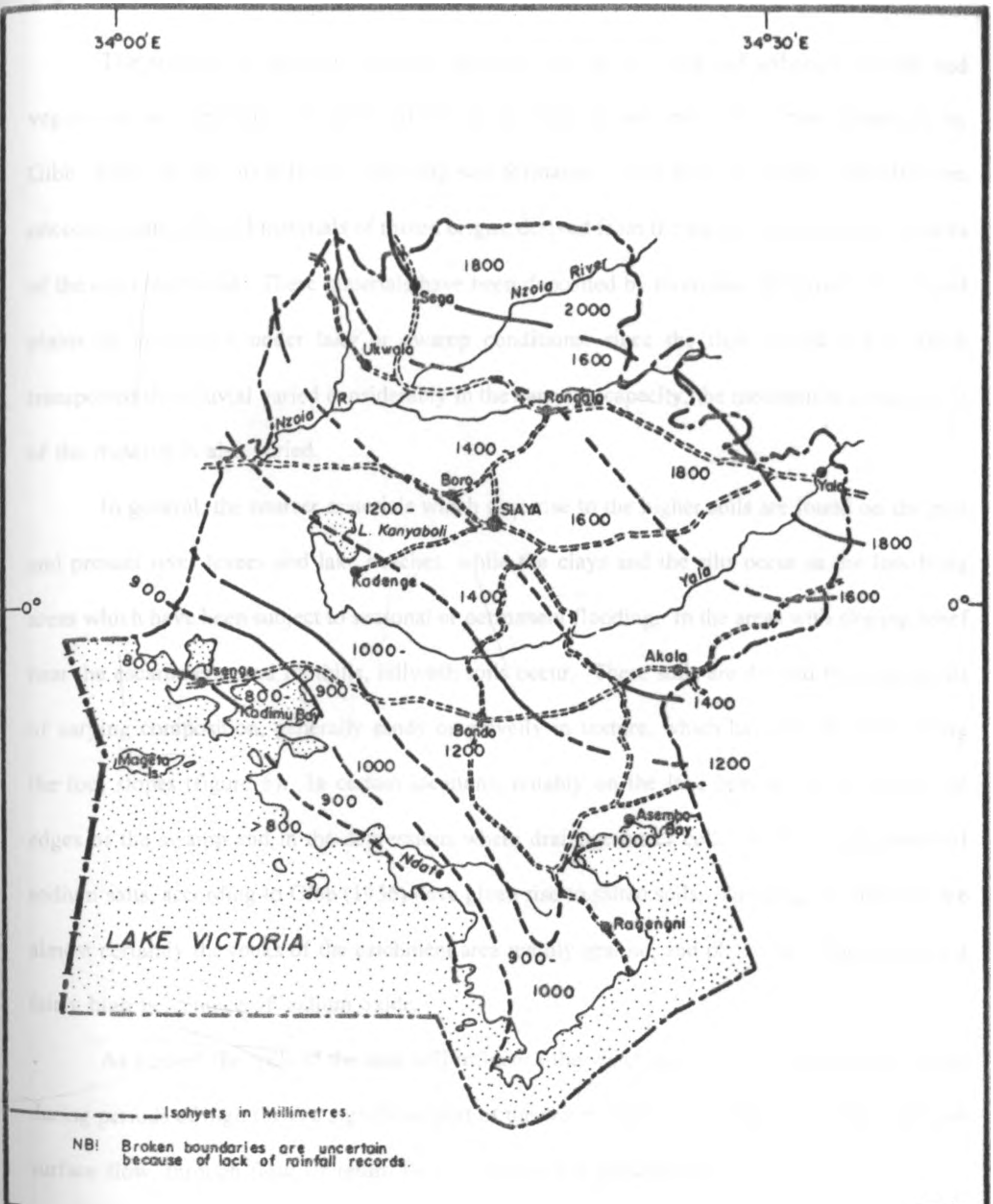


Fig. 5 : Average annual rainfall for Siaya District.
(Source : Farm Management Handbook of Kenya 1982)

2.4 SOILS

The soils of the area are youthful without defined horizons and although climate and vegetation are important, the nature of the parent material and relief have been identified by Gibb (1956) as the main factors affecting soil formation. The soils are formed mainly from unconsolidated alluvial materials of mixed origin, derived from the weathering products of rocks of the catchment area. These materials have been deposited by rivers and streams in their flood plains or laid down under lake or swamp conditions. since the flow of the water which transported the alluvial varied considerably in the carrying capacity, the mechanical composition of the material is also varied.

In general, the coarser materials which give rise to the higher soils are found on the past and present river levees and lake beaches, while the clays and the silts occur in the low-lying areas which have been subject to seasonal or permanent flooding. In the areas with sloping relief near the escarpments and foothills, hillwash soils occur. These soils are derived from materials of varying composition, generally sandy or gravelly in texture, which have accumulated along the foot slopes (figure 6). In certain locations, notably on the lake beaches, river levees, the edges of the swamp and in the depressions where drainage water collects, the accumulation of sodium salts, according to Gibb (1956) have given rise to salted soils. The origin of the salts are almost certainly the rocks of the catchment area mainly granite, and phonolite, which contain a fairly high percentage of sodium oxide.

As a result the soils of the area will influence the water quality of lake Kanyaboli in that during periods of high flows a significant part of the water entering the lake will be derived from surface flow, through flow, or return flow as opposed to ground water.

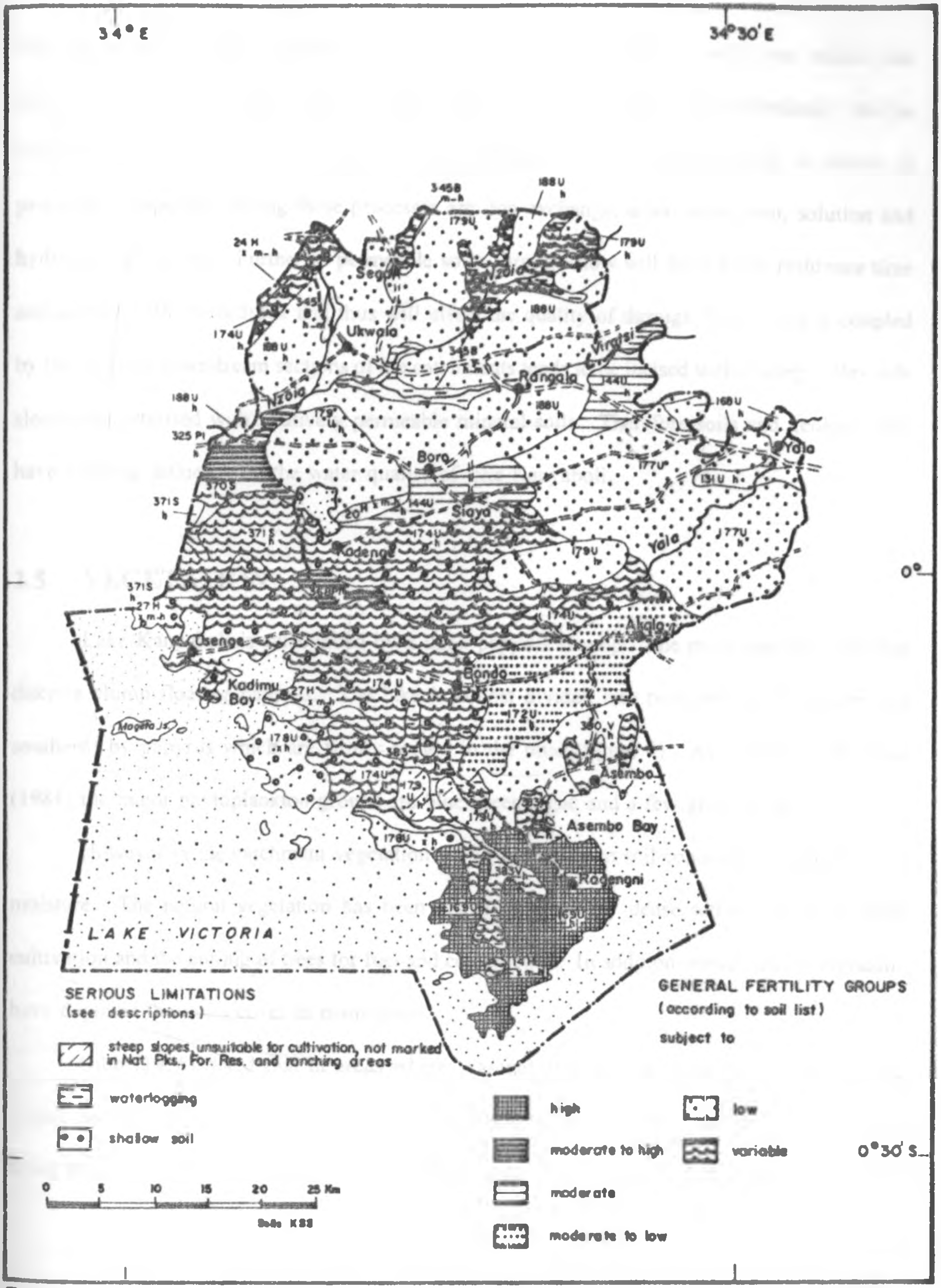


Fig. 6 : Soils of Siaya District.

Source : Farm Management Handbook of Kenya 1982

The chemistry of water flowing through a particular type of soil will thus reflect the chemistry of the soils over, or through which they have flowed rather than the bedrock. On the chemistry of water held within and flowing through the soil is influenced by a variety of processes. Important among these processes are: ion exchange, anion adsorption, solution and hydrolysis of the soil. Further in permeable soils, through-flow will have along residence time and contact with the bedrock and thus will affect the quality of through-flow. This is coupled by the fact that downstream sections of the catchments tends to be incised within steep valley side slopes characterised with relatively permeable mineral soils. Therefore soils and geology may have a strong influence on the water quality of lake Kanyaboli.

2.5 VEGETATION

Lake Kanyaboli is surrounded by a thick papyrus swamp. The most common type has discrete clump floating papyrus. The lake is almost divided into two sections (Northern and southern) by papyrus which are firmly rooted in the mud (figure 4). According to Okemwa (1981) the major phytoplankton groups are blue green algae and a few green algae.

However in the catchment vegetation varies according to soil conditions, especially soil moisture. The natural vegetation has been heavily affected by dense settlement, widespread cultivation and the cutting of trees for fuel and construction. In addition erosion and overgrazing have depleted the grass cover in many parts.

Gibb (1956) noted that in areas where seasonal and shallow flooding or waterlogging occurs the climax vegetation is woodland with Acacia-seyal, A. fistula, and A. drepanolobium being the dominant species. The vegetation which occurs in the seasonal and permanent swamps is controlled by the duration and depth of flooding. In the permanent swamp papyrus is dominant while in the seasonal swamp perennial grasses are dominant. In the hilly areas with shallow soils, scanty vegetation of bushland and shrubs occur.

In this case the vegetation of a catchment influences atmospheric inputs, evapotranspiration and nutrient cycling as well as runoff processes all which can, in turn influence the quality of drainage water and hence the quality of water in the lake.

2.6 POPULATION AND LANDUSE

The periphery of the lake and its immediate areas are densely populated. There are about 117,000 people living in Boro division (where the lake lies) with around 20,000 house holds (farm families), a population density of 192 people per square kilometre and an average family size of 8 persons per family and a dependency ratio of 50%. Table 2 below shows population distribution in each Location in Boro division.

Table 2: Population Per Location

LOCATION	POPULATION	HOUSEHOLD	AREA (km^2)	DENSITY
East Alego	43,305	10,144	104	416
Central Alego	27,802	6,647	124	224
South Alego	27,479	6,402	125	220
West Alego	28,517	7,017	104	274
North Alego	17,509	4,103	55	318
Usonga	11,059	2,828	80	138
Boro	155,671	37,111	592	263

Source: Population Census, 1989

Figure 7 shows population distribution per division in Siaya District. Much of the total agricultural land in the area is either left for grazing or is fallow while another additional area is under bushland or under swamp or marsh. The crops which are grown under subsistence in the area include maize, sorghum, and cassava which forms the staple food of the people in the area. Irrigation is developed to substantial levels around the lake especially in the Yala swamp. Most important crops grown by irrigation are horticultural crops. Others include rice, sugar cane, beans, cow peas, maize, sorghum and cotton (figure 8). Grazing is also an important feature in this area where mainly local breeds are reared. Sheep and goats are also reared in the more drier areas where they exploit the scanty vegetation.

Lake side communities have become closely integrated with the natural cycle of the lake, adjusting to seasonal changes in fish distribution and availability, to vegetation growth and to changing water levels. The local population use diversity of resources including fish for local consumption, vegetation for livestock or construction, and lake-shore substrate for vegetables and other crops. Arguably the most important resource of Lake Kanyaboli is its diverse and abundant fish populations. This is particularly so in this area where, given the critical food situation and the rapidly growing population, the lake water, and in particular the fisheries resources of the lake are seen as a major means by which to increase the availability of dietary protein and improved health. Thus it is important to note that a combination of such landuse activities as settlement, cultivation, cutting of vegetation, and rearing of livestock are bound to generate a lot of waste. As a result these activities effect changes in the physical, chemical, and biological structure of the lake.

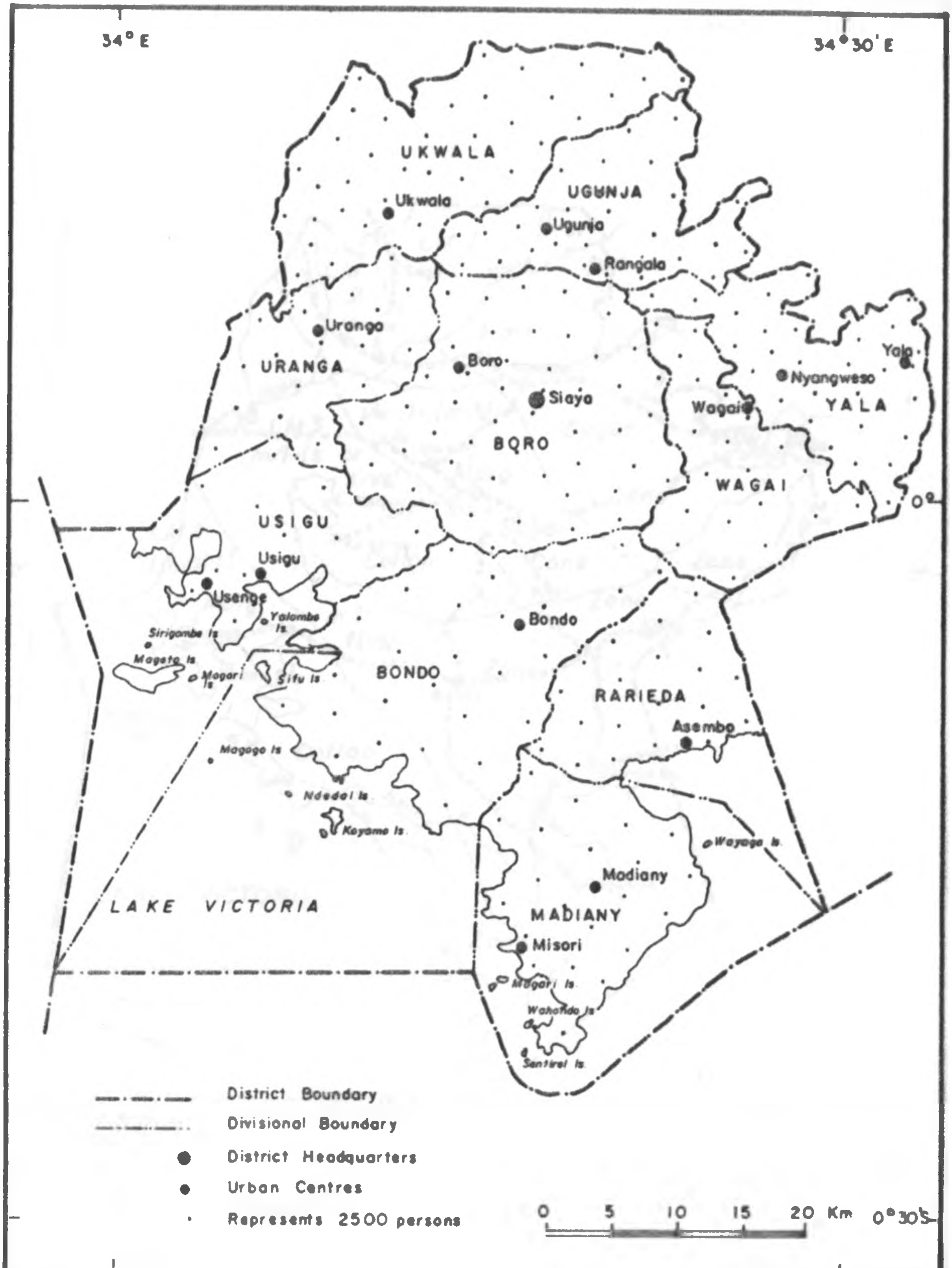


Fig. 7 : Population distribution in Siaya District by Divisions.

Source: Siaya D.D. Plan 1994-96

Fig. 8 : A simplified Agro-ecological Zones of Siaya District.
(Source : Farm Management Handbook of Kenya - 1982)

CHAPTER THREE

METHODOLOGY

Techniques used for data collection, data analysis and data presentation in this study are discussed below.

3.1 SAMPLING DESIGN

The whole of lake Kanyaboli (10.5 square km) formed an area of interest during the study period (February to May). The lake was first stratified into two (northern and southern section) and then the random sampling procedure was used to establish sampling stations. This was based mainly on the shape of the lake (the lake is almost divided into two by the papyrus swamp) and were related to the total lake area made of up that section. The sampling sites were further considered on the basis of their proximity to major sources of runoff and other human activities which may influence the water quality. Sampling sites were also established in the open waters away from the intensive use areas and away from near-shore influence. This was based on the fact that the inshore or littoral zones usually exhibit different biotic communities and therefore sustains different level of production from that of deeper, open water areas. These differences are therefore expected to be reflected in water quality characteristics.

A total of 13 sampling points were established (figure 9) from which water samples for physical and chemical analysis were collected. This mainly depended on time available to collect and process the sample. For interstitial water samples, bottom sediment samples were collected

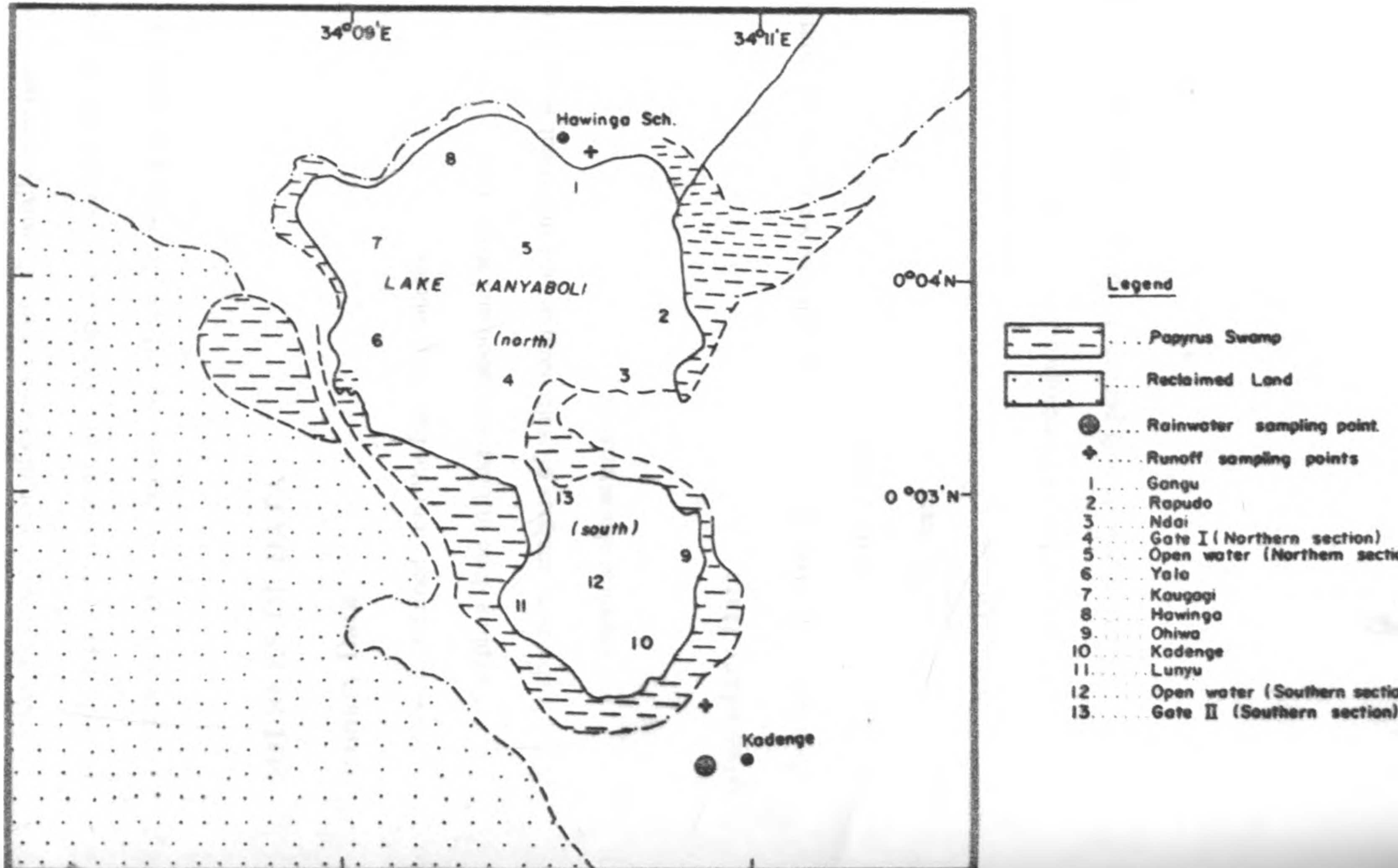


Fig. 9 : Location of sampling sites at Lake Kanyaboli.

with sampling stations selected so as to coincide with those established for surface water samples.

River Yala was also sampled at Siaya/Bondo bridge before it enters the Yala Swamp. A total of five samples were obtained from each sampling station and sampling was done twice a month. This was considered on the basis of the variability of the environment. The main reason was that in lakes the concentration of extrinsic materials usually increases slowly throughout the entire lake and the problem is one of time with space or space and distance playing a small role. During the rains rainwater samples and run- off samples were also collected.

3.2 SOURCES OF DATA

3.2.1 Primary Data

These were obtained from the following sources:

1. Sampling done in Lake Kanyaboli and River Yala.
2. Laboratory analysis of water samples and interstitial water samples for physical and chemical characteristics.

3.2.2 Secondary Data

These are mainly work done by other people and were obtained from:

1. Records from the LBDA.
2. Ministry of Water.
3. District Offices.
4. Records from Kenya Metrological Department.
5. Literature review of both published and unpublished work relevant to the study.

3.3 METHODS OF DATA COLLECTION

3.3.1 Water Samples

A small row boat was used from which water samples were taken from the lake water. An integrating sampler was used to sample. This is a bottle placed in a metal holder attached to a string and immersed in water ensuring that it does not touch the bottom. An approximate integrated sample of water between the bottom and the surface is then taken. This is then transferred into a 2.5 litre plastic bottles. To ensure that the collected samples were representative of the lake water conditions the sampling bottles were rinsed two times with the water before sampling. In the case of river Yala samples were collected at the Siaya/Bondo bridge.

3.2.2 Runoff and Rainwater Samples

For the purpose of this study, a rainwater sampling station was located at Kadenge meteorological station (figure 9). In this case a rain gauge was sterilised before a storm. After the storm, the collected rainwater was then transferred into the sampling bottle. The collected samples were then analyzed for pH, Calcium, Magnesium, Chloride, and nitrate.

Stations for runoff samples were set around the lake (figure 9). During storms samples were collected using the sampling bottles from all the stations. After collection all hand collected samples were analyzed for pH. Iron, Manganese. Nitrite. Nitrate, Ammonia, and Total dissolved solids.

3.3.3 Interstitial Water Samples

Sediment samples were obtained from the bottom of the lake using "Ekman" grab from a small row-boat. The "Ekman" grab consists essentially of a bucket having jaws which are spring loaded. The sampler is lowered to the bottom on a rope and the jaws snap shut to take a sample. The trigger for the jaws to shut is a messenger weight dropped by the rope. To get the interstitial water the sediment water mixture was decanted and then filtered. Each filtrate was then stored in a clean plastic bottle.

3.3.4 Depth of the Sampling Points

Before obtaining a sample from the lake-bed, depth was measured using a weight tied to a string. This was suspended slowly until it touches the bed. A marker was then used to indicate the level at the water surface after which the weight is pulled out and the height measured using a metre rule. The height between the marked point up to and including the weight was then taken as the depth of the lake at that particular point at which the measurement was taken. It is important to note that these was just rough measurement of the lake depths.

3.3.5 Water Quality

The determination of the specific physical and chemical characteristics of water done in accordance with standard analytical methods and techniques and these are discussed in detail in this chapter.

3.3.6 Data Collection Limitations

The following are believed to be the most important data limitations in this study:

1. Most of the laboratory equipments used for physical and chemical analysis (for both surface water and interstitial water samples) were accurate up to only one decimal place. Consequently, some parameters could have passed undetected.
2. In the case of secondary data, it was not easy to obtain accurate and reliable information from some sources due to poor record keeping sources and the absence of required information.

3.4 DATA ANALYSIS AND PRESENTATION

Techniques and methods of used in this study for data analysis and presentation of the results are discussed below.

3.4.1 Laboratory Methods

The analysis of water samples for the studied parameters were performed at the Ministry of Water laboratory (Kisumu). Due to the congestion in the laboratories all the analysis were performed by the laboratory staff. Techniques and methods used in this study for laboratory analysis of water samples are discussed below and standard works on this subjèct are readily available for reference on books such as Rainwater *et al* (1960): IWE (1960); APHA (1973); and Mackereth *et al* (1989).

i) Gravimetric Analysis

This form of analysis depends on weighing of solids obtained from the sample by evaporation, filtration or precipitation. The procedures tend to be tedious and time consuming because of the need for careful drying to drive off the moisture before weighing, both from the solids and the dish or the container in which they are placed. In this study TDS was analyzed by evaporating well-mixed and filtrated sample to dryness in clean and dry platinum dish and by weighing and deducting the weight of the dry dish, the total weight of the residue is obtained.

ii) Volumetric Analysis

Many determinations in water quality can be rapidly carried out by volumetric analysis. This depends on the measurements of volume of liquid reagent of known strength. The requirements for volumetric analysis relatively are simple as outlined below:

1) Equipment to measure the sample accurately, e.g pipette
2) A standard solution of suitable strength (a standard solution of known strength.
3) An indicator to show when the stoichiometric endpoint has been reached.
4) A graduated burette for accurate measurement of volume of solution.

Majority of these parameters were analyzed using this technique. Dissolved oxygen was analyzed using Winkler method where oxygen is converted in a series of steps, using manganous sulphate, alkaline iodide and sulphuric acid to free iodine which is then titrated with sodium thiosulphate. Starch is used as an adsorption indicator to indicate the end point. Chloride content was determined by titration with silver nitrate with potassium precipitation indicator. Other parameters analyzed by this technique included Total Alkalinity, Total Hardness, pH (with Phenolphthalein as indicator) and Permanganate Value (mixed with sulphuric acid and placed in a water bath for four(4) hours, add potassium iodide and titrate with sodium thiosulphate solution).

iii) Colorimetric Analysis

Colorimetric analysis are particularly useful when dealing with dilute solutions and there are many determinations in water quality control which can be carried out by this method. This method is based on the formation of a compound or complex with definite colour characteristics and the density of the colour is proportional to the concentration of the parameter being determined. The coloured solutions must follow two principles:

a) Light absorbed is proportional to the concentration of substance

b) Light intensity transmitted is inversely proportional to the length of light path in solution.

The colour produced is measured by the process of colour matching of liquid columns illuminated from below. The procedure was used to analyze parameters such as calcium and magnesium (by filtration with ammonium oxalate), iron (heated with dilute nitric acid and filtered), manganese (add sulphuric acid and evaporate to dryness), fluoride (by filtration with mercuric nitrate solution). Nitrates, nitrites, phosphorus and ammonia forms were all determined according to APHA (1973).

3.4.2 Statistics Analysis

Statistics have been used in this study to describe certain characteristics of the data set.

This enables us to decide whether it is in order to carry out any further analysis. The statistics that have been used in this study include summary statistics (mean, range and maximum values, minimum values and standard deviation) and inferential statistics (correlation analysis and regression analysis. These statistical techniques can be found in the works of Lapin (1980); Chakravarti *et al* (1967); Harber *et al* (1969) and Fisher (1990). The formulae of the used techniques are presented in appendix 6 while the data used in these computations are in appendix 5(a) to 5(b).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 LEVELS AND SOURCES OF POTENTIAL POLLUTANTS

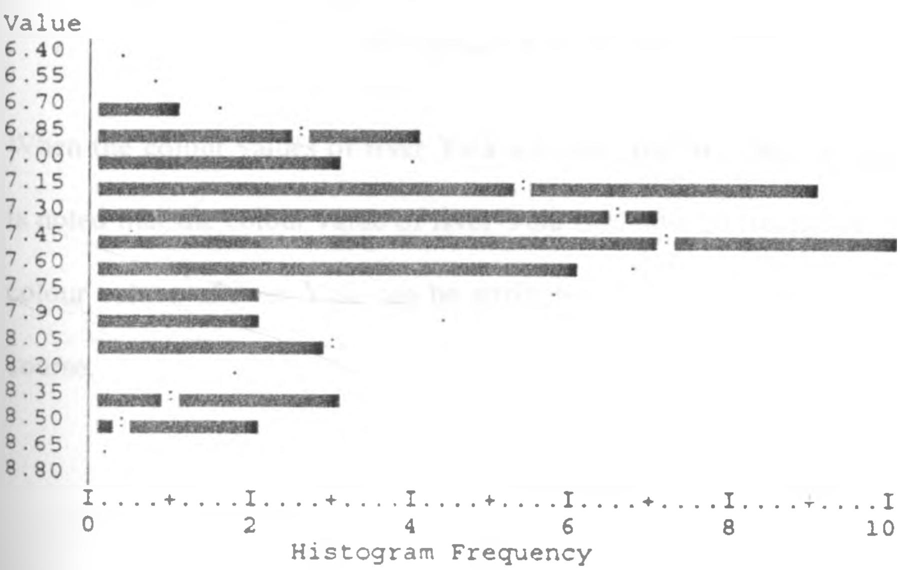
The results of physical and chemical analysis of water samples collected are presented and discussed below.

4.1.1 Normal Characteristics of Water

a) pH

This is the intensity of acidity or alkalinity of water as measured by the concentration of hydrogen ions.

Figure 10a: Frequency Distribution of pH

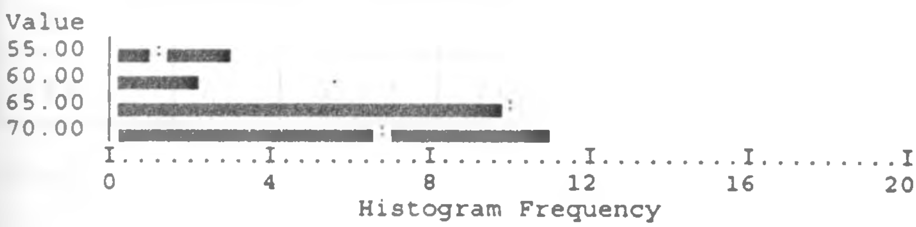


Many chemical reactions are controlled by pH in the range of 6 to 8. The mean pH value for Lake Kanyaboli was 7.08 (table 4). However results per sampling station show that the values range from 7.4 to 7.7 with a mode of 7.7 (table 3). These values are normally distributed as shown in figure 10a.

b) Colour

Colour in water is usually caused by decomposing organic matter (i.e. dissolved organic). As a result industrial effluent entering a water body may cause high coloured water. However, water from peat areas, swamps and marshes also results in high colour. In lake kanyaboli the mean colour value was 65.58mg/l with a spatial variation such that higher values are generally found in the southern section (tables 3 and 4). The distribution is negatively skewed.

Figure 10b: Frequency Distribution of Colour.



When the colour values of river Yala are compared with that of lake Kanyaboli (appendix 2) it is noted that the colour value of river Yala is almost 20 times that of lake Kanyaboli. The high colour values of river Yala can be attributed to raw effluent from the sugar jaggaries along its course.

Table 3: Mean Concentration of Normal Physio-chemical Characteristics.

Station	pH	Colour	DO	TA	TH	Turb	PV	TDS
1	7.4	60.0	7.0	16.0	8.0	13.3	4.40	104
2	7.8	65.0	6.0	14.0	10.0	13.6	3.70	114
3	7.3	55.0	6.0	34.0	4.0	13.0	4.25	104
4	7.7	65.0	7.0	20.0	22.0	13.6	4.10	105
5	7.6	70.0	6.0	38.0	10.0	13.0	4.00	108
6	7.5	65.0	7.0	16.0	38.0	17.7	3.35	105
7	7.4	65.0	6.0	14.0	28.0	13.0	3.80	107
8	8.0	70.0	7.0	12.0	13.0	16.3	4.85	105
9	7.7	70.0	6.0	20.0	40.0	15.7	4.10	118
10	7.7	70.0	8.0	10.0	34.0	15.0	4.10	108
11	7.7	65.0	7.0	32.0	12.0	13.3	3.75	110
12	7.7	70.0	12.0	38.0	14.0	15.0	3.80	106
13	7.7	65.0	7.0	12.0	42.0	13.0	4.30	104

Source: Research Data

Table 4: Summary of Physio-chemical Characteristics

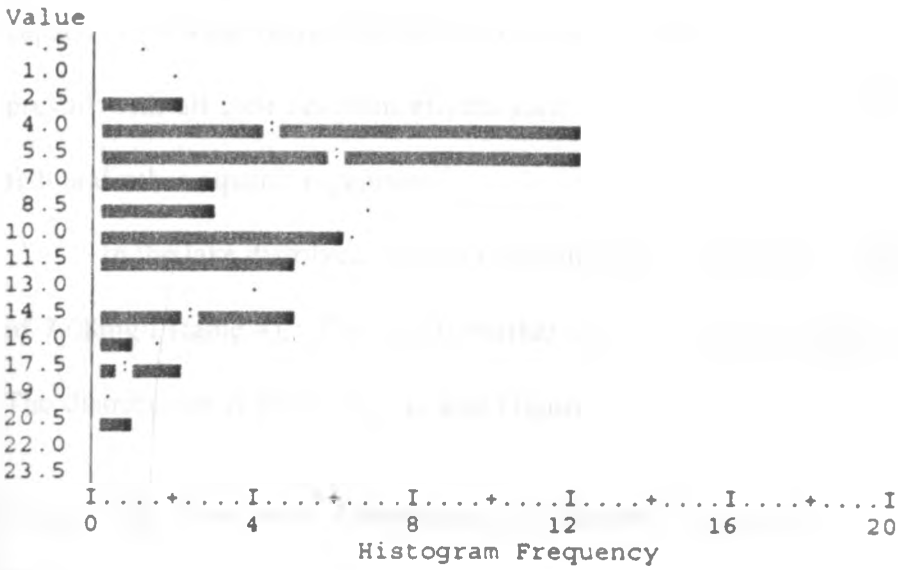
Variable Label	Mean	Std Dev	Range	Minimum	Maximum	N
DO(mg/l)	7.08	1.36	6.00	6	12	52
PH	7.47	.44	1.80	6.7	8.5	52
COL.	65.58	4.97	15.00	55	70	26
TA(mg/l)	17.46	6.56	28.00	8	36	52
TH(mg/l)	28.63	12.39	42.00	4	46	52
TDS(mg/l)	103.69	6.53	18.00	95	113	52
CA(mg/l)	12.27	2.69	8.00	8	16	52
MG(mg/l)	16.46	10.88	32.00	0	32	52
TURB(NTU)	8.19	4.47	17.00	3	20	52
CL(mg/l)	23.17	2.82	14.50	16.0	30.5	52
F(mg/l)	.07	.02	.06	.04	.10	52
PV(mg/l)	4.08	.42	2.20	3.5	5.7	52
FE(mg/l)	.17	.18	.60	.00	.60	50
MN(mg/l)	.09	.07	.20	.000	.200	50
NH3(mg/l)	.11	.04	.18	.02	.20	51
FNH3(mg/l)	.05	.02	.08	.02	.10	52
ANH3(mg/l)	.06	.03	.14	.03	.17	52
P(mg/l)	.00	.00	.00	0	0	52
NO3(mg/l)	.00	.00	.00	0	0	52
NO2(mg/l)	.07	.23	.12	.00	.12	52

Source: Research Data

c) Turbidity

Turbidity in water is caused by the presence of suspended matter such as clays, silt, finely-divided organic and inorganic matter, plankton, and other microscopic organisms. According to Walker (1978), this can also be caused by finely divided air bubbles. In lake Kanyaboli turbidity values range between 3 to 20 N.T.U with a mean value of 8 (table 4). The distribution of turbidity is stretched towards the high (positive) as shown in figure 10c.

Figure 10c: Frequency Distribution of Turbidity.



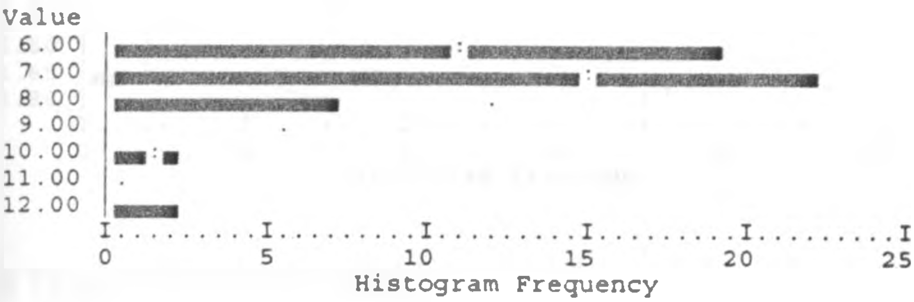
Turbidity values follow almost a similar pattern as other parameters already discussed with the Southern section recording the highest mean value (appendix 1). The high turbidity values recorded in lake Kanyaboli are as a result of silt and clays washed into the lake by streams and runoff water. In addition, algal production within the lake may also be responsible for the high turbidity values. On the other hand wind action should also be taken into account considering the fact that the lake is shallow and any small disturbance caused by the wind is enough to disturb bottom materials hence causing turbidity (appendix 4). As a result turbidity values are expected to vary greatly.

d) Dissolved Oxygen

Dissolved oxygen is the most important element in water quality control. Its presence is essential to maintain the high forms of life and the effect of a waste discharge is largely determined by the oxygen balance system. Thus high oxygen values means a high assimilative capacity of a water body while an exhaustion of oxygen in water means that septic conditions will prevail with all their resultant effects such as offensive odours, floating black sludge, death of fish and other aquatic organisms.

In the lake dissolved oxygen concentrations was generally high in all stations with a mean of 7.08mg/l (table 4). The results further show that values range from 6 to 12 mg/l (table 3). The distribution is positively skewed (figure 10d).

Figure 10d: Frequency Distribution of Dissolved Oxygen.

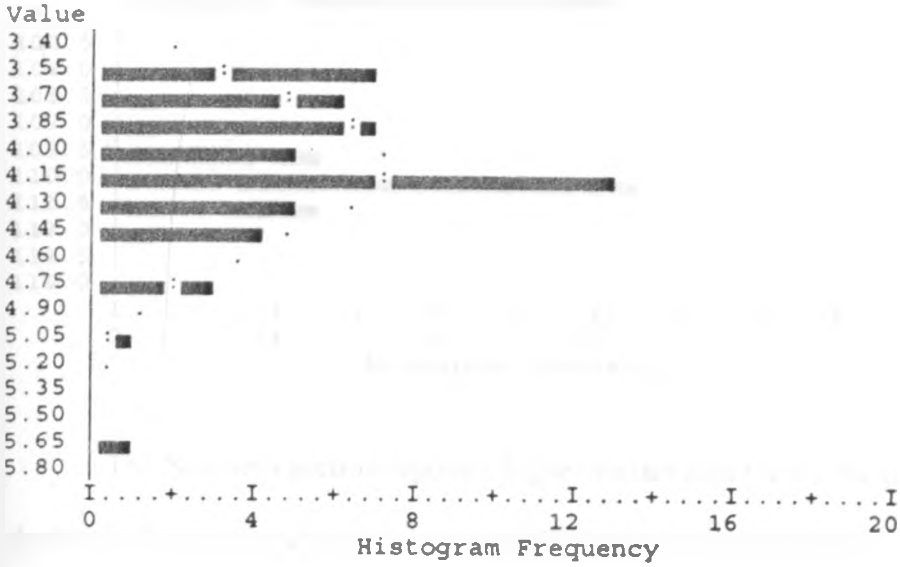


Spatial variation in dissolved oxygen are such that the high values generally occur in the Southern section as opposed to the Northern section. The generally high values throughout the lake suggest that the lake is well mixed. It may also be said that the lake receives sufficient replenishment of oxygen through aeration from the atmosphere, by dilution with clean well oxygenated water (especially during the rainy season) and by photosynthesis of the aquatic plants.

e) Permanganate Value (PV)

This is the amount of oxygen absorbed from acid permanganate. The absorption is very slight with very pure waters but it is considerable in those polluted with animal or vegetable organic matter. In lake Kanyaboli high values are reported in the range of 3.5 to 5.7mg/l with a mean of 4.08mg/l (tables 3 and 4). Thus the high values reported may imply some organic pollution. The frequency distribution of permanganate value is shown in figure 10e.

Figure 10e: Frequency Distribution of Permanganate Value.

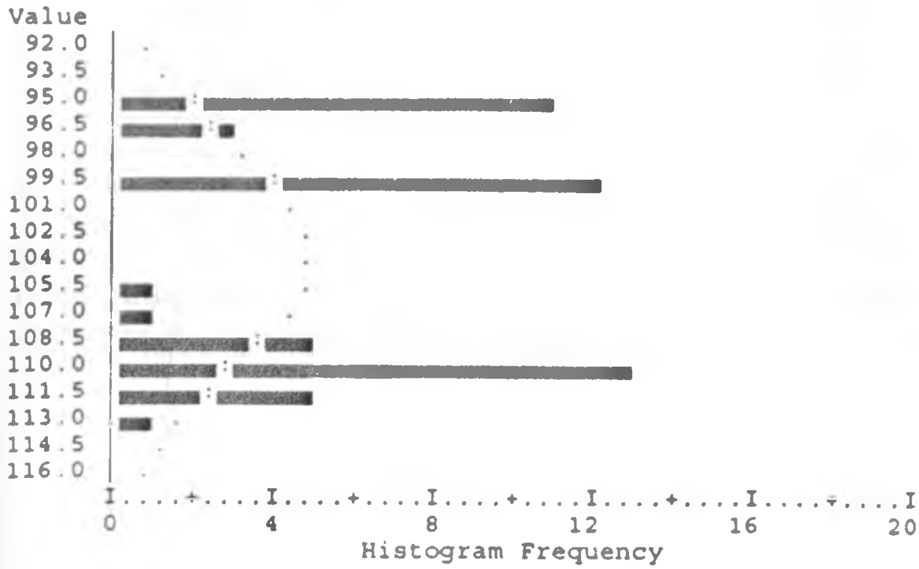


f) Total Dissolved Solids (TDS)

The dissolved solids in a water body depend in part upon the geological character of a watershed, on the rainfall, and partly on the amount of pollution taking place. A sudden rise in the content of TDS in a water body may be due to pollution and a fall may be caused by heavy rainfall. Soluble salts (dissolved solids) commonly found in a water body include chlorides, sulphates, nitrates, bicarbonates, and phosphates of sodium, potassium, calcium, magnesium, iron, and manganese.

In lake kanyaboli this study reported generally low values of TDS ranging from 95 To 113mg/l with a mean of 103.69mg/l (tables 3 and 4). The frequency distribution tends to be normal. It clearly shows distinct seasonality.

Figure 10f: Frequency Distribution of Total Dissolved Solids



The Southern section reported higher values than the northern section (appendix 1). Thus the low values reported for lake Kanyaboli may be interpreted as largely reflecting the interaction of rainfall (interms of runoff and sub-surface flow) and lithology. In other words, the low dissolved solids encountered in this study may be attributed to the existence of ancient basement rocks with a low susceptibility to chemical weathering. Further the results provide some insights into the influence of rainfall interms of runoff. For instance in appendix 2, the TDS of runoff is 25mg/l as opposed to an average of the lake (103.69mg/l). This can be accounted for interms of a general dilution effect as runoff volume increases. Interms of TDS (Salinity) surface water can be classified into four classes as shown in table 5.

Table 5: Classification of Water interms of Salinity (TDS)

Concentration	Degree
less than 500mg/l	Fresh
500 to 1000mg/l	Marginal
1000 to 3000mg/l	Brackish
More than 3000	Saline

Source: Australian Water Resource Council, 1975

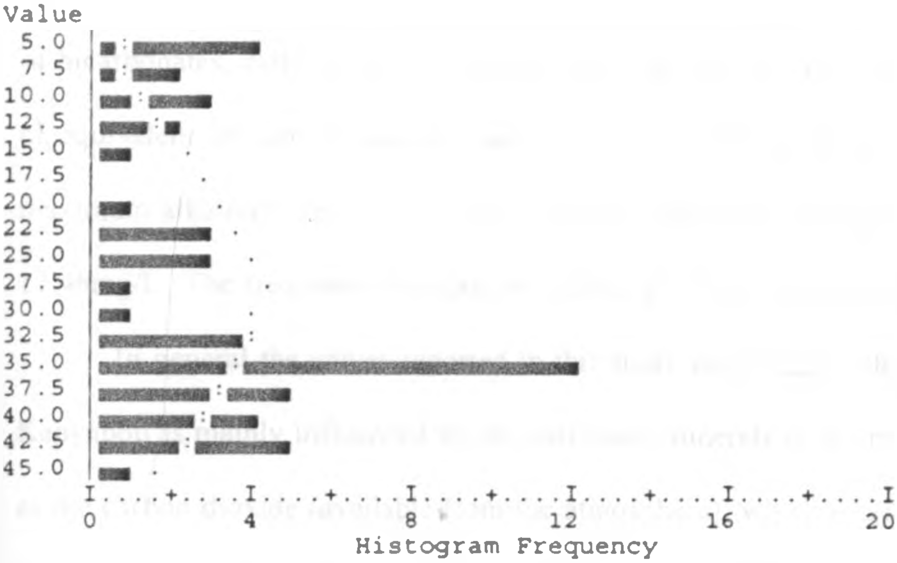
From the above classification, it is clear that Lake Kanyaboli is a fresh water lake.

g) Hardness

This is the property of a water which prevents lather formation with soap and produces scale in hot water systems. It is due mainly to the presence of bicarbonates of calcium and magnesium ("temporary" or carbonate hardness) or sulphates and chlorides of calcium and magnesium ("permanent" or non carbonate hardness). A connection between high carbonate hardness and organic pollution have been found to exist in the case of ground waters, as is described, by Klein (1959), to the increased solubility of calcium carbonate in the presence of proteins, humus and weak acids produced by the oxidation of organic matter. The hardness of water from a particular source is also of considerable significance in connection with the discharge of effluent containing certain toxic metallic ions to fishing waters. In particular, zinc and lead have been identified to be less toxic in hard waters containing considerable amounts of calcium salts than in soft waters.

In lake Kanyaboli values reported in this study were generally low. The results show a mean value of 28.63mg/l, a mean maximum of 42mg/l and a mean minimum of 4mg/l (table 4).

Figure 10g: Frequency Distribution of Total Hardness.



The frequency distribution above (figure 10g) show that values of total hardness are slightly positively skewed. The low values may be attributed mainly to the composition of the basement rocks within the catchment. Table 6 below shows classification of water interms of hardness. According to the classification, it is clear that the water of lake Kanyaboli is soft.

Table 6: Classification of Surface Water interms of Hardness

Degree	Concentration
Soft	Less than 50mg/l
Moderately hard	50 to 150mg/l
Hard	150 to 300mg/l
Very hard	More than 300mg/l

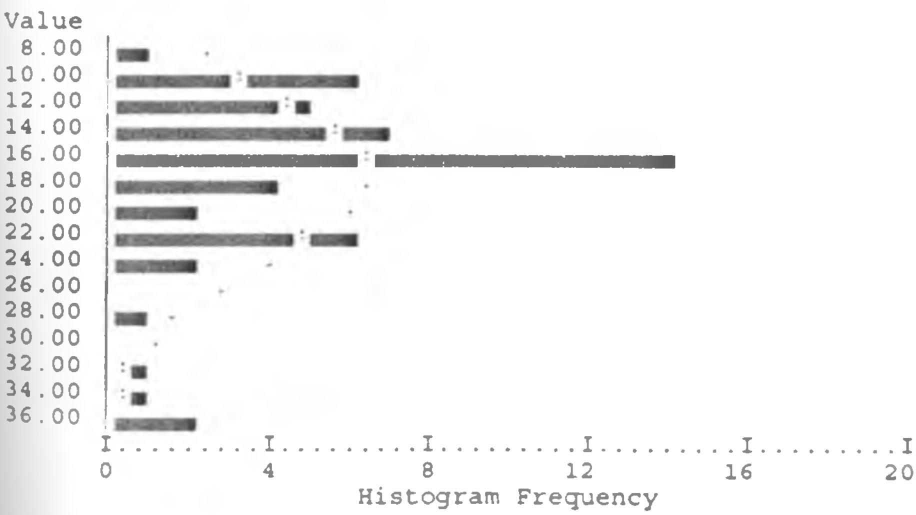
Source: Walker, 1978

h) Alkalinity

The property of alkalinity is its ability to neutralize acid. Thus it is important in water in that it provides buffering to resist changes in pH. Alkalinity of water is due to the presence of bicarbonates, carbonates or hydroxide ions. In this alkalinity values are all reported interms of equivalent amount of calcium carbonate. From the results of analysis (table 3 and 4) the maximum alkalinity reported is 36mg/l and the minimum is 8mg/l. The mean concentration is 17.46mg/l. The frequency distribution of total alkalinity is positively skewed (Figure 10h).

In general the values reported in this study may suggest that levels of alkalinity in lake Kanyaboli is mainly influenced by the carbonate minerals in the rocks of the catchment as well as the carbon dioxide (available from the atmosphere), which enters with them into equilibrium in water solution. However, the values reported can also be attributed to the effect of other factors such as evaporation.

Figure 10h: Frequency Distribution of Total Alkalinity.



4.1.2 Ionic Constituents of Water

a) Calcium

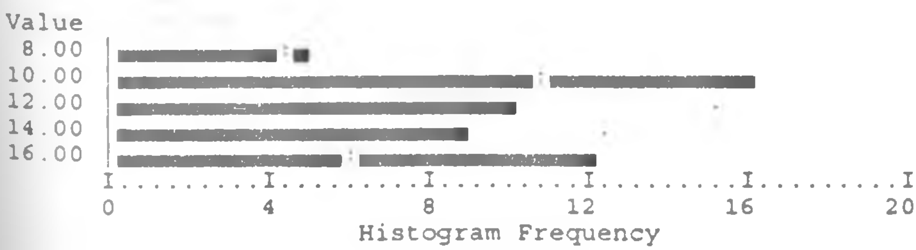
This is one of the alkaline-earth metals and is always abundant in water more than any other alkaline metal. Calcium occurs in rocks and soils and therefore reach water through leaching. Calcium and magnesium both contribute to hardness in water. In lake Kanyaboli calcium levels were low as shown by the results of analysis (table 7). It is evident from table 6 that calcium concentration in the whole lake rarely changes from a mean of 12.27mg/l with a range of 8mg/l. Frequency distribution for calcium levels is positively skewed (figure 11i). These results may thus suggest that calcium in lake Kanyaboli mainly come from leaching of weathered rock materials and soils by runoff.

Table 7: Mean Ionic Concentrations (mg/l)

Station	Ca	Mg	Cl	F	Fe	Mn
1	14.0	15.5	31.3	0.05	0.02	0.20
2	10.0	22.0	29.0	0.09	0.02	0.10
3	12.0	18.5	27.5	0.10	0.10	0.20
4	14.0	17.3	27.8	0.07	0.05	0.10
5	10.0	26.7	26.3	0.05	0.20	0.10
6	14.0	24.6	24.5	0.08	0.10	0.05
7	10.0	18.0	28.3	0.09	0.4	0.15
8	12.0	26.0	26.7	0.06	0.05	0.10
9	14.0	26.6	26.3	0.06	0.60	0.05
10	10.0	14.0	23.0	0.05	0.10	0.10
11	12.0	20.0	27.0	0.07	0.10	0.10
12	14.0	24.0	26.3	0.04	0.10	0.15
13	14.0	28.0	25.3	0.06	-	-

Source: Field Research

Figure 10i: Frequency Distribution of Calcium

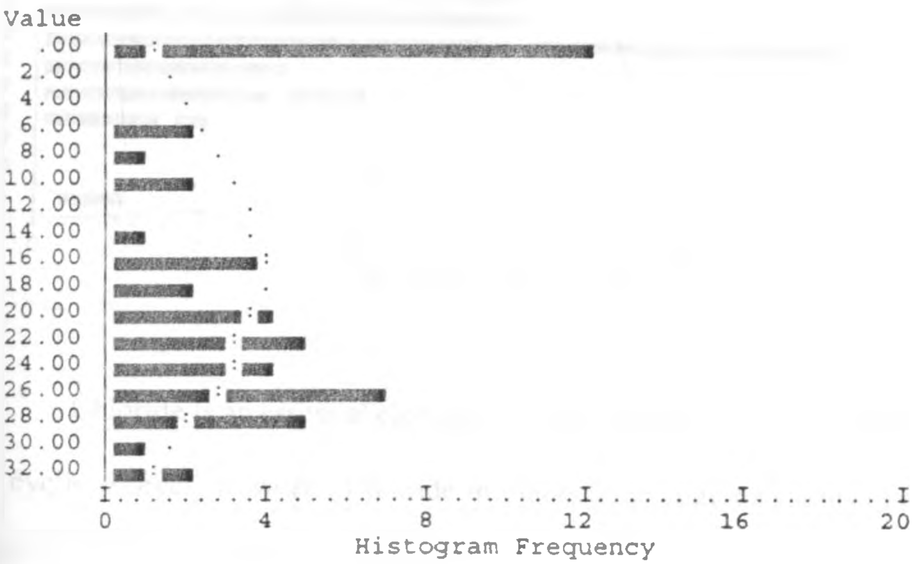


b) Magnesium

Magnesium is an important content of rock type. Like calcium magnesium in water is normally present in ionic form. Once in solution, magnesium has a stronger tendency to remain in that status than does calcium. Magnesium is also concentrated to a considerable content in evaporate sediment. Magnesium is the other constituent causing hardness in water.

From the results of analysis (table 7), it is important to note that low values of magnesium were reported in this study. The mean concentration of the lake is 16.46mg/l with a maximum and a minimum concentration of 32mg/l and 0mg/l respectively (table 4). The frequency distribution of magnesium is shown in figure 10j.

Figure 10j: Frequency Distribution of Magnesium

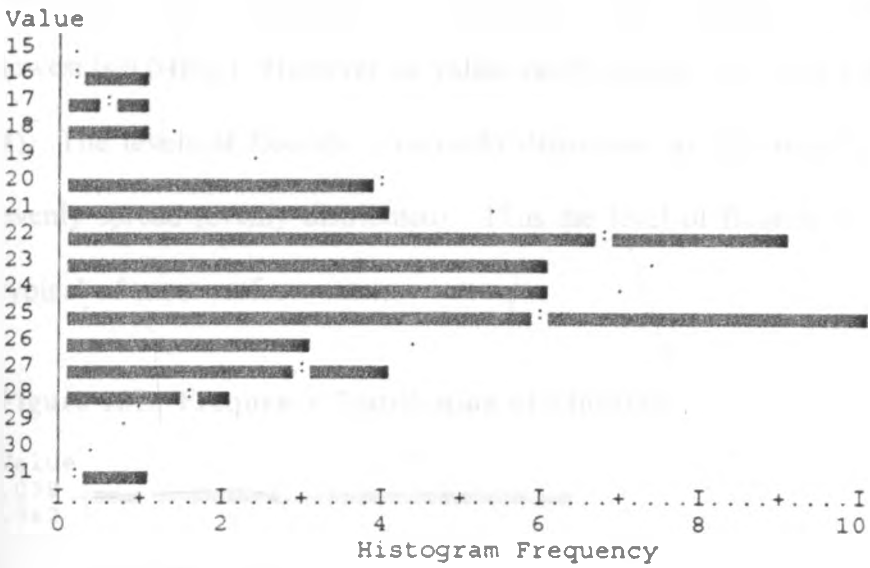


The main source of magnesium in lake Kanyaboli may thus be attributed to the basement rocks and soils of the catchment as values reported by the study are not high enough to suggest other sources.

c) Chloride

Chloride is present in igneous rocks. Chloride is present in all naturally waters, although in many areas the amounts are small. Exceptions may occur where a water body receives inflows of high-chloride ground water or industrial waste or are affected by oceanic tides.

Figure 10k: Frequency Distribution of Chloride

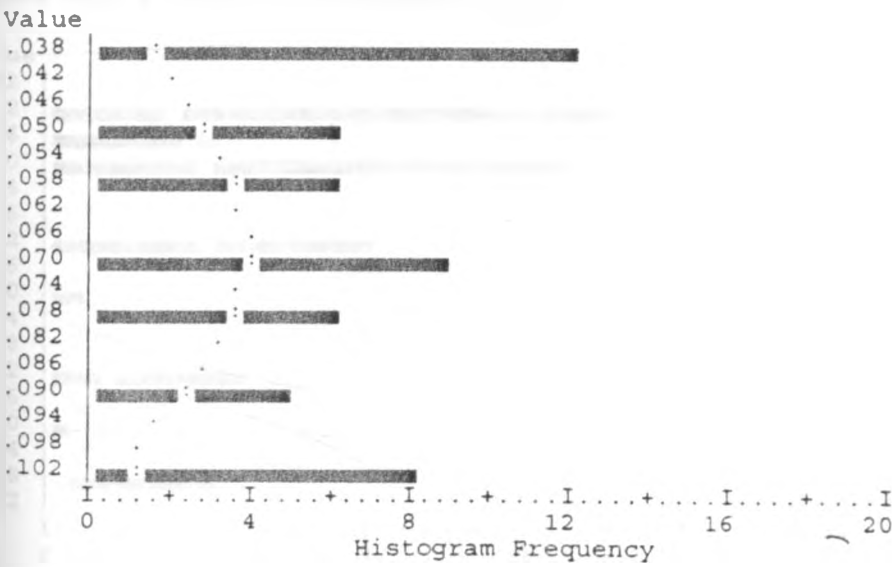


Chloride is an essential element for plants and animals and both may constitute secondary or cyclic sources in water. Chloride in domestic sewage may cause important increases in the chloride content into waters in which such waters are emptied. Thus it may be used as an indicator of organic pollution. However, in lake kanyaboli the study revealed that low values existed through out the study period with a mean value of 23.17mg/l (table 4). The levels of chloride is normally distributed as shown in figure 11k. These low values are an indication of chlorides originating from a typical terrane without regard to climatic conditions.

d) Fluoride

The quantity of fluoride present in the earth's crust is less than the quantity of chloride. Unlike the chloride, most of the fluoride are low in solubility and amount which can be present in natural waters are therefore limited. In general, fluoride concentrations of water may range from 0 to 50mg/l or more. However surface waters have seldom been observed to contain more than 1mg/l. In this analysis, it is evident from table 7 that the highest value is 0.1mg/l while the lowest is 0.04mg/l. However the values rarely change from 0.07 ± 0.02 for lake Kanyaboli (table 4). The levels of fluoride is normally distributed as shown in figure 10L. That is the values evenly spread (evenly distributed). Thus the level of fluoride in Lake Kanyaboli implies that typical of most surface waters.

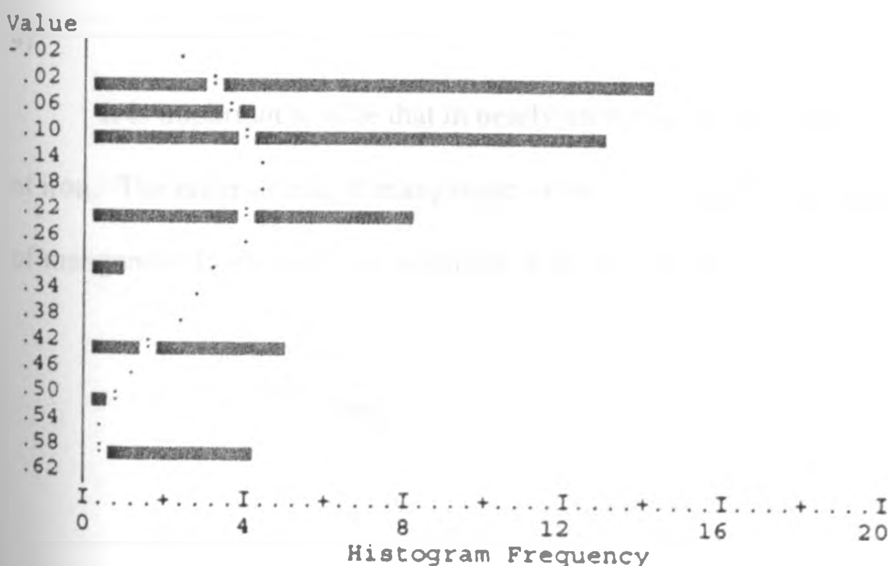
Figure 10L: Frequency Distribution of Fluoride.



e) **Iron**

This is one of the most abundant constituent of rocks and soils. The importance of determining small amounts in water is to evaluate the suitability of water for industrial and domestic purposes. Industrial waste disposal and acid mine contribute concentration to water bodies in some areas. In fully aerated water of normal pH (slightly alkaline) iron is normally present in amounts less than 0.1mg/l (i.e iron is normally present in ferric form). In acid waters on the other hand, ferric iron may be present in amounts exceeding 1000mg/l. Such waters are found in some thermal springs and in some surface waters strongly affected by disposal of wastes containing acids and iron. In lake Kanyaboli results of analysis (tables 4 and 7) indicate that iron concentration varies between 0mg/l and 0.6mg/l with a mean of 0.17mg/l. The Frequency distribution of iron is positively skewed.

Figure 10m: Frequency Distribution of Iron



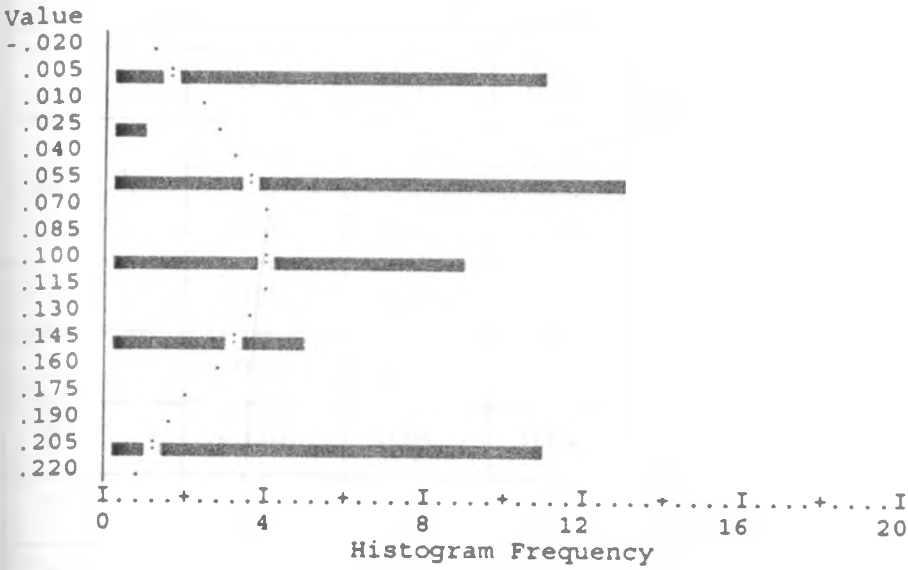
Thus from the above analysis it is clear that the low values suggest that the iron mainly originate from rocks of the catchment. This fact is further supported by the evidence that runoff water showed extremely high iron concentration which had undergone little dilution (appendix 2). The low iron content may also be explained, by the fact that the lake water has got a high pH (alkaline), and this probably tend to precipitate iron from solution through oxidation process.

f) Manganese

Manganese in natural water resembles iron in its chemical behaviour and occurrence. However, the concentration of manganese in water is generally less than that of iron. Manganese mainly occur in igneous rocks and tend to accumulate in soils as they are formed from rock weathering. In most natural waters manganese levels have been observed to be less than 0.2 mg/l. However, higher concentrations may be contributed by mining or industrial wastes. In lake kanyaboli manganese levels varied from 0 to 0.2 mg/l (table 7) with the mean of 0.09mg/l (table 4).

It is important to note that in nearly all the sampling stations, manganese is only a fraction of iron. The main source of manganese in this lake therefore appears to be the results of solution of manganese from soils and sediment aided by bacteria and organic matter.

Figure 10n : Frequency Distribution of Manganese.



4.1.3 Nutrients

The levels of nutrients of the lake for each sampling station are presented in table 8 below. From the table, it is clear that:

1. No phosphate was detected at any time at any station.
2. All nitrogen forms at one time or another in all stations.
3. Nitrate concentration occurred only in trace amounts in all stations through out the study period.
4. Other forms of nitrogen (i.e nitrites, and ammonia) were found in significant amounts.
5. No evaluation of nutrient movement, such as might be involve in sediment transport can made on the basis of the data obtained. Data presented in this study will thus provide a basis for future investigations in other areas of nutrient relationships such as mode of transport, and time of travel.

Table 8: Nutrient Concentration in Surface Water (mg/l)

Station	No_3	No_2	A/N	A/NH_3	F/NH_3	Po_4
1	<0.01	0.02	0.08	0.04	0.03	0.00
2	<0.01	0.05	0.10	0.06	0.06	0.00
3	<0.01	0.12	0.09	0.05	0.03	0.00
4	<0.01	0.05	0.17	0.05	0.05	0.0Q
5	<0.01	0.10	0.10	0.08	0.25	0.00
6	<0.01	0.05	0.08	0.04	0.08	0.00
7	<0.01	0.05	0.20	0.06	0.05	0.00
8	<0.01	0.01	0.10	0.07	0.04	0.00
9	<0.01	<0.01	0.08	0.04	0.05	0.00
10	<0.01	0.01	0.13	0.04	0.03	0.00
11	<0.01	0.04	0.13	0.05	0.06	0.00
12	<0.01	<0.01	0.14	0.12	0.04	0.00
13	<0.01	0.05	0.17	0.06	0.04	0.00

Source: Field research

a) Phosphorus

Phosphorus is an essential element in the growth of plants and animals, and some sources that contribute nitrate such as organic wastes and leaching of soils, may be important as sources of phosphates in water. In some areas agricultural fertilizers may yield some phosphorus. A more important source is the increasing use of phosphate detergents. Domestic and industrial sewage may therefore contain considerable amounts of phosphorus. It is important to note that in lake kanyaboli no phosphorus was detected throughout the study period (table 8). This may mainly be attributed to the fact that during the period of this study, it is possible that the lake was very active biologically (as implied by high values of dissolved oxygen) most of the phosphorus of the phosphorus were taken up by algae and other aquatic organisms.

The above results therefore supports Edzwald's (1976) argument that in a lake at any one time, most of the phosphorus is either tied up in organisms or on solids-organic detritus and inorganic particles such as clays. According to Odum (1971), the maximum amount of phosphorus that is likely to be in soluble form at any one time is only 10 percent of the total phosphorus. There is an extensive movement of phosphorus between solid and dissolved state in a lake. However this movement is often irregular with periods of net release from sediments followed by periods of net uptake by organisms or sediments depending on the limnological conditions. In short, the distribution and exchange of phosphorus between the sediments and water are important factors affecting the productivity of lakes.

Phosphorus may be transported to the sediments by settling or organic particulate Phosphorus such as sinking phytoplankton, settling of solid inorganic phases, and settling of inorganic clays containing adsorbed phosphorus. Phosphorus may be released from the sediments by organic mineralization of organic matter in the sediments by diffusion of sediments-interstitial water system. Edzwald (1976) and Stumm *et al* (1972) found out that factors affecting phosphorus exchange with sediments include mineral water equilibria, sorption processes, redox conditions, and activities of organisms.

b) Nitrogen

This is an element in biological systems. Nitrogen exists in four forms:

i) Organic nitrogen in the form of proteins, amino acids and urea. Albuminoid nitrogen (albuminoid ammonia) measures part of organic matter.

ii) Ammonia nitrogen as ammonium salts or as free ammonia.

iii) Nitrite nitrogen - this is an intermediate stage of oxidation and does not exist in large amounts.

iv) Nitrate nitrogen - final oxidation product of nitrogen.

Nitrogen enters surface water from many sources primarily from the decomposition of organic matter, sewage, surface runoff and use of nitrogenous fertilizers.

c) Nitrates

The presence of nitrates usually indicates the possibility of some contamination. However nitrates not normally a problem in surface water supplies where they rarely exceed 5mg/l and are less than 1mg/l in most waters. The role of nitrate as a plant nutrient is reflected in its ability to cause eutrophication in surface water. In lake Kanyaboli only trace amounts is reported in this study (table 8). The low (trace) in the lake can be partly explained by:

a) the fact that nitrate could have been assimilated by aquatic plants such as microphyte and phytoplankton during the study; and

b) that nitrate may have undergone natural denitrification in the lake water,-in which case bacterial action under low oxygen conditions convert nitrate into free nitrogen and

Figure 10p: Frequency Distribution of Ammonium Nitrate.

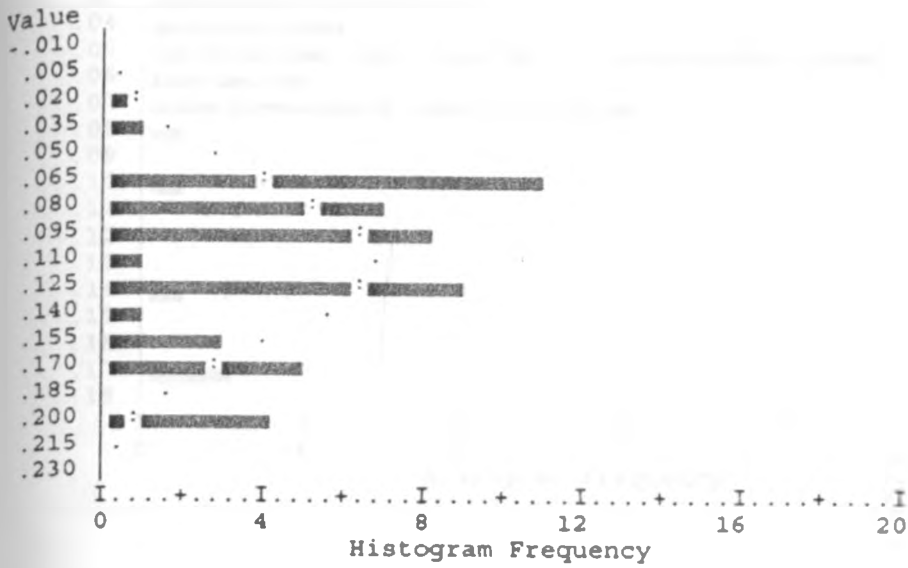


Figure 10r: Frequency Distribution of Free Ammonia.

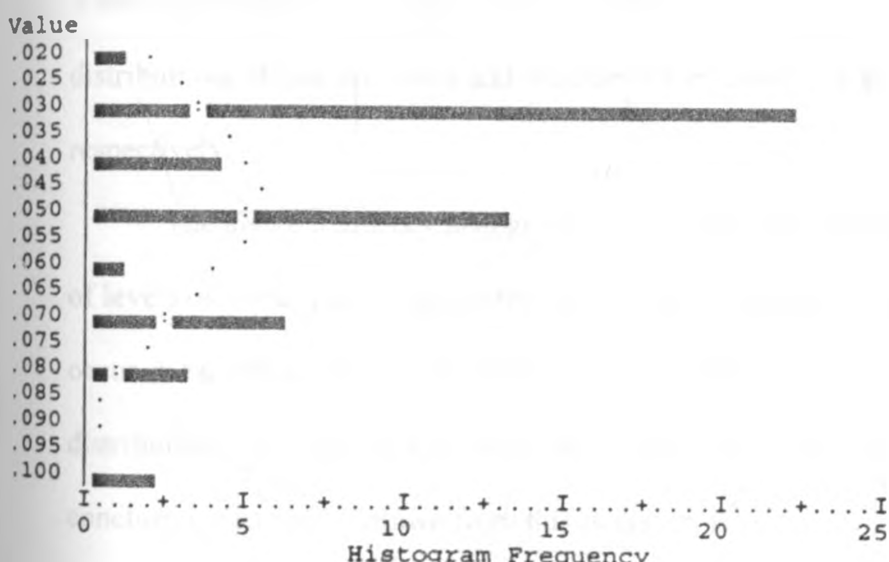
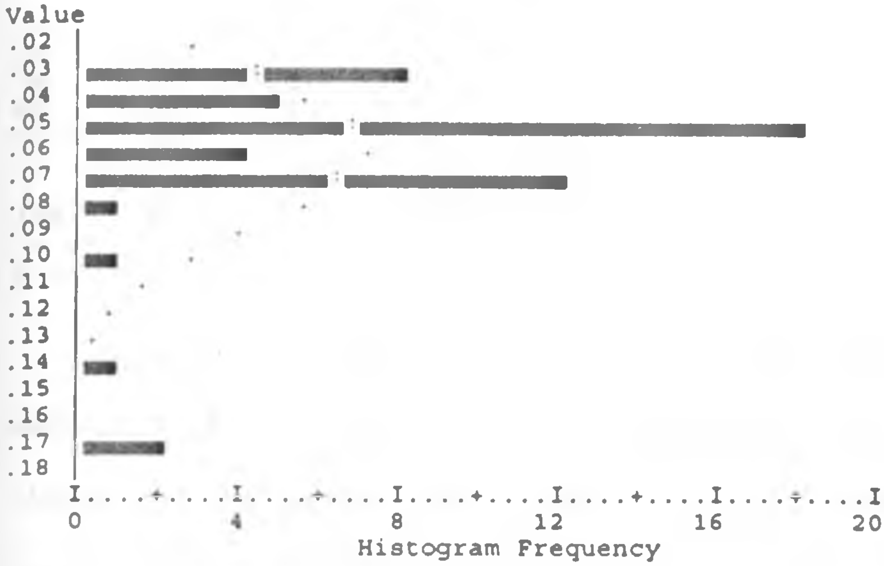


Figure 10s: Frequency Distribution of Albuminoid Ammonia



Free ammonia has a mean of .05mg/l and range between .02mg/l and .01mg/l. Albuminoid ammonia ranges between .03mg/l and .17mg/l with a mean of .06mg/l. The distributions of free ammonia and albuminoid ammonia are shown in figure 10r and figure 10s respectively.

The above frequency histograms show a clear impression of the shapes of the distribution of levels of water quality parameters considered in this study. It is also easy to tell which values occur most often. It is noticeable that most of the values tend to fall in the middle of the distribution. In contrast very high values and very low values tend to fall at the ends. The conclusion that can be drawn from this is that most of the values tend to bunch up in the middle of the distribution.

The table below provides correlation coefficients among the water quality parameters considered in this study.

Table 9: Correlations of Water Quality Parametersy

	DO	TH	MG.	TURB	Cl	F	ANH3
DO	1.00**						
TH	.15	1.00**					
MG	-.03	.94**	1.00**				
TURB.	.11	.39	.33	1.00**			
CL	-.1	-.60**	-.53*	-.67**	1.00**		
F	-.41	-.56*	-.46	-.23	.16	1.00**	
ANH3	.49*	.21	.23	-.01	-.05	-.18	1.00**

N of cases: 24   1-tailed Signif: * - .01   ** - .001

From the table 9, six pearson moment correlation are significantly correlated. The data demonstrates significant correlations between Total hardness and magnesium (0.94, $p<0.001$), chloride and total hardness (-0.60, $p<0.001$), chloride and turbidity (-0.67, $p<0.001$), total hardness and fluoride (-0.56, $p<0.01$), magnesium and chloride (-0.5272, $p<0.01$), and dissolved oxygen and albuminoid ammonia (0.4858, $p<0.01$). The above correlations show that there exists a strong relationship between magnesium and total hardness, while the rest are either moderately or weakly related. Therefore it can be concluded that apart from the correlation between magnesium and total hardness, these correlations are relatively low and consistently bordered on the trivial. Although some correlations are statistically significant, the only supported conclusion from these results is that, the lake water like those in the observed sample a number of the corresponding correlations would be different from zero. These correlations might, however, differ from zero by trivial amounts.

When regression analysis was performed on total hardness against magnesium, chloride and fluoride, the resulting equation was: Total hardness = 112 + 1.06(Magnesium). Appendix 7 contains the results of a multiple regression analysis of total hardness against magnesium, chloride and fluoride.

Figure 11 shows a plot of the data, that is, total hardness against magnesium. The graph

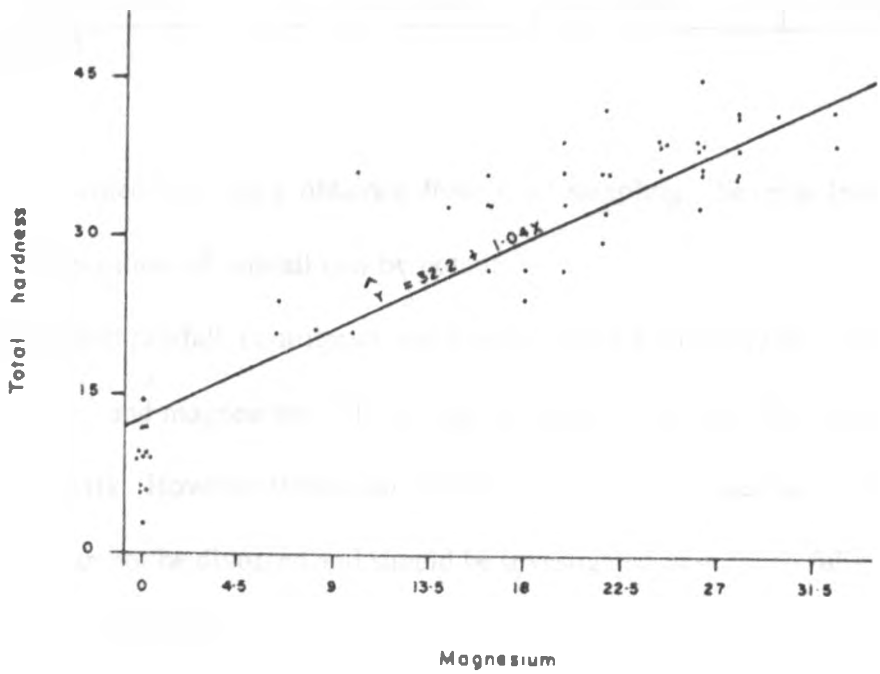


FIG. 11 PLOT OF TOTAL HARDNESS WITH MAGNESIUM

shows an upward-sloping straight line relationship. It shows that about 86% of the variation in total hardness can be explained by magnesium amount in the lake water. Furthermore for each increase in magnesium amount, the amount of total hardness is expected to increase by 1.06.

4.2 CHEMICAL CHARACTERISTIC OF RAINFALL

The chemistry of rainwater (mean values) in the study area are presented in the table below.

Table 10: Quality of Rainwater

pH	Calcium	Magnesium	Chloride	Nitrate
5.7	0.24mg/l	0.096mg/l	17.5mg/l	<0.01mg/l

Source: Field Research

The results presented here were obtained from field sampling. Several features of the study of chemical composition of rainfall can be noted:

1. It is apparent that rainfall contributes significant amount of inorganic salts such as chloride, calcium, and magnesium. These may be related to the soil dust associated with agricultural activity. However the action of wind in transporting the inorganic salts over long distances can not be divorced and should be investigated in order to fully understand major sources of these salts.
2. Trace amounts of nitrates are also present in rainfall, suggesting that these ions are removed by plants for nutritional purposes and are either returned to the atmosphere or enter into the earth-water reactions. The major sources of fixed nitrogen are bound to certain geographical areas overland. Although some nitrogen found in rainwater is attributed to industrial activity and to fertilizers several scholars have concluded that the

formation appears to be primarily bound to the soil.

3. The low pH (5.7) can be explained by the presence of the atmospheric gases mainly carbon dioxide (CO_2) and carbon monoxide (CO). These gases usually come from many sources such as vegetation and the burning of wood fuel. These may also result from industrial activities as well as release by vehicles (mainly in Urban areas). The effect of these may be the problem of acid rain which may result in devastating effects interms of water as well as other aquatic resources in the region.

The above results suggest that although primary attention has generally been given to direct waste discharge, the atmospheric routes such as through precipitation are also significant. As a result Lake Kanyaboli also acts as a sink to atmospheric pollutants. While the primary influence of atmospheric pollution on water quality have always been greatly felt in coastal areas near major Urban centres, atmospheric pollutants may be transported hundreds to thousands of kilometres from the source areas owing to their relatively long residence time.

The relatively high concentration of chloride in precipitation (17.5mg/l) may suggest long distance transport of particles from high temperature anthropogenic sources. This therefore calls for a proper management of the catchment activities so as to reduce such activities which may lead to atmospheric pollution and hence exert an influence in the precipitation quality. As the effect of long distance transport can not be controlled in the same way, studies should be carried out with a view to ascertain their sources.

4.3 RUNOFF QUALITY

Pollutant transport by surface runoff from land surface is probably the most widespread single source of contamination of surface water. In order to fully identify th major pathways by which pollutants reach lake Kanyaboli, water quality studies have been conducted on runoff as a factor in the pollution of this lake. The results obtained in the analysis of runoff water is presented in table 12 below.

Table 12: Quality of Runoff

pH	Fe	Mn	No_3	No_2	NH_3	Tds
5.9	14mg/l	.15mg/l	.05mg/l	.01mg/l	.33mg/l	25mg/l

Source: Field Research

From the table the major point from the data obtained in this study is that water flowing across agricultural land, grazing land, homesteads (including cattle pens) is the most important mechanism in the transport of plant residues, soil particles, salts and nutrients from land into the surface water bodies. This demonstrates the fact that nitrate-nitrogen, ammonia, iron and manganese readily go into solution and can readily be carried by runoff into Lake Kanyaboli. The main sources of nitrate nitrogen in runoff are likely to be animal waste, rainwater and plant materials which the runoff comes into contact with as it moves downslope. The ammonia (.33mg/l) imply mainly anthropogenic sources such as animal waste and plant materials.

It is also important to observe that the level iron is highly elevated in runoff (14mg/l). This imply that runoff dissolve the iron from the catchment rocks as it moves towards the lake. The sources of manganese (.15mg/l) are the same as those of iron as they are closely associated. It is also important to note the change of pH as rain water turns into runoff (from 5.7 to 5.9).

This is explained by the fact that as runoff moves overland it dissolves the alkaline catchment rocks thus changing the value of the pH from acidic to slightly alkaline.

The change of pH may also be explained by other factors other than the dissolution of the rocks (i.e the dissolution of vegetative materials as well as various polluting substances). The low total dissolved solids (25mg/l) reflects the effect of geology. This is just the direct influence of the hard basement rocks of the catchment rocks and their mineral composition and hence can not easily be dissolved by running water.

The analysis of both precipitation (rainwater) and surface runoff suggest that pollutants reach lake kanyaboli from precipitation and surface runoff. As a result precipitation, soil and anthropogenic sources seem to be important sources while other sources such as lithologic sources remains unexplored.

Precipitation in this area is sometimes problematic. In this area safe disposal of runoff flow can be a problem, mainly in the wet season(s), but also during intense storms which may punctuate dry season(s). Precipitation in this area varies from season to season and from year to year. The difficulties caused by temporal variation are exemplified by other rainfall characteristics. In particular, rainfall intensities tend to be high and a considerable proportion of rain is concentrated into a comparatively small number of heavy storms. Much of this type of rainfall does not become available to agriculture.

Instead of contributing to soil moisture reserves which can be used by plants during dry weather, storm water runs over the ground surface causing soil erosion, flooding and pollution. The amount of runoff varies with such factors as soil structure, gradient, and length of slope, rainfall intensity, vegetative cover and antecedent soil moisture content. On the other hand factors controlling pollutant transport include the nature of soil colloids, and of the pollutant as determinants of adsorption-desorption interactions, runoff events, rainfall characteristics, climatic characteristics, landuse and soil management. As such there is an urgent need of proper management of runoff which can best be achieved through farming activities which favour infiltration of runoff as well as through afforestation program in the catchment.

4.4 ASSESSING POLLUTANTS LEVELS IN THE INTERSTITIAL WATER

Considering the low levels of pollutants in the lake water during this study, it would seem that the lake bottom sediments are permanent sink of these pollutants. Therefore the establishment of pollutant levels in interstitial water can play a key role in detecting sources of pollution in the lake. The results of the interstitial water analysis are given in table 12 and summarised in table 13.

It was expected that the concentration of various parameters would be highest where considerable runoff enters the lake. Though this was the case, the data was not definitive, as expected. However the general pattern is present. Three stations (nos 5, 4 and, 12) were located generally away from the influences of runoff discharges and other human activities. Data on the distribution of iron, manganese, phosphorus, nitrates and free ammonia were more definitive. Their mean concentrations at the inner stations (numbers 4, 5 and 12) were 0.23mg/l ,0.05 mg/l, 0, 0 and 0.22mg/l respectively. The concentrations of Iron, manganese, phosphorus, nitrates and free ammonia at the near-shore stations were 0.74mg/l, 0.15mg/l, 0.74mg/l, 0.12mg/l, and 0.93mg/l respectively. As expected, the locations that received runoff from the surrounding settled areas showed higher concentrations of these parameters in the interstitial water.

Table 12: Concentration of each Parameter in Interstitial Water

Parameter	1	2	4	5	6	7	9	10	11	12
pH	6.7	6.7	7.2	6.3	6.5	6.5	6.8	6.3	6.8	6.5
TDS	103	135	99	124	104	105	150	110	124	116
Fe	0.8	0.2	0.2	0.4	0.4	-	1.6	0	0.8	0.1
Mn	0	*	0	0	*	-	0.3	0	0	.05
P	0.8	2.0	0	0	0	-	0.8	0.8	1.2	0
PV	885	104	45	770	320	240	372	64	472	1100
Nitrite	*	*	*	0	0	*	0	*	0	0
Nitrate	.09	*	*	*	.09	-	*	*	.18	*
F/NH_3	.46	.46	.03	.25	.05	.08	4.92	.49	.13	.15
A/NH_3	.85	.33	.08	.52	.25	.16	4.92	.82	.84	.93

* means trace, - means not measured and 0 means not detected

Table 13: Summary of Characteristics of Interstitial Water

Parameter	Mean	Minimum	Maximum
pH	6.6	6.3	7.2
TDS	117.0	99.0	150.0
Fe	0.58	0.1	1.6
Mn	0.175	0.01	0.3
P	1.12	0.80	2.0
PV	437.28	45.50	1100.0
Nitrite	<0.01	-	-
Nitrate	0.12	0.09	0.18
FA	0.7	0.033	4.92
AA	0.9	0.082	4.92

Accumulation of pollutants in the bottom sediments generally leads to their re-mobilization as a result of the physical, chemical, and biological activities in the lake and hence their consequent increase in their concentration in surface water. The frequency distributions of these parameters are shown in figures 12a to 12e below. It is evident from these figures (12a to 12e) that, apart from phosphorus and iron, the values tend to bunch at the extremes as opposed to the middle of the distribution. This reflect the dynamic nature of the pollutants and hence show that they are mainly affected by the permanent characteristics of the lake environment, such as wave action, lake morphometry, and depth of the lake.

Figure 12a: Frequency Distribution of Manganese

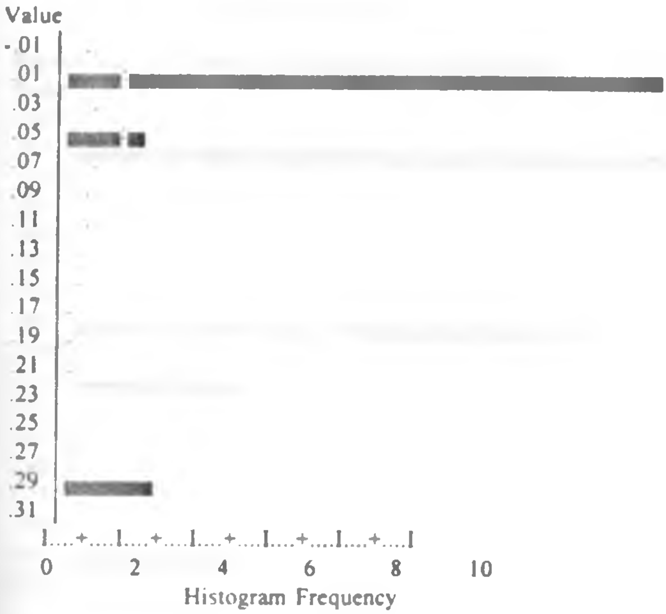


Figure 12b: Frequency Distribution Iron

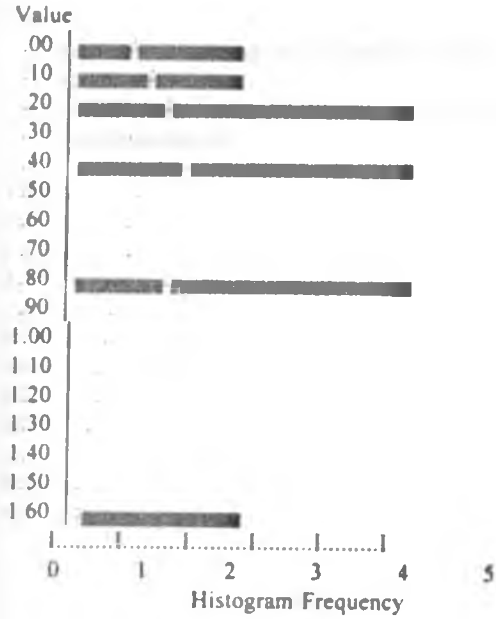


Figure 12c: Frequency Distribution of Phosphorus

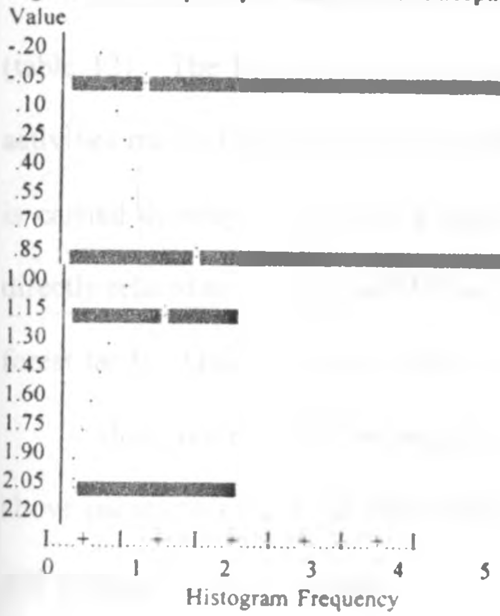


Figure 12d: Frequency Distribution of Nitrate

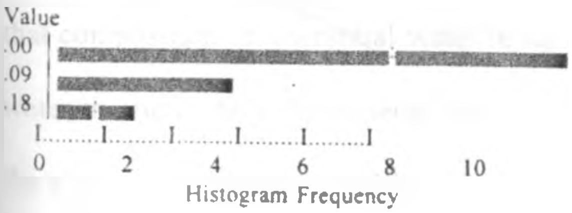
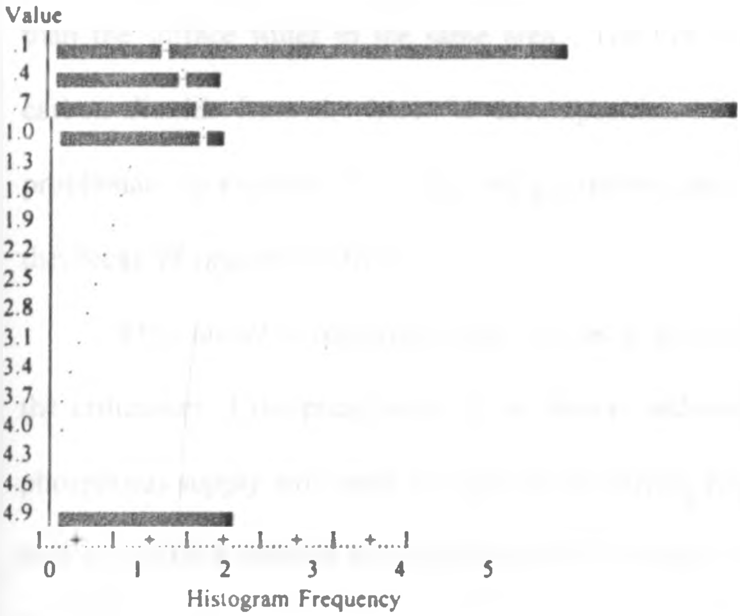


Figure 12e: Frequency Distribution of Albuminoid Ammonia



The presence of pollution parameters in the interstitial water is evident from the data (table 12). The lake catchment is covered with settlement, farming activities, and economic activities most of which are in the vicinity of the lake. Runoff from the catchment in most cases is carried directly to the lake without detention or retention. The origin of nutrients can be directly related to surface runoff from farms, homesteads including cattle pens, grazing lands and forest lands. Other sources of nutrients include direct bathing and washing in the lake.

However most of the origin of other parameters is not clearly defined. However the above parameters reach the lake sediment via 3 routes; precipitation, runoff from the catchment and through seasonal streams.

Because of the processes that take place in the lake bottom, there is little reason to expect that composition of interstitial water in lake sediments be similar to the composition of the lake water through which the material settled or to that of the free lake water above the sediments at the time of sampling (table 14).

From this study it is observed that interstitial water showed higher TDS, and lower pH than the surface water in the same area. The low pH can be attributed to the production of carbon dioxide from the bacterial decomposition of organic matter, but high TDS are more problematic to explain. Ammonia and phosphorus are also enriched in the interstitial water from the decay of organic material.

The content of nutrients in the interstitial water imply that if massive algal growth occurs, the utilization of the phosphorus in the bottom sediment will be affected in the sense that high phosphorus supply will result in algal blooms giving rise to more organic mud. This will further lead to greater formation of methane and thus increased return of dissolved orthophosphate from

Table 14: Comparison of surface water characteristics and interstitial water characteristics

Parameter	Surface Water		Interstitial Water	
	Mean	Range	Mean	Range
pH	7.47	6.7-8 5	6.6	6.3-7.2
TDS	7.08	95-113	117	99-150
Fe	0 17	0-0 6	0 58	0.1-1 6
Mn	0 09	0-0 3	0.175	0.01-0.3
P	0.00	-	1.12	0.8-2.0
PV	4.08	3.5-5.7	437.3	45.5-1100
Nitrite	<0.01	<0 01	<0.01	<0.01
Nitrate	<0 01	< 0 01	0 12	0.09-0 18
AN	0.12	0.02-0.2	-	-
F/NH_3	0.06	0.03-0.47	0.7	0 033-4 92
A/NH_3	0 06	0.03-0.17	0.9	0 082-4 92

Source: Field Research

the interstitial water. However, provided that oxygen is present, the iron at the sediment interface remain in the trivalent, oxidized form. This trivalent form of iron act as a precipitant for the dissolved orthophosphate. A large part of the dissolved inorganic phosphate is thus chemically fixed as iron (III) phosphate or is absorbed on precipitated iron (III) hydroxide.

The results also indicate that iron and manganese have accumulated to high concentrations in the bottom sediments, although for the time being, they are relatively harmless. Since the basin in question is sparsely populated, predominantly rural, contains no major industrial development and covered with the secondary vegetation, these data suggest that the contribution of iron and manganese is primarily geologic in origin. However changes in the overlying water conditions may result in new-sediment water equilibria, and affect the mobilization of these metals.

Various mechanisms of metal mobilization have been proposed, for example diffusion, adsorption, dissolution, redox reaction, complex formation, biological effects, or physical disturbance. Remobilization of these metals from sediments is potentially hazardous for the aquatic ecosystem and for drinking water supply.

4.5 RELATION OF THE LAKE WATER QUALITY TO VARIOUS USES

The purpose of this objective is to relate the levels of potential pollutants in the lake water to water quality criteria and standards established for the protection of beneficial uses, including the rationale underlying the qualitative limitations imposed on the various quality factors. Hopefully, by this comparison of lake Kanyaboli water quality to legitimate water-uses, one may have a reference by which to measure the magnitude of the pollution problems identified in this study.

The principal beneficial uses of water considered are listed below.

a) domestic water supplies;

b) Industrial water supplies;

c) Fish and other aquatic life;

d) livestock watering; and

e) Recreation and aesthetics.

4.5.1 Domestic Water Supplies

Mainly quantitative limits are used in this case. There are mainly two types of such limits.

1. Mandatory limits - These are limits which if exceeded, shall be ground for rejection of the supply having adverse effects on health; and

2. Recommended limits - These are limits which should not be exceeded whenever more suitable supplies are available at reasonable costs. Substances in this category when present in concentrations above the limits, are either objectionable to an appreciable number of people or exceed the levels required by good water quality control practices. The parameters that are discussed below are only those that either exceed the set limits or those that occur in slightly elevated limits.

a) Turbidity

Five units are the recommended limit. The major consideration is an aesthetic one, and that of consumer acceptance. The lake water show very high values (up to 18mg/l) and although varying turbidities must be expected with high turbidities occurring during high flows. But generally turbidity should not be considered a major problem since it can readily be removed by conventional water treatment.

b) Colour

Recommended limit is 15 units. Consumer acceptance and aesthetics are given the major considerations. While not a health risk, colour which is not removed by coagulation and filtration may react with chlorine to give trihalomathanes. Generally colour values higher than the recommended have been reported in all sampling points in lake Kanyaboli (40mg/l to 90mg/l). However the problem is not of major importance since conventional water treatment will adequately reduce colour.

c) Iron

Recommended limit is 0.3mg/l based on aesthetic problems. Objectionable in drinking water due to the staining of laundry/ plumbing fittings and unacceptable taste. Iron deposits in distribution systems reduce the flow and promote both microbial growth and biological activity. Changes in flow patterns are likely to cause several water quality problems. The levels reported in some stations are above recommended limits and may present some problems thus require some treatment before use (the reported values range between 0.06mg/l to 0.6mg/l).

d) Manganese

Recommended limit is 0.05. Standards are based upon considerations of staining properties of manganese, the aim being to keep concentrations of soluble form to minimum. Manganese levels above 0.05 produce unsightly staining of laundry goods and plumbing fittings and can impart an unpleasant taste to drinking water. Although manganese is highly toxic to human, it presents no known health problems at levels reported in lake Kanyaboli. However most values are above the recommended limits (mean for the whole lake is 0.12mg/l). In addition, manganese is not removed by conventional methods of treatment.

e) Phosphates

Causes algae blooms, tastes and odours, slime growth and may adversely influence the coagulation process. However this was not detected on the surface water.

f) Nitrates

45 mg/l is the recommended limit. This is due to possibility of infantile nitrate poisoning. It is usually not removed by conventional treatment. However the levels indicated by the study are below the recommended level (trace) and therefore present no health risk.

In general the water quality factors in Lake Kanyaboli considered most significance to domestic water supplies are iron, manganese, colour and turbidity. While technology is available to remove or to reduce the concentrations of these constituents, only colour and turbidity can be effectively removed by what is currently considered conventional water treatment processes within the range of economic feasibility.

Quality factors considered of secondary significance, primarily because their effects are presently difficult to assess, are nitrates and phosphates. Again removal of these constituents is not effective by conventional treatment means.

Evidence indicates that the remainder of the potential pollutants discussed in this study are not serious water quality degradation factors for domestic water use because of their low concentrations.

4.5.2 Industrial Supplies

The quality requirement for industrial water supplies range widely, and almost every industrial application has different standards as pointed out by Hem (1959). Water is used as an ingredient with other raw materials in the finished products, as a buoyant transporting medium, as a cleansing agent, as a coolant and as a source of steam heating and power production.

It is not the main aim of this study to quote many physio-chemical quality standards for industrial water because of the wide variation from industry to industry. Further the study does not emphasize the specialized needs of specific types of industry, but only present facts and interpretations of a general nature that can be further studied by those who have specialized requirements.

Appendix 4b and 4c give water requirements for certain industrial uses. These requirements essentially state that such waters shall be free from objectionable settleable, floatable, toxic substances, colour and odour, and other nuisances.

Iron and manganese are above the recommended limits and may thus adversely affect industrial uses. However removal by special treatment is possible although may be costly.

Colour and turbidity are also above recommend limits for many industrial uses as levels reported in this study range from 0.06 to 0.6mg/l and 0.02 to 0.12mg/l for iron and manganese respectively. On the other hand colour and turbidity can readily be removed by conventional treatment.

In conclusion, industry that is likely to use lake Kanyaboli water will have to treat the available supplies in accord with specific their needs. Fortunately, water treatment technology available today permits use of water supplies of almost any quality to produce water suitable to a given industrial use, and while the cost of such treatment may be high, it is usually a small part of the total production and marketing costs.

4.5.3 Fish and Other Aquatic Life

The problem is more complex since it involves not only changes in water quality, but also changes in quality of the ecological system affected. Different concentrations of various compounds or elements will affect different wildlife species in a variety of ways. Also the concentration of a given chemical quality required to produce a toxic or lethal effect on the adult of a species may be considerably more than the concentration required to produce the same effect on the young of that species.

Pertinent water quality requirements for maximum fish production have been published by FWPCA (1962). These include pH from 6.0 to 9.0; dissolved oxygen above 5mg/l; dissolved solids upto 3000mg/l provided that non is toxic and all are physiologically balanced; turbidity values not over 50 units; carbon dioxide not above 30mg/l; ammonia not over 1.5mg/l; fluorides not over 100mg/l; nitrates and phosphates not toxic; calcium; magnesium; sodium; sulphate; and chlorides apparently not toxic in normal conditions.

Adverse water quality may interfere with the migration of fish, kill them, create pathological conditions, interfere with spawning, or with the production of an adequate food supply. Of the parameters considered in this study, non occur in concentrations sufficiently great to be toxic to fish or to other components of the aquatic ecosystem.

However both nitrates and phosphorus concentrations must be considered with great caution because of the difficulty to asses them and given the fact that their concentrations in the bottom sediments are just enough to cause algal bloom. Since they serve as nutrients particularly in the production of plants, their enrichment can yield startling results. This may cause increased production which may have deleterious effects on the habitat and food organisms of fish. High levels of these nutrients favour growth of sphaerotilus, algae and rooted aquatic plants.

The results of the study also show that there is continuous organic loading. As a result when organic loading is increased, it can also serve as a nutrient. Organic materials has a direct effect on the production of such bacteria as sphaerotilus which are nourished directly on dissolved organic. An increased production in the lake may choke the water with plant materials and debris. Subsequent oxidation of plant material may decrease oxygen concentration in water. Once oxygen concentration is reduced in the water, decomposition of organic material produced by the enrichment will continue anaerobically and may result in release of such noxious gases as hydrogen sulphide, which is toxic to a variety of aquatic organisms.

Increased production of vegetable material may results in production of certain species of algae which produce toxins as secretions that may be to invertebrates alike. Invertebrates population in water may be changed in diversity by certain algae. Many invertebrates are sensitive to decrease in dissolved oxygen concentration in the water and where nutrient enrichment is not uncommon. When such a change occurs in the environment the vertebrates with high oxygen requirements are eliminated from the system and replaced by invertebrates of lower oxygen requirement, thereby changing the ecological system and affecting the species feeding upon the invertebrates.

This effect of enrichment on animal community also occurs among plants. Enrichment induces changes in the production of plants including algae. Optimum range of nitrate concentration for aquatic plant production is between 0.9 and 3.3mg/l; for phosphate between 0.9 and 0.18mg/l. In this study, nitrate in the interstitial water is reported to range between 0.09 and 0.18mg/l while values ranging between 0.8 and 2.0mg/l of phosphorus is reported for interstitial water.

4.5.4 Livestock

The tolerance of animals to salt and other pollutants in water depends on many factors, such as species, age, physiological condition, content of the feed, as well as the kinds and amounts of salts. However water to be used by stock is subject to quality limitations of the same type as those relating to quality of drinking water for human consumption. Apparently animals can tolerate more salt than can humans and vary intolerance to different substances. A tentative guide for evaluating the quality of water for livestock is given in appendix 4. Of the parameters considered in this study none seems to occur in concentrations sufficiently great to be toxic to livestock.

4.5.5 Recreation and Aesthetic

Recreational uses of water as discussed here refers primarily to water contact activities including swimming, wading, skin diving, boating, shoreline activities, and aesthetic enjoyment. but not fishing. Water quality criteria for recreational uses have been limited and either vary generally and quantitatively in nature based on arbitrary assumptions. Appendix 4e gives guideline values for aesthetics and recreation.

In this study only colour and turbidity concentration are above the guideline values. These parameters potentially have serious adverse effects on body contact activities and aesthetic appeal. In the study it has been found that the lake is organically polluted and this may also have a negative bearing on both aesthetic activities as well as recreational activities. As a result it can be said that there is an urgent need for systematic surveillance on traditional sanitary standards to include aesthetic qualities of waters and waste sources to make effective use of criteria practice. It is noted that the management of water for aesthetic purposes must be planned and executed in the context of landuse, near-shore activities and water surface.

4.6 IMPLICATION OF THE RESULTS

In general the lake appears to manage a certain amount of pollution control, the question is raised as to how this is accomplished. Some possible factors are suggested below:

1. There is also the possibility of pollutants adsorption by silt in the lake bottom and in suspension.
2. Given the fact that lake Kanyaboli is surrounded by a thick mass of papyrus vegetation,

the papyrus vegetation itself function during the rains and in the interception of runoff from adjacent high ground as is subsequently discussed. During the hydro-period, the papyrus vegetation is receiving silt, organic wastes and toxic chemicals from agricultural and domestic wastes. Thus it is suspected that the papyrus swamp vegetation process or treats these materials, releasing them slowly to both the biota community and the lake.

However the reason for low pollutant levels and yet high permanganate value (PV) indicates that the lake is naturally susceptible to pollution. This can be attributed to shorter residence time, shallow water and climate of the area (interms of long sunshine hours, evaporation, wind direction e.t.c). As a result when the incoming polluted water from the catchment is retained for a short time period, the polluted water has a shorter time for purification by biological and physical processes in the lake. This further suggests that in an extreme case where there is no purification in the lake, the lake water quality would be as polluted as the incoming polluted water.

Lake Kanyaboli is shallow and as a result has a small volume of water and as such the effect of polluted bottom sediments may be high. Further the climate of area (tropical climate) implies high production in the lake due to high temperature and high photosynthetic oxygen production, which is reflected in relatively high dissolved oxygen values reported for the lake.

It has also been noted that water quality parameters of ammonia nitrogen, free ammonia, albuminoid ammonia and PV show a sign of water pollution in lake Kanyaboli. Their analysis further implied that the lake is mainly polluted by manurial and vegetable matter, suggesting that human activities are the main contributors.

Lake sediments have been identified as a source of nutrients, iron and manganese to the underlying water. The physical, chemical and in particular, the biological processes that occur at the mud water interface have been implicated in the release and removal of nutrients. All the above processes play a role in sediment-water pollutant interchange and the importance of each will depend on the individual sediment and the basin in question.

Ammonia has been shown to be generally the most abundant form of inorganic combined nitrogen present in the interstitial water of the sediments. It results from the excretion and from the bacterial deamination of amino acids, proteins and other nitrogenous compounds. Nitrate like other soluble nutrients can be lost from sediments by diffusion into overlying water. It can also undergo reduction to molecular nitrogen (denitrification by bacteria) when oxygen is absent or at least limiting through microbial respiration.

Bacteriological action is probably the most important process causing nutrient transformations in sediments. Bacteria are known to be plentiful in surface sediments and their abundance decreases with depth. The environmental variables such as temperature, pH, redox potential, oxygen content, hydrogen sulphide content, and other physical and chemical variables greatly influence the growth of these organisms and must be taken into account when assessing their activity in sediments. The activities of animals are also significant in sediment are also significant in sediment-water interchange. Benthic organisms physically alter the sediment by their activities and life processes. Their activities greatly enhance the exposure of the interstitial water to the water overlying the sediments.

Therefore the above results indicate that soluble nutrients such as phosphate and ammonium bound in sediments can become available for algal growth by diffusion into the overlying water. Various physical processes which cause waterflow over the sediment or result in sediment being resuspended can greatly increase the rate of nutrient release.

4.7 SUMMARY OF FINDINGS

i) The levels of albuminoid ammonia, free ammonia and permanganate value imply that the lake is mainly polluted by organic materials. The levels of colour, turbidity, iron, and manganese are also elevated.

ii) Nitrate is below the minimum detectable limit while phosphorus was not detected in surface water.

iii) It is significant that precipitation can no longer be ignored as a source of pollutants at least judging from the above results.

iv) The concentration of most of the parameters considered in this study compares well with the recommended standards and guideline values for various uses.

vi) Higher concentration of pollutants were found in interstitial water than surface water.

vii) Analysis of interstitial water has additionally proved useful as a screening device for detection and identification of pollutants not really detected by the analysis of surface water.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The previous chapter has outlined the levels of pollutants generated mainly by the currently prevailing domestic and agricultural activities, through runoff, river water and precipitation.

High level of ammonia forms and permanganate value reported by the study imply that the lake suffer from manurial and vegetable matter pollution. This suggests that human activities are the major contributors. The study further identified precipitation and surface runoff as the main pathways of pollutants into the lake.

The analysis of interstitial water showed that the bottom sediments are the main sources of nutrients, iron and manganese to the underlying water. More importantly, the study reported nutrient levels in interstitial water that are enough to cause eutrophication.

Thus the water quality characteristics considered in this study provides a valuable insight into certain functional relations and processes occurring within the lake system. Thus this knowledge must be placed in perspective with the unique characteristics of the system concerned and the implementation of cost-effective and environmentally sound management approaches.

5.2 RECOMMENDATIONS

As a result of the above findings, the following recommendations have been suggested.

5.2.1 Recommendations to Policy Makers

i) Implementation of a program of public education aimed at ensuring a proper understanding of factors affecting the development and use of water resources and a sense of responsibility in relation to these matters. This will encourage their movement toward the control of these pollution loads.

ii) Effective measures should be worked out to reduce pollutant loads by effluent from such activities such as fishing, temporary markets and hotels within the lakeshore.

iii) Support should be given for the voluntary program for controlling agricultural runoff, and considerations should be given to providing incentives to improve participation in the program if such a need becomes apparent.

iv) Better control of runoff from animal pens and homesteads should be achieved.

v) Forest practices in the catchment should be reviewed and clear cutting of the vegetated areas in close proximity to the lake and major catchment areas should be discouraged.

vi) A mechanism is needed to integrate data from diverse sources, test management alternatives, facilitate communication and point up where additional evaluation is required.

vii) Encouragement of an active interest and involvement of the local community in planning and management of water resources.

5.2.2 Recommendations for Future Researchers

i) High priorities should be given to the identification of sources of pollutants entering the lake. Analysis of such contaminants sources should provide recommendations for reducing activities which contribute disproportionate quantities of pollutants to the lake.

ii) An investigation of mass balance of the lake water should be carried out. The study should place emphasis on precise evaluation of runoff from the catchment areas, assessment of the input/output of water to and from the lake and estimation of the rate of evaporation.

iii) Studies should also be carried particularly on nutrient inputs by evaluating various components of the total inputs and their relevance and evaluating pathways such runoff, dry deposition, river inputs and ground water.

iv) For effective strategies of pollution control, more attention has to be paid as to the dynamic of pollutants distribution, and in particular to their relative stabilities within interim storage sites.

v) Present conditions of facilities affecting the water environment such as sewage facilities in small Urban and market centres and sanitary facilities in rural area should be evaluated. Effects of these facilities on the lake should be quantitatively evaluated.

vi) The results show that the lake suffers from organic pollution. This calls for monitoring of the bacteriological quality of the water draining into the lake.

vii) The behaviour of pollutants in this lake (i.e surface water and bottom sediment) has not been studied. A research is strongly needed since such a lake is a major ecological unit and, compared with other ecological units in the hydrologic cycle are more subject to stress imposed by man.

Viii) In order to reflect the current quality of the lake and the historical development of certain hydrological and chemical parameters, comprehensive studies should carried out to analyze sediments.

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APPENDICES

The appendices consists of eight tables. Appendix 1 provides information on water quality characteristics of both the northern and the southern sections of The lake. Appendix 2 provides data on water quality characteristics from various sources. Reference are made on these tables in the section of levels of potential pollutants. In addition appendix 3 provides data on depth measurements of various sampling stations. These measurements were taken during the study. This information is useful since it points precisely to where the bottom sediments was sampled.

Appendix 4(a) to appendix 4(e) provides water quality standard and guidelines for various water uses. References have been made to these tables in the main text on the section on relation of lake Kanyaboli water quality to various uses.

Appendix 5(a) to appendix 5(d) provides the results of water sample analysis before any statistical analysis is performed. Lastly appendices 6 and 7 provides formulae and results of regression analysis respectively.

Appendix 1: Physio-chemical characteristics of Southern and Northern section of the lake

Parameters	Northern	Southern
pH	7.6	7.8
Colour	64.4	68.0
DO	6.5	8.0
TA	20.5	22.4
TH	16.6	28.4
Ca	12.0	10.0
Mg	21.1	22.4
Turb	14.2	14.4
Cl	27.7	25.6
F	0.07	0.06
PV	4.05	4.01
Fe	0.16	0.27
Mn	0.13	0.08
Nitrate	Trace	Trace
Nitrite	0.06	0.08
AN	0.12	0.13
F/NH3	0.08	0.04
A/NH_3	0.06	0.06
PO_4	0.00	0.00
TDS	106.50	109.20

Source: Researcher

Appendix 2: Quality of water from various sources

Parameter	Lake Kanyaboli	River Yala	Runoff	Rainfall
pH	7.6	7.1	5.9	5.7
Colour	65.8	1278.0	-	-
DO	7.1	11.3	-	-
TA	21.2	44.5	-	-
TH	21.2	36.0	-	-
Ca	12.3	3.5	-	0.24
Mg	21.6	33.0	-	0.096
Turb	14.3	88.0	-	-
Cl	26.7	7.8	-	17.5
F	0.07	0.09	-	-
PV	4.04	8.50	-	-
Fe	0.22	2.9	14.0	-
Mn	0.12	0.3	0.15	-
Nitrate	Trace	0.6	Trace	trace
Nitrite	0.06	-	Trace	-
A/N	0.12	-	0.33	-
F/NH_3	0.06	-	-	-
A/NH_3	0.06	-	-	-
PO_4	0.00	0.2	0.00	-
TDS	107.5	74.9	25.0	-

Source: Researcher

Appendix 3: Depth of various sampling stations

Station	Depth (m)
1	1.80
2	1.75
4	1.65
5	3.30
6	2.00
8	2.25
9	1.10
10	1.50
11	1.85
12	2.35

Source: Researcher

Appendix 4(a): Maximum acceptable levels in water used for domestic consumption

Parameter	Level
pH	6.8 - 8.5
Colour	< 15 TCU
Turbidity	< 5 NTU
Total alkalinity	> 30 mg/l
Total hardness	-
Calcium	< 200 mg/l
Magnesium	< 150 mg/l
Sodium	< 270 mg/l
Aluminium	-
Chloride	< 250 mg/l
Fluoride	< 1.5 mg/l
Nitrite	< 1 mg/l
Sulphate	< 500 mg/l
Phosphate	< 0.1 mg/l
Total suspended solids	None
Total dissolved solids	< 500 mg/l
Zinc	< 5 mg/l
Iron	< 0.3 mg/l
Manganese	< 0.05

Source: WHO, 1982

Appendix 4(b): Guideline values for chemical and allied industries

Parameter	Level
pH	6.5 - 8.5
Colour	< 20 TCU
Total alkalinity	< 150 mg/l
Total hardness	< 250 mg/l
Calcium	< 50 mg/l
Magnesium	< 25 mg/l
Iron	< 0.3 mg/l
Manganese	< 0.05 mg/l
Silica	< 50 mg/l
Sulphate	< 250 mg/l
Total suspended solids	< 15 mg/l
Total dissolved solids	< 750 mg/l

Source: Hem, 1959

Appendix 4(c): Guideline values for food processing industries

Parameter	Level
pH	6.5 - 8.5
Colour	< 20 TCU
Turbidity	-
Total alkalinity	< 150 mg/l
Total hardness	< 150 mg/l
Iron	< 0.2 mg/l
Manganese	< 0.2 mg/l
Silica	< 50 mg/l
Total dissolved solids	< 500 mg/l
Total suspended solids	< 10 mg/l
Chloride	< 250 mg/l
Fluoride	< 1 mg/l

Source: Hem, 1959

Appendix 4(d): Guideline values for water used for livestock consumption

Parameter	Level
pH	5.6 - 9.0
Total dissolved solids	< 5000 mg/l
Calcium	< 1000 mg/l
Sodium	< 1000 mg/l
Magnesium	< 2000 mg/l
Total hardness	< 500 mg/l
Chloride	< 3000 mg/l
Fluoride	< 6 mg/l
Nitrate	< 400 mg/l
Nitrite	none
Sulphate	< 500 mg/l
Cadmium	< 5 mg/l

Source: McGauhey, 1968

Appendix 4(e): Guideline values for recreation and aesthetics

Parameter	Water contact	Aesthetic
pH	6.0 - 10.0	6.0 - 10.0
Visible solids	none	none
Dissolved solids	-	-
Suspended solids	< 100 mg/l	< 100 mg/l
Turbidity	< 50 NTU	-
Colour	< 15 TCU	< 100 TCU
Odour number	< 256	< 256
Temperature	< 50	< 50

Source: McGauhey, 1968

Appendix 5(a): Water quality characteristics on 15/2/93

Parameter	1	2	3	4	5	6	7	8
DO	7	6	6	7	6	7	6	7
pH	7.2	7.1	6.7	7.2	7.2	7	7.2	7.2
Colour	60	65	55	65	70	65	65	70
TA	16	14	34	20	14	16	14	12
TH	8	10	14	22	38	38	28	38
TDS	110	112	110	110	110	110	110	106
Ca	14	10	12	14	10	14	10	12
Mg	0	0	0	8	28	24	18	26
Turb	5	6	4	6	4	18	4	12
Cl	25	25	24.5	23.5	22.5	17.5	23	21.5
F	.05	.09	.1	.07	.05	.08	.09	.06
Pv	4.1	3.7	4.3	3.9	3.7	3.5	4.1	4
Fe	.1	.1	.04	.1	.2	0	.6	.1
Mn	.15	.05	.1	.2	.05	.05	.05	.05
No3	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
No2	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
NH3	.06	.1	.09	.17	.07	.08	.03	.1
FNH3	.03	.08	.03	.07	.47	.1	.05	.05
ANH3	.03	.05	.05	.03	.1	.05	.07	.07
P	0	0	0	0	0	0	0	0

Source: Researcher

Appendix 5(a) continued...

Parameters	9	10	11	12	13
DO	6	8	7	12	7
pH	7	7	7.2	7.1	7.2
Colour	70	70	65	70	65
Total Alkalinity	20	10	14	24	12
Total Hardness	40	34	32	38	42
TDS	110	108	110	107	108
Calcium	14	10	12	14	14
Magnesium	26	14	20	24	28
Turbidity	12	10	5	10	40
Chloride	23.5	22	24.5	22	24
Fluoride	.06	.05	.07	.04	.06
PV	4	4.1	3.5	3.5	3.9
Iron	.6	.1	.2	0	-
Manganese	0	.2	0	.2	-
Nitrate	<.01	<.01	<.01	<.01	<.01
Nitrite	<.01	<.01	<.01	<.01	<.01
NH3	.09	.13	.13	.2	.17
ANH3	.03	.03	.05	.17	.05
FNH3	.07	.03	.08	.05	.05
P	0	0	0	0	0

Source: Researcher

Appendix 5(b): Water quality characteristics on 5/3/93

Parameter	1	2	3	4	5	6	7	8
DO	7	7	7	7	6	6	7	7
pH	7.9	8.5	7.8	7.6	8.4	8.1	7.7	7.9
Colour	65	70	55	70	60	55	65	65
TA	24	16	36	16	16	12	10	18
TH	10	10	4	20	42	36	26	42
TDS	110	110	110	111	109	111	112	108
Calcium	16	12	14	10	10	16	10	12
Magnesium	0	0	0	10	32	22	20	30
Turbidity	6	7	4	12	4	20	8	14
Chloride	28	27	24.5	23.5	24.5	16	22	24.5
Fluoride	.06	.1	.1	.05	.04	.07	.1	.04
PV	4.7	3.6	4.2	4.3	4.3	4.2	3.5	5.7
Iron	.2	.1	.2	.1	.4	.1	.4	0
Manganese	.15	.2	0	.2	.2	.05	.2	.2
Nitrate	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Nitrite	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
NH3	.09	.07	.09	.15	.17	.07	-	.13
ANH3	.05	.07	.05	.07	.07	.03	.05	.07
FNH3	.03	.03	.03	.03	.03	.03	.05	.03
P	0	0	0	0	0	0	0	0

Source: Researcher

Appendix 5(b) continued...

Parameter	9	10	11	12	13
DO	6	12	6	8	7
pH	8.5	7.6	8.3	8.0	8.4
Colour	70	70	65	70	70
Total Alkalinity	22	10	16	22	14
Total hardness	42	36	34	36	40
TDS	112	113	110	110	109
Calcium	14	10	8	16	10
Magnesium	28	10	16	22	32
Turbidity	10	8	4	12	3
Chloride	21.5	22	22.5	20	22
Fluoride	.06	.04	.05	.04	.08
PV	4.2	4.1	4.0	4.1	4.7
Iron	.6	0	.03	0	.03
Manganese	.1	.05	.1	.1	Trace
Nitrate	<.01	<.01	<.01	<.01	<.01
Nitrite	<.01	<.01	<.01	<.01	<.01
NH3	.08	.11	.15	.07	.14
ANH3	.07	.05	.05	.07	.07
FNH3	.03	.03	.03	.03	.03
P	0	0	0	0	0

Source: Researcher

Appendix 5(c):water quality characteristics on 14/4/93

Parameter	1	2	3	4	5	6	7	8
DO	6	8	6	7	6	7	6	6
pH	7.4	7.6	8.1	7.4	7.3	7.5	7.3	7.3
Colour	-	-	-	-	-	-	-	-
TA	14	16	36	22	16	18	16	16
TH	6	12	6	24	36	36	32	36
TDS	95	97	95	95	95	97	95	95
Ca	16	8	12	16	12	16	8	10
Mg	0	0	0	6	26	28	18	28
Turb	7	5	4	14	5	18	`3	14
chloride	27	23	22.5	21.5	30.5	17	21	19.5
F	.04	.1	.1	.07	.04	.08	.07	.08
PV	4.3	3.9	4.0	3.7	3.9	3.5	3.7	4.7
Fe	.2	.4	.06	0	0	.1	.2	.1
Mn	.05	.05	.1	0	.05	.05	.2	0
No3	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
No2	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
NH3	.07	.13	.07	.13	.08	.07	.2	.07
ANH3	.05	.06	.05	.04	.07	.04	.05	.07
FNH3	.03	.05	.03	.07	.03	.07	.05	.06
P	0	0	0	0	0	0	0	0

Source: Researcher

Appendix 5(c) continued....

Parameter	9	10	11	12	13
Dissolved Oxygen	7	6	7	8	7
pH	7.6	7.3	7.5	7.4	7.4
Colour	-	-	-	-	-
Total Alkalinity	22	8	16	28	16
Total Hardness	40	36	32	42	40
TDS	95	95	95	95	95
Ca	16	8	10	10	16
Mg	24	16	22	26	26
Turbidity	14	12	6	10	5
Chloride	23.5	20	26.5	22	22
Fluoride	.08	.04	.09	.04	.04
Permanganate value	4.1	4.0	3.7	3.7	4.1
Iron	.5	.05	.1	.6	-
Manganese	0	.2	.1	.025	-
Nitrate	<.01	<.01	<.01	<.01	<.01
Nitrite	<.01	<.01	<.01	<.01	<.01
Ammonia	.07	.15	.11	.07	.2
Albuminoid ammonia	.04	.05	.05	.17	.05
Free ammonia	.03	.02	.05	.03	.05
P	0	0	0	0	0

Source: Researcher

Appendix 5(d): Water quality characteristics on 28/4/94

Parameter	1	2	3	4	5	6	7	8
DO	8	7	6	7	6	10	6	8
pH	6.9	7.4	6.9	7.3	7.3	7.4	6.9	7.6
Colour	-	-	-	-	-	-	-	-
TA	12	10	32	22	10	18	16	14
TH	8	12	6	22	36	42	26	36
TDS	100	100	100	100	100	100	100	100
Ca	10	12	10	16	8	10	12	14
Mg	0	0	0	6	26	22	16	20
Turb	7	6	4	4	4	16	5	10
Cl	25	25	26.5	25.5	22.5	19.5	26	20.5
F	.05	.07	.1	.09	.07	.09	.1	.06
PV	4.5	3.5	4.5	4.5	4.1	4.3	3.9	5
Fe	0	.2	.1	0	.2	0	.4	0
Mn	.05	.1	.2	0	.1	.05	.15	.1
No3	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
No2	.02	.05	.12	.05	.1	.04	.05	.01
NH3	.08	.1	.13	.17	.13	.08	.2	.1
ANH3	.03	.06	.05	.06	.08	.04	.07	.07
FNH3	.03	.08	.03	.03	.47	.1	.05	.04
P	0	0	0	0	0	0	0	0

Source: researcher

Appendix 5(d) continued...

Parameter	9	10	11	12	13
DO	6	8	7	10	7
pH	7.3	7.4	6.9	7.6	7.4
colour	-	-	-	-	-
Total Alkalinity	16	12	10	22	18
Total Hardness	38	32	30	36	46
TDS	100	100	97	100	100
Calcium	16	12	10	16	16
Magnesium	20	16	22	24	26
Turbidity	14	10	5	8	4
Chloride	20.5	25.5	24.5	24	28
Fluoride	.04	.07	.07	.04	.08
Permanganate Value	4.1	4.2	3.8	3.9	4.5
Iron	.06	.1	0	.4	0
Manganese	0	0	.15	.15	0
Nitrate	<.01	<.01	<.01	<.01	<.01
Nitrite	<.01	.02	.12	<.01	<.01
Ammonia	.08	.13	.13	.2	.17
Albuminoid ammonia	.04	.03	.05	.14	.06
Free ammonia	.04	.04	.04	.05	.03
Phosphorus	0	0	0	0	0

Source: Researcher

Appendix 6

The Mean

This is symbolically expressed as:

$$\bar{X} = \Sigma x/n$$

Where:

$\bar{x}$ = Sample mean

Σx = Summation of individual observations

Σ = Summation sign

n = Number of observations

Mean Deviation

This is given by:

$$\text{Mean deviation} = \Sigma(x-\bar{X})/n$$

Where:

x = An observation value

$\bar{X}$ = Mean of the observations

n = Number of observations

Standard Deviations

This is a measure of variability. It is usually expressed by:

$$S = \sqrt{\Sigma(x-\bar{X})^2/n-1}$$

Where:

S = Sample standard deviation

x = Value of each of the n observations

$\bar{X}$ = Mean of the sample

n = Number of observations

Correlation Analysis

This concept of correlation analysis concerns the relationship among variables. It is usually given by the formula:

$$r = \frac{\Sigma XY-(\Sigma X)(\Sigma Y)/n}{\sqrt{(\Sigma X^2-(\Sigma X)^2/n)(\Sigma Y^2-(\Sigma Y)^2/n}}$$

Where:

r = Pearson correlation

X, Y = Variables

n = Number of observations

3.4.4.2 Regression Analysis

Regression analysis may be defined as the analysis of relationship among variables. The relationship is expressed in the form of an equation connecting the response or dependent variable y, and one or more independent variables x_1, x_2, ..., x_p. In this case the regression equation takes the form:

$$Y = b_o + b_1x_1 + b_2x_2 + \ldots + b_px_p$$

where b_o, b_1, b_2, ..., b_p called the regression coefficients are determined from the data. A regression equation containing only one independent variable is called a simple regression equation. An equation containing more than one independent variables is referred to as a multiple regression equation.

Appendix 7: Results of Regression Analysis

Variable(s) Entered on Step Number
1.. MG Magnesium

Multiple R	.92883
R Square	.86272
Adjusted R Square	.85998
Standard Error	4.63717

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	6756.88934	6756.88934
Residual	50	1075.16835	21.50337

F = 314.22471 Signif F = .0000

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
MG	1.05795	.05968	.92883	17.726	.0000
(Constant)	11.21911	1.17421		9.555	.0000

Variables not in the Equation

Variable	Beta In	Partial	Min Toler	T	Sig T
CL	-.07017	-.17637	.86735	-1.254	.2157
F	-.09236	-.23495	.88841	-1.692	.0970