SOME ASPECTS OF HYDROCHEMISTRY, LAKE LEVEL AND VEGETATION DYNAMICS IN THE LAKE ELEMENTEITA BASIN, RIFT VALLEY, KENYA

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DECLARATION

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

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This thesis has been submitted for examination with my approval as the University supervisor.

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DEDICATION

THIS WORK IS DEDICATED TO MY MOTHER
MARY WANJIKU AND MY FATHER GEOFFREY
MWANGI MWANIKI FOR ALL THEY HAVE
DONE FOR ME

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ABSTRACT

Some aspects of water chemistry, vegetation structure and water level fluctuations of the Lake Elementeita drainage basin in Kenya's Rift Valley were studied. The analysis of water samples showed that the lake was highly alkaline and saline. Total alkalinity and electrical conductivity of 3832 mg $CaCO_3$/l and 12842 µS/cm respectively in the lake was 60-70 times higher than in rivers of the catchment and resembled conditions of other saline lakes in the Rift Valley notably: Nakuru, Bogoria and Magadi.

In the vegetation analysis, mapping was implemented from transect and profile data. The Shannon-Weiner index together with arbitrary cover abundance classes were used to estimate vegetation diversity and abundance. Over 150 different plant species were identified within the basin in nine major plant associations. Dominant species in the catchment included ***Olea africana, Juniperus procera, Acacia tortilis*** and ***Tarchonanthus camphoratus***. The lake region exhibited some distinct plant communities notably the ***Acacia xanthophloea*** woodlands, ***Typha-Cyperus*** swamps and ***Sporobolus spicatus*** grasslands. The distribution of species around the lake was influenced by water chemistry. ***Cyperus papyrus*** for example was restricted to areas where fluoride concentration was below 1.0 mg/l. This species was replaced by ***Cyperus laevigatus*** and ***Cyperus immensus*** in areas where conductivity exceeded 150 µS/cm.

Climatic variations were found to be a major factor influencing water level fluctuations at Lake Elementeita. Average annual rainfall has declined in the recent past, rarely exceeding 900 mm while average annual temperature appears to have risen from 14°C in the 1960s to 16°C in the 1980s. Apart from

the influence of climatic cycles, rapid population growth in the watershed has instigated significant landscape modifications. Colour Infra-red LANDSAT imagery was used to estimate the rate of forest and woodland depletion in the watershed which was found to be between 11 km^2/yr (1973-76) and 4 km^2/yr (1976-84), mostly through conversion to agro-ecosystems.

Several conclusions were drawn from findings in this study. Lake water chemistry was found to be influenced by geology and thermal springs in the region. Volcanic rocks in the area contribute to high mineralization particularly with regard to sodium (Na^+), potassium (K^+) and fluoride (F^-) ions. River kariandus was found in this regard to form a major input of mineral salts into the lake. The lake-bed springs south of the lake were also found to be a prominent source of sodium (Na^+), chloride (Cl^-) and sulphates (SO_4^{--}) ions into the lake.

The loss of forest and woodlands in the drainage basin was found to have been particularly rapid in the 1970s as a result of increased human settlements. The study concluded that such depletion will result in declines in water levels at Lake Elementeita particularly during periods of drought. Water level fluctuations were however, found to emanate mainly from changes in climatic factors.

The study recommends conservation of remaining tracts of ***Olea-Juniperus-Acacia*** forest and woodlands as essential ecosystems in the watershed and rehabilitation of degraded areas through improved land management practices. Several other recommendations have been advanced mainly for further research and experiment.

CHAPTER ONE

INTRODUCTION

1.1.0: GENERAL OVERVIEW

This introduction provides a statement of the research problem and a literature review. The research problem is discussed more explicitly under research objectives. Also discussed in the introduction is the basis for the study area selection and definitions of terms and concepts are given.

1.2.0: STATEMENT OF RESEARCH PROBLEM

This study attempts to give an explanation for the current environmental situation of Lake Elementeita through the investigation of spatial and temporal variations in aspects of hydrochemistry, vegetation and lake levels of the Lake Elementeita region (Fig. 1).

The hydrochemistry of Lake Elementeita like that in Lakes Nakuru, Bogoria and Magadi is characterized by high water salinity which has often been attributed to the aridity prevailing in the area. However, the geological make-up of the region may also exert a great influence. Thermal springs have also been known to contribute towards high salinity in East African lakes notably; Lakes Magadi, Bogoria, Manyara, Katwe and Kivu. The hydrochemical contribution of thermal springs in Lake Elementeita is not clear.

A detailed phytogeographical analysis of the Lake Elementeita region does not exist. The low vegetation cover abundance and species diversity observed for littoral macrophytes around the lake might not only be associated with the prevailing arid conditions in the region but also with the hydrochemical structure within the lake. In addition, structural changes in vegetation distribution in core watershed areas through increased human activities could be linked to lake level fluctuations which are common in many

East African lakes, and which have otherwise been attributed to climatic change. There is need, to examine the role of humankind in instigating and accelerating both physical and biological changes within ecosystems, particularly with regard to the depletion of forest and woodlands.

The three main topics studied here therefore are:

(1) Water chemistry in the drainage basin with particular reference to the lake itself and the role of thermal springs as far as this is concerned. The study examines the influence of water chemistry on the distribution of littoral macrophytes vegetation in the lake ecosystem.

(2) Vegetation mapping in the Lake Elementeita drainage basin. Some attention is directed to forest and woodlands in a bid to examine how their extent has declined over recent years, as a result of increased human population in some parts of the watershed.

(3) Water level fluctuations at Lake Elementeita are examined. Such fluctuations are common in most of the Rift Valley lakes in Eastern Africa but in Lake Elementeita, the decline in lake level has aroused great concern in recent years. There are two aspects; first, this study will consider the extent of climatic influence. Second, there is the possibility of local human activity as a factor in influencing lake level fluctuation.

1.3.0: LITERATURE REVIEW

This section:

(i) Examines work on the subject of spatial and temporal dynamics with regard to water chemistry, macro-flora and lake levels in the Rift valley lakes of East Africa.

(ii) Identifies areas of research weaknesses and ascertains gaps in past research efforts.

1.3.1: THEORETICAL BASES

Ecological structure of any lake ecosystem is the product of numerous physical and biological interactions around the drainage basin. Few watersheds are natural, because various management practices will usually change the ecological status of land, rivers and lakes (Goodman, 1984) particularly with regard to vegetation, soils and water quality. Agricultural development in many parts of the world has often been followed by substantial scenery changes, and scientists have often pointed out the serious environmental disorders that arise in watersheds as a result of land degradation and the application of agro-chemicals (Haslam, 1975; Roberts and Roberts, 1984;). Pratt (1974), while studying environmental problems from a mathematical perspective, concludes that an environmental problem arises whenever there is a change in the quality or quantity of any environmental factor that directly or indirectly affects the health and well being of the biota in an adverse manner.

Changes in the physical and hydrochemical order in aquatic environments may have adverse effects on vegetation structure. Klein (1962) reporting on studies done on macrophytes along British rivers observed that water current and the nature of the stream-bed constituted two major factors determining the distribution of larger plants while water chemistry affected only the distribution of some plant species. Haslam (1975) discusses the influence of topographic and climatic factors with regard to vegetation structure. It is noteworthy that she stresses the role of human activities in changing natural vegetation patterns.

Studies of vegetation structure around aquatic ecosystems have shown the significance of plants as indicators of environmental quality (Daetz and Partell, 1974) and a lot of information on the structure of stream habitats can be deduced from lists of plant species. Over the years, the use of aquatic plants for the detection of environmental change has received increased attention.

Many people have studied water level fluctuations in tropical lakes but greater interest has been directed towards possibilities of climatic change (Lamb, 1966; Washbourn-Kamau, 1970; Butzer, 1972; Beadle, 1974). A few workers have also pointed out the significance of human activities in watersheds in influencing the sizes of lakes (Pereira, 1959; Goudie, 1986).

This work represents an example of a watershed-ecosystems study. A major intention is to explore linkages between terrestrial and aquatic ecosystems within a drainage basin to determine how the former can influence the latter, specifically with regard to selected aspects of water chemistry, vegetation and lake levels. The geographic basis of this study requires that emphasis be directed to the spatial and temporal dynamics of these three aspects.

1.3.2: EMPIRICAL BASES

Saline lakes are widespread in Eastern Africa and shallow soda lakes cover part of the Great Rift Valley in Ethiopia, Kenya and Tanzania. Despite such a widespread distribution, saline lakes remain largely neglected by limnologists (Kilham, 1971; Melack, 1976), let alone biogeographers. Lake Elementeita is no exception to this.

Very few researchers have studied some physical and biological aspects of Lake Elementeita, notably lake morphometry, light attenuation, water temperature, lake levels, water chemistry and phytoplankton diversity and photosynthetic rates. Studies have mostly been done for comparison with either freshwater ecosystems or saline aquatic environments of greater interest (eg. Melack, 1976). Thus much of the work has been centered around lake ecosystems except for a geological investigation done by McCall (1967).

An adequate understanding of the structure and character of saline lakes and their watersheds is lacking, particularly within the tropics. This study aims at filling some of the existing gaps. It specifically reinforces existing information on water chemistry in Rift Valley saline lakes and provides a detailed analysis of vegetation structure within the Lake Elementeita drainage basin. The role of climate in so far as water level changes are concerned in Rift Valley lakes has been studied to allow us to understand the significance of climatic oscillations in the Elementeita region. Meanwhile, this study is an exploration for other possible factors behind water level changes at Lake Elementeita.

1.3.3: HYDROCHEMISTRY

The water chemistry of Lake Elementeita shows marked temporal variation. In 1961, electrical conductivity in the lake was recorded at 43 μmhos/cm (Talling and Talling, 1965) and this had declined to only 11 μmhos/cm by 1971 (Kilham, 1971). Melack (1976) also recorded some monthly conductivity deviations from a 4-year mean salinity level of 28 μmhos/cm (1971-74) which is not surprising when one appreciates the wide monthly climatic oscillations existing around Lake Elementeita where evaporation may occasionally exceed inflows and as the water evaporates, salinity increases rapidly.

Kilham and Hecky (1973) reported a fluoride concentration of 1627 mg/l for Lake Elementeita. Chemical analysis in Kariandus river water revealed sodium (Na), fluoride (F) and sulphate (SO_4^{--}) levels at 44.8, 7.13 and 25.4 mg/l, respectively.

High fluoride concentrations in Lake Elementeita have been attributed to the geological make-up of the area (Kilham & Hecky 1973). Saggerson (1970) observed relatively high percentages of silicon dioxide (SiO_2) and sodium oxide (Na_2O) at 50.27% and 3.85% by weight, respectively, in a basalt rock extract from the area compared to 40.7% and 0.36%, respectively for a similar sample from the Naivasha area. For the south western volcanic zones of Uganda, Viner (1975) reported significant geologic influence on the mineralogy of existing lakes with calcium (Ca) and magnesium (Mg) oxides accounting for 34% and sodium (Na) and potassium (K) oxides about 15% of total dissolved solids by weight. Overlying geology of an area therefore forms an undisputable mineral source for aquatic ecosystems across the Rift Valley but this is complicated by the role of thermal springs which are sources of mineralization for some aquatic ecosystems in the Rift Valley, notably Lakes Nakuru and Magadi.

Without a direct outlet, Lake Nakuru is very alkaline with a mean pH of 10.5 (Koeman ***et al.***, 1972). In 1971, the concentrations of sodium, potassium, chloride and sulphate were recorded at 38 000, 1 312, 13 000 and 4 270 mg/l respectively. During the same period, related levels at Elementeita were measured at 9 450, 381, 5 200 and 2200 mg/l respectively (Richardson and Richardson, 1972). Sodium carbonate (Na_2CO_3) has been isolated as a major solute in the lake (Koeman ***et al.***, 1972). The source of salts in the lake has been traced back to highly saline hotsprings which deposit trona (Na_2CO_3 $NaHCO_3.H_2O$).

Two major hotspring areas have previously been identified across Elementeita basin within Kariandus and Chamuka catchments (McCall, 1967) but their contribution to the hydrochemistry of Lake Elementeita has not been clear. In Lake Magadi, a highly saline Kenyan Rift Valley lake, much of the lake is covered by crystalline trona, mostly carbonates and bicarbonates of sodium with smaller quantities of sodium fluoride (NaF), sodium chloride (NaCl) and sodium sulphate (Na_2SO_4). Coe (1960) observed that the lake is characterized by alkaline springs around its margins capable of releasing up to 693 483 m^3 of water daily into the lake and at this rate, about 1 194 tonnes of sodium carbonate. This has been confirmed by Beadle, (1974) and Jones ***et al.***, (1977).

Elsewhere, studies in saline lakes have confirmed the mineralized hotspring phenomenon. Lake Katwe in Uganda's Western Rift Valley, for example, is reportedly fed by over fifty small springs whose discharge ranges from 25 to 40 l/min (Arad and Morton, 1969). In the same area, seismic and chemical analyses around Lake Kivu indicate that 'jets' or fumaroles of saline water are being injected into the bottom layers, making the lake progressively more saline (Viner, 1975). Hotsprings are also common around Lakes Bogoria and Manyara in Kenya and Tanzania respectively.

In his study of African inland waters, Beauchamp (1953) suggests that a high sulphate content may exist in the soda lakes of the East African Rift Valley, and the existence of low phosphorus content within Lakes Nakuru, Elementeita and Naivasha has been found by some workers notably Peters & McCintyre (1976) and Kalff (1983).

An investigation into the structure of algae populations in some soda lakes of East Africa indicated that water chemistry has significant influence on aquatic plant life (Kilham and Hecky, 1973). The population dynamics of the blue-green algae, ***Spirulina platensis*** in Lakes Elementeita, Nakuru and Bogoria has for example been attributed to physiological stresses emanating from salinity rises. Melack (1976) concluded that the persistence of salinity levels at approximately 6000 µS/cm for up to 40 days could be disastrous to the phytoplankton.

In the Naivasha basin lakes, the saline environment around Lake Sonachi displays a general absence of some plants present in the neighboring freshwater lakes notably, ***Cyperus papyrus*** (Njuguna, 1982). ***Cyperus papyrus*** is largely absent around Lake Elementeita except for a small area at the mouth of Mbaruk and Chamuka rivers. ***Cyperus papyrus*** vegetation in Lake Naivasha´s North Swamp constitutes an important wetland ecosystem that is today threatened with elimination through burning, slashing and grazing with the rising demand for reliable agricultural and grazing land (Mwaura, 1987).

1.3.4: VEGETATION

The Cambridge Kenya expedition of 1978 outlined some of the bushland plant species across the Rift Valley floor (Cambridge, 1978). The bushland vegetation across most of the area between Kedong valley and Lanet includes species such as; ***Maerua triphylla, Aspilia mossambicensis, Tarchonanthus camphoratus*** and ***Psiadia punculata***. ***Acacia xanthophloea*** and ***Teclea simplicifolia*** form outstanding woodland tree species. The vegetation around Lake Elementeita displays strong similarities with other saline alkaline aquatic ecosystems in Kenya, notably Lakes Sonachi (Njuguna, 1982), Nakuru (Koeman ***et al.***, 1972; Melack, 1976), Bogoria and Simbi (Melack, 1976). A peculiar feature of alkaline saline lakes in East Africa is the almost unialgal bloom of the cyanophycean ***Spirulina platensis*** that may persist for years. At Lakes Bogoria, Nakuru and Elementeita, this blue green algae forms a major food base for the Lesser Flamingo (***Phoeniconaias minor***).

Studies on Lake Elementeita's flora are restricted to phytoplankton. Little attention, or none at all, has been directed to the character of littoral macrophytes and vegetation in the catchment. Plants have been considered important in portraying environmental conditions of different ecosystems (Cain & Castro, 1959; Klein, 1962 and 1966; Haslam, 1965; Kullberg, 1968; Williams ***et al.***, 1969; Fager, 1972; Daetz & Pantell, 1974; Pratt, 1974; Inhaber, 1976; Pielou, 1977; Green, 1979). Muiruri (1978) saliently recognizes the fact that vegetation cover of any place reflects to a large extent, the sum total of environmental conditions and can be counted as a fairly reliable indicator of ecological potential. She might also have added that vegetation is also a good indicator of the extent of human interference into the directional flow of processes in ecosystems.

The impact of deforestation across watershed belts is a threat, not only to existing lake ecosystems (Goudie, 1986), but also to the continued supply of domestic water. It is understood that excessive rates of forest destruction across major watersheds through clearing and burning will almost always precede environmental damage. A study done in the Hubbard Brook Watershed in North America revealed that forest clearing had profound effects on both the quality and quantity of water (Likens *et al.*, 1969).

In Kenya, the demand for agricultural land is increasing with decreasing job opportunities in the urban "target" areas, together with the inequitable distribution of resources. Consequently, the urge to encroach into protected watershed and marginal areas is great. Baker (1986) has observed this and concluded as follows:

> " ... in this context, access to land is the only form of security open to the growing community *particularly* (emphasis added) of the rural poor for there are no pensions, no social security and a diminishing ratio of jobs to people. They have little option other than to move onto hill-slopes, into forests and out into the dry zones"

An empirical study relating rainfall, agriculture, livestock and human density in the marginal lands of Kenya suggested that many densely populated semi arid districts have populations well above their carrying capacities (Kalff *et al.*, 1985). The aftermath of this is almost always increased environmental degradation particularly in the absence of proper land management.

1.3.5: LAKE LEVELS

Tropical lakes, particularly in Africa, have frequently manifested changes in size. Studies have revealed the existence of large lakes within the Sahara in the recent geological past (Unesco, 1978). Lake Chad, for example, has been known to fluctuate in size historically from season to season. During the driest part of the period between ca.14400 and 1200 BP, Lake Victoria water levels fell by at least 26 m (Kendall, 1968) while Lake Mobutu Seseseko is known to have been dry at ca.1300 BP. Lake Turkana was low from 9500 to 3500 BP when it rose again to fluctuate between 60 and 80 m above current levels (UNESCO, 1978).

Lake level fluctuations have been common within Lakes Naivasha, Nakuru and Elementeita. Radio-carbon dating has revealed that their basins were filled about 9000 years ago (Butzer *et al.*, 1972) after which Elementeita and Nakuru temporarily merged to share a common outlet northwards while Naivasha flowed out southward.

Washbourn-Kamau (1970) discusses the large ancient pluvial lake that joined the Nakuru and Elementeita basins some 8600-9600 years ago. She asserts that such a large water basin could have been maintained by an increase in annual precipitation of between 430 and 450 mm over the current annual average of about 820 mm. Her view is shared by other researchers, notably Richardson & Richardson, (1972), Butzer *et al.*, (1972) and Beadle, (1974). Butzer *et al.* (1972) suggest that East African temperatures were about 2° C lower 9000 years ago resulting in a reduction of annual evaporation of 152 mm. Runoff under moister conditions was probably closer to 10% of precipitation than the current 3.3%, in which case an annual precipitation of about 1470 mm as compared to the present average of 965 mm for the Elementeita basin would have maintained the enlarged lake at its spillway.

Lamb (1966) in his study of global changes in wind circulation suggests that lake levels will respond to integrated rainfall patterns over the years.

This may not be that direct in the light of numerous hydrological interactions that runoff undergoes before actual storage in a water body.

Revelations for possibilities of past incidence of climatic change in East Africa have not been restricted to aquatic environments. Western and Praet (1973) suggest that ecological changes evident in the Amboseli Game Reserve in the Kenya south-lands may be attributed to changes in climatic conditions. Their study observes that the death of ***Acacia xanthophloea*** trees in some parts of the reserve may have only been accelerated by increased elephant and cattle populations out of de-barking, but the major cause might be directed more towards aspects of climatic change. The Amboseli basin is the site of a lake that formed during the Pleistocene and dried out during a recent epoch. The changes in Amboseli have also been attributed to raised water table and increased salinity.

While views about the climatic change theory for lake level fluctuations may appear sound and unrefutable they may not represent a sole cause behind fluctuating lake levels in Africa and even with the current state of knowledge, it would be appropriate to explore possibilities for alternative causes. This has been suggested by several researchers, notably Pereira, (1959) and Goudie (1986).

1.4.0: JUSTIFICATION

In light of some information gaps in studies carried out around Elementeita and elsewhere, this study sets out to fill some with respect to hydrochemistry, vegetation and lake level characteristics.

The future management of Lake Elementeita as a base for recreation, tourism or merely for aesthetic satisfaction will depend heavily on preservation of an entire spectrum of existing plant and animal species. We therefore want to know what impacts natural or even mankind induced ecological shifts may have on existing vegetation. In the case of humankind-induced changes, then the possible damage once expected can be minimized or even more favorably, abated.

The findings from this study on the extent to which humankind has interrupted natural vegetation across the catchment, particularly forest and woodlands in the upper catchment, may emerge useful in watershed planning. The study identifies ´disaster`zones where environmental solution may inevitably lie on more strict conservation measures. The continued supply of water is inevitably bound to the protection of core watershed belts which constitute the origin for all water springs that comprise river systems across the basin.

The question of lake level decline has not been clearly addressed by past studies. This study, by examining the extent of human influence through deforestation, suggests new ways of maintaining reliable environmental order, particularly in terms of water quality and quantity both in lake and watershed.

This study has largely been prompted by the saddening past trend of too little concern for an ecological understanding of saline lake ecosystems, a trend which may be unwarranted. A general contention that saline lakes are of borderline economic significance hence a justification for lack of research concern is wrong. Even when certain ecosystems had no other value and were an economic detriment, they would still be worth understanding and preserving for many people for their sheer beauty and appeal to the human spirit. The state of affairs at Lake Elementeita should not obscure our appreciation for what ecological potential the lake may hold as, indeed, no ecosystem is literally useless. Apart from providing seasonal habitats to hundreds of Greater and Lesser Flamingos (*Phoenicopterus ruber* and *Phoeniconaias minor*, respectively) and other bird species, the lake may hold a significant fishery potential. It is true that *Tilapia grahami* in Lakes Magadi and Nakuru thrives amidst extreme environments to constitute a major food base for a variety of bird species.

1.5.0: RESEARCH OBJECTIVES

This study was aimed at achieving the following objectives:

(1) Analyzing the hydrochemistry of Lake Elementeita and its river systems, including an investigation into the significance of hotsprings to water chemistry in the lake ecosystem.

(2) Conducting a general vegetational survey across the basin and examining the relationship between plant communities and prevailing hydrochemical conditions around Lake Elementeita.

(3) Estimating forest and woodland depletion rates in relation to human population growth and distribution in the watershed and examining possible hydrological implications of this with respect to Lake Elementeita.

(4) Establishing the role of climate in lake level fluctuations at Lake Elementeita.

1.6.0: HYPOTHESES

The following working hypotheses (Null) were postulated for this study:

(1) The hydrochemistry of thermal springs does not manifest any significant variation from the general water chemical conditions in rivers and lake.

(2) Plant communities around Lake Elementeita do not manifest significant variation with varying hydrochemical conditions within the lake.

(3) Rainfall, temperature and evaporation trends in the drainage basin do not correspond to lake level trends at Elementeita.

1.6.0: THEORETICAL/CONCEPTUAL FRAMEWORK

This section discusses the conceptual basis upon which this study is built. This is preceded by operational definitions for some terms which are widely used here.

DEFINITIONS

Hydrochemistry. is limited in this study to a description of both physical and chemical factors in both lake and river water. Physical factors include colour, turbidity and pH, while chemical factors include the levels of electrical conductivity, Total dissolved solids (TDS), Total alkalinity, Total hardness, iron (Fe), magnesium (Mg), manganese (Mn), calcium (Ca), sodium (Na), potassium (K), fluoride (F), chloride (Cl), phosphorus, nitrogen, Free carbon dioxide (Free CO_2), and permanganate number (P.V. NO).

Plant association refers to the assemblage of plant populations in a prescribed area or habitat. It involves the presence of several plant species in an area, and relates closely to plant communities consisting of ecologically related plant species coexisting in similar habitats. **Species diversity** refers here simply to a total number of different plant species of all lifeforms existing in a community of specified spatial dimensions such a quadrat or a strip sampling plot. Further, **abundance** is here taken to refer to a total count of existing plants within a specified area with little regard to the species involved.

<u>**Thermal springs**</u> refer here to both warm and hotsprings in geothermal active areas around the lake or in the catchment where water temperatures normally range between 30° and 50° C.

<u>CONCEPTUAL FRAMEWORK</u>

The watershed-ecosystem approach, utilizing measured parameters of hydrological and chemical input, output and related dynamics, is a powerful tool for the study of biogeochemical and ecological relationships of individual ecosystems. This study represents an example of the watershed approach to ecosystem studies.

The ecosystem concept is taken to represent a basic functional unit of nature which includes both organisms and their non-living environments, each interacting with the other and both necessary for the maintenance and development of the system.

Boundaries of an ecosystem are most often defined to meet the pragmatic needs of the investigator. The Lake Elementeita drainage basin study is based on various interactions between terrestrial and aquatic ecosystems. Such ecosystems are visualized as being connected on the whole to the surrounding biosphere by input, output systems in the form of water, chemicals, gases and organic matter through meteorological, geological and biological processes.

The hydrochemistry in the lake and streams of the watershed bears a strong association with the nature and distribution of geologic materials in the catchment. Precipitation falling in the drainage basin travels either as surface runoff, shallow interflow, groundwater flow through unconsolidated surficial materials, or through bedrock fractures. Water which moves as surface runoff and interflow, moves rapidly to rivers and lake and has little time to react with the minerals in the soil; only reactions which occur rapidly can occur. Water flowing through the groundwater reservoir moves much more slowly and has time to react with minerals comprising the aquifer skeleton. Measurement of dissolved and particulate matter in water samples from across the watershed provide a good estimate of geological output.

Vegetation distribution in the watershed is dependent on a wide assortment of abiotic factors including; climate, topography and geology. The distribution of plant species constituting littoral macrophytes in aquatic ecosystems is influenced by such additional factors as; nature of substrate, wind characteristics and water chemistry. The hydrochemical status of a lake constitute a basis for differentiation between freshwater and saline aquatic ecosystems. Extreme hydrochemical conditions in saline lakes can influence vegetation cover abundance as well as bio-diversity around such ecosystems through specific biochemical checks on different plant species.

Human activities within the watershed will have a strong influence on the quality and quantity of water in the lake and rivers, and conditions in such aquatic systems will respond greatly to a wide range of human activities. The incidence of environmental degradation through accelerated soil erosion and increased agro-chemical effluent can change the quality of water in rivers and lakes. Mining activities, on the other hand, can increase stream-bank erosion and the discharge of industrial effluent into nearby streams thereby off-setting the natural chemical status of the water systems. Likewise, deforestation through tree felling, overgrazing, burning or replacement by agro-ecosystems can adversely affect the quantity of water available in water systems thereby influencing water level changes in lakes.

This can similarly emerge as a result of artificial stream manipulations in the form of reservoirs and the creation of stream diversions mainly for agricultural and livestock husbandry. Thw watershed-ecosystem approach is useful in evaluating the ecological effects resulting from the role of humankind in land, water and forest management.

Figure 1a is a highly generalized theoretical working model for the Elementeita watershed study. Strictly speaking, a representation of the intricate ecological interactions involved in such a watershed is almost impossible, because some of the interactions are yet to be clearly understood. The model in Figure 1a should therefore be seen mostly as a tool to be used in the attempt to meet the research objectives and it may not necessarily represent an accurate model of nature.

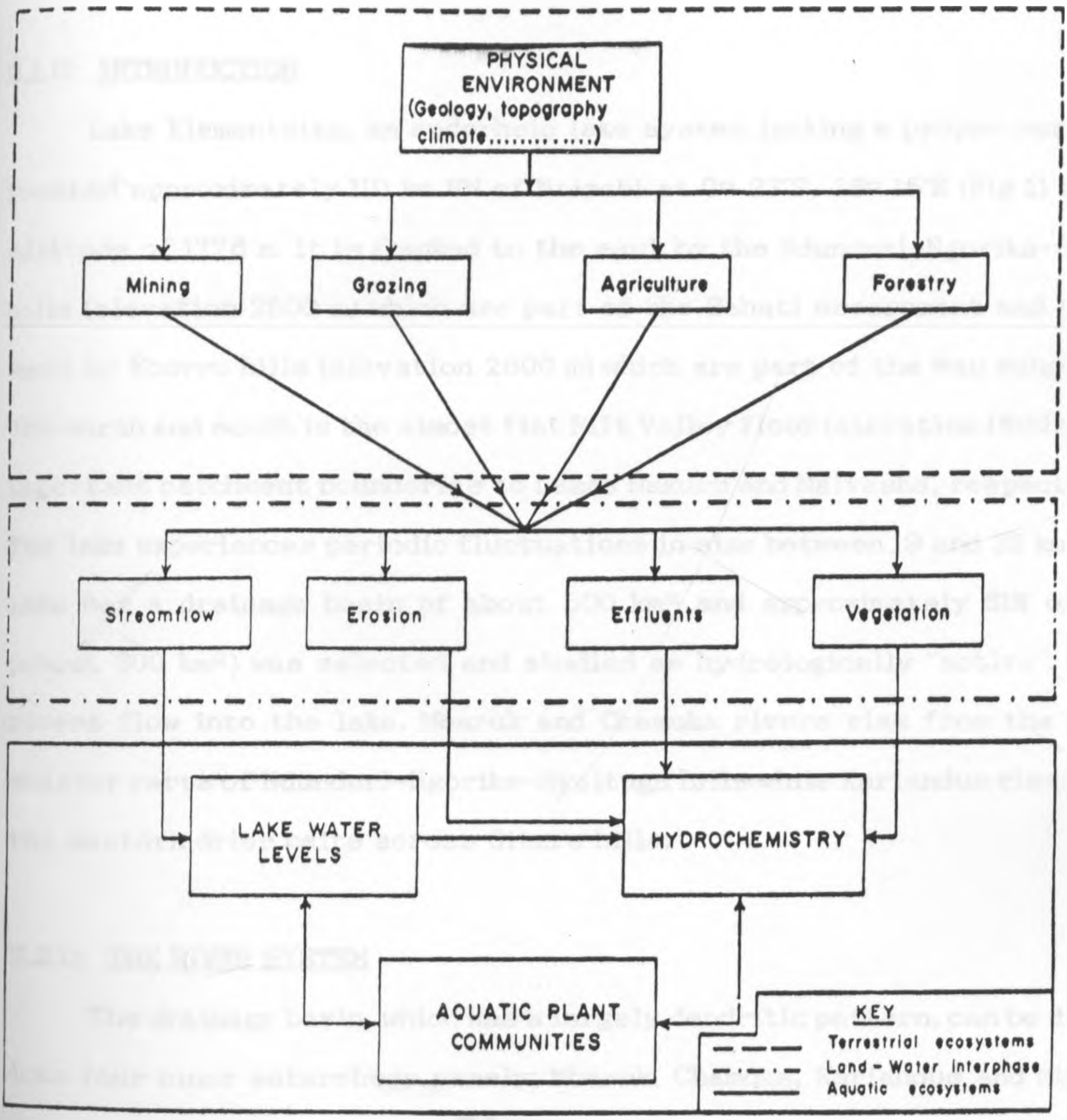


Fig Ia. A theoretical working model representing some terrestrial - aquatic ecosystem relationships examined in the Elementeita watershed study. (Author).

CHAPTER TWO

THE STUDY AREA

2.1.0: INTRODUCTION

Lake Elementeita, an endorheic lake system lacking a proper outlet is located approximately 110 km NW of Nairobi at 0° 27′S, 36° 15′E (Fig 1) and an altitude of 1776 m. It is flanked to the east by the Ndunduri-Ngorika-Gitare hills (elevation 2500 m) which are part of the Bahati escarpment and to the west by Eburru hills (elevation 2600 m) which are part of the Mau ranges. To the north and south is the almost flat Rift Valley floor (elevation 1800 m) with important catchment boundaries to Lakes Nakuru and Naivasha, respectively. The lake experiences periodic fluctuations in size between 19 and 22 km^2. The lake has a drainage basin of about 500 km^2 and approximately 61% of this (about 300 km^2) was selected and studied as hydrologically "active". Three rivers flow into the lake. Mbaruk and Chamuka rivers rise from the upper moister parts of Ndunduri-Ngorika-Nyaituga hills while Kariandus rises from the eastern drier belts across Gitare hills.

2.2.0: THE RIVER SYSTEM

The drainage basin, which has a largely dendritic pattern, can be divided into four minor watersheds namely; Mbaruk, Chamuka, Kariandus and Mbaruk-Chamuka (Fig 2). Mbaruk watershed is the largest and wettest while Kariandus is the driest. Both Chamuka and Kariandus manifest geothermal activities.

Mbaruk watershed

The major tributaries include Bonde, Rutara, Gichure, Ndunduri and Weru-ini. Stream depths vary between 0.1 and 4 m while widths rarely exceed 5 m, with some streams only 0.5 m wide. The landscape is relatively rocky in the upper zones of Rutara and Ha-njubi. Stream basal materials in the area indicate higher proportions of fine sediments and silt except around Mbaruk railway station where clay is abundant.

Chamuka watershed

Major tributaries include Ndiri-ini, Nyaituga, Kanjuiri and Kiringa. The middle watershed areas are relatively rocky, particularly across Kasambara and Kiringa where the proportion of sand and gravel in stream basal material is much higher. Upper catchment areas are relatively non rocky and unlike the rest of the basin are characterized by more detritus silts with small quantities of clay. Stream depths vary between 0.1 and 0.8 m while widths rarely exceed 3.5 m.

Mbaruk-Chamuka watershed

This represents the flow into the lake of both Mbaruk and Chamuka after converging about 1.5 km from the lake shore. The landscape is monotonously flat at an elevation of about 1880 m and river depth varies between 0.5 and 1 m with fairly wide channels generally between 3 and 3.2 m. Sand, silt and gravel constitute the dominant stream basal materials in that order of abundance.

Kariandus watershed

This extends from the upper areas of Gitare and Northern Gilgil, into the mid lowland and lowland zones of Kariandus and Elementeita. The landscape is prone to degradation with increased aridity. Stream basal material consists of sand, gravel and diatomaceous earths. Major tributaries include Kabugi, Gitare, Kekopey and Mai-mahiu. These relatively small streams are ephemeral in nature with widths and depths ranging between 0.1-0.3 m and 0.1-1.5 m respectively.

2.3.0: THE LAKE

Lake Elementeita is the smallest of a chain of alkaline saline lakes lying in the floor of the Kenyan-Tanzanian Rift Valley. Depths in the lake range between 3.7 and 0.9 m (McCall, 1967; Melack, 1976). Water temperature in the lake manifests remarkable monthly variations generally ranging between 17° C and 22° C. The lake is characterized by a basal sediment layer consisting of fine clayey silts and some gravel. The western part of the lake is dominated by numerous islands of black lava, mostly bare but occasionally invaded by the grasses *Sporobolus spicatus* and *Chloris gayana*. In dry years, these islands are connected to the shore by stretches of mud-flat and have been found to provide suitable nesting and breeding grounds for the Greater flamingo (Brown 1957).

The lake manifests geothermal activity in the form of warm springs at the southern end (Fig 2). These lake-bed springs have diameters ranging between 0.2 and 0.3 m and are continuously ejecting warm water at approximately 30-40° C. At high water levels, these springs would well be concealed which then raises suspicion about other similar occurrences below the water surface.

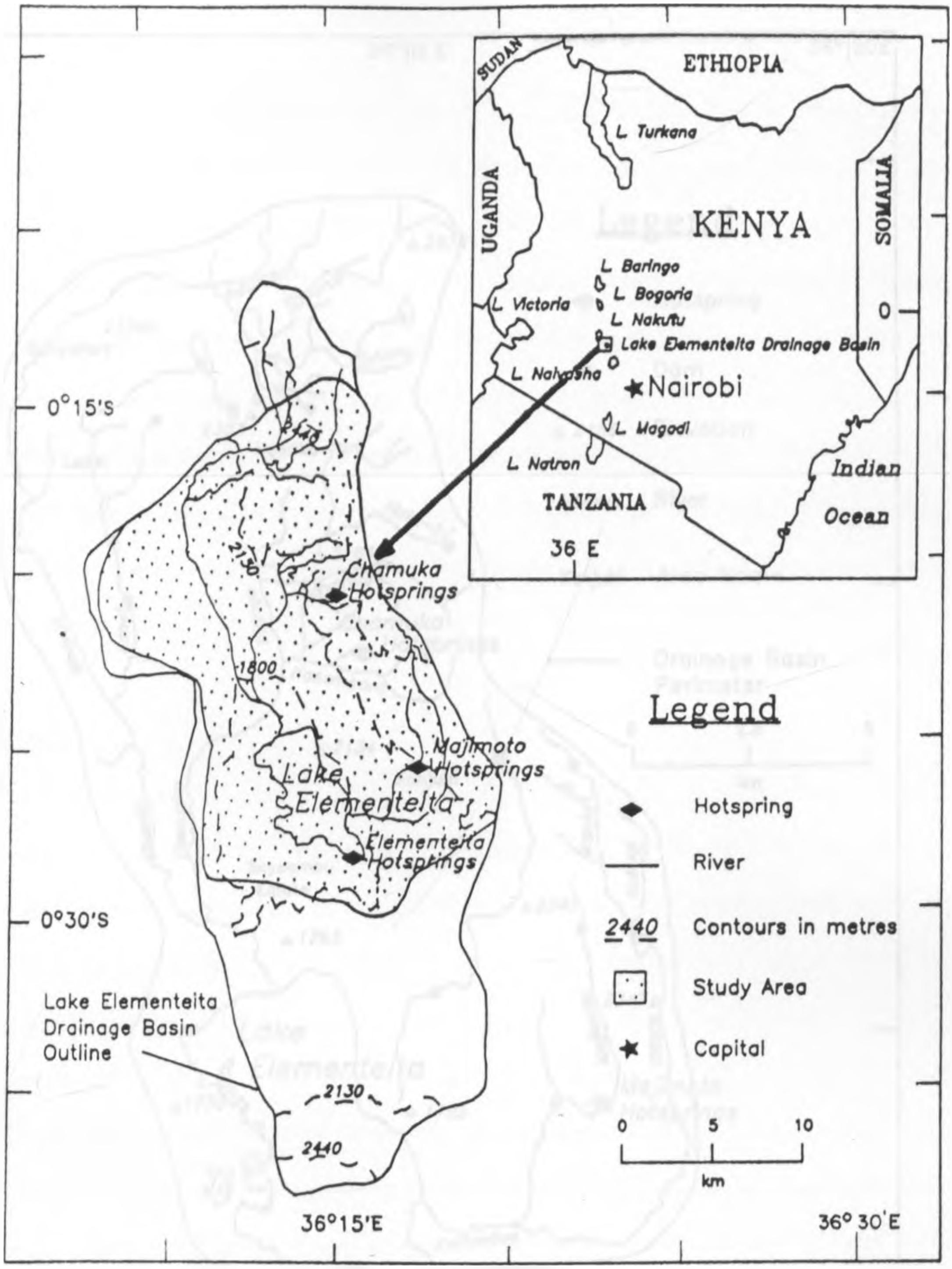


Fig. 1: The location of study area.

Source: Field Survey.

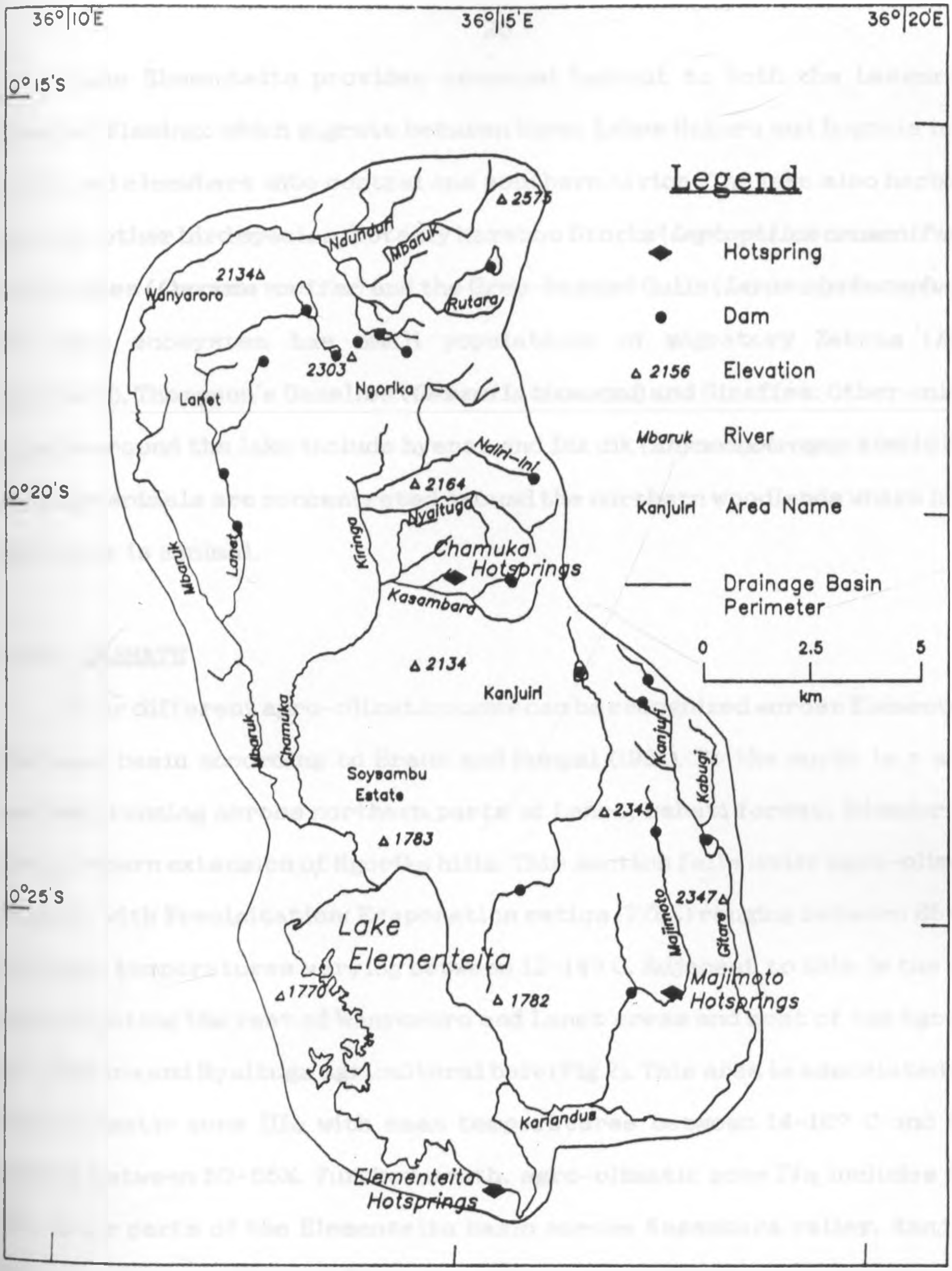


Fig. 2: Characteristics of the Elementeita drainage basin.

Source: Field Survey

Lake Elementeita provides seasonal habitat to both the Lesser and Greater Flamingo which migrate between here, Lakes Nakuru and Bogoria in the north and elsewhere into central and southern Africa. The lake also harbours several other bird species, notably Marabou Storks (***Leptoptilos crumeniferus***), Fish Eagles (***Cuncuma vocifer***) and the Grey-headed Gulls (***Larus cirrhocephalus***). The lake ecosystem has small populations of migratory Zebras (***Equus burchelli***), Thompson's Gazelles (***Gazzella thomsoni***) and Giraffes. Other animals common around the lake include hyenas and Dik dik (***Rhynochotrogus kirkii***) Most of these animals are concentrated around the northern woodlands where human influence is minimal.

2.4.0: <u>CLIMATE</u>

Four different agro-climatic zones can be recognized across Elementeita drainage basin according to Braun and Mungai (1981). To the north is a short wet belt running across northern parts of Lanet, Bahati forest, Ndunduri and the northern extension of Ngorika hills. This section falls under agro-climatic zone II_7 with Precipitation: Evaporation ratios (P/E_o) ranging between 65-80% and mean temperatures varying between 12-14° C. Adjacent to this is the zone incorporating the rest of Wanyororo and Lanet areas and most of the Ngorika, Kio, Rutara and Nyaituga agricultural belt (Fig 2). This area is associated with agro-climatic zone III_6 with mean temperatures between 14-16° C and P/E_o ratios between 50-65%. Further south, agro-climatic zone IV_6 includes most the drier parts of the Elementeita basin across Kasambara valley, Kanjuiri, Thiginui, Gitare and upper Kariandus where mean temperatures range between 14 and 17° C and P/E_o ratio between 40-50%. The lake ecosystem is situated on an extensive, dry semi arid belt of the Rift Valley extending from Mbaruk to the north and Kedong valley in the south (Zone V_5), with mean temperatures ranging between 16 and 18° C and P/E_o ratios between 25-40%.

The basin can generally be categorized into the humid highlands (zones II,III and IV) and the dry lowlands (zone V). Rainfall records from several stations representative of the humid highlands amounted to a mean annual value of 1066 mm (Ndunduri, Oljoro orok and Wanjohi) for the last 27 years (1959-85). Much of the rain falls during the months of February to May (Long rains) while a short spell between October and December is fairly wet (Short rains). January is the driest month. Average evaporation records for Oljoro orok indicate a mean evaporation of about 1380 mm/yr.

Similar records in the dry lowland areas indicate a mean precipitation of 733 mm for the last 30 years between 1958 and 1987 (Soysambu, Nderit and Winston estate, Kekopey ranch, Lanet police station and Chokora farm near Mbaruk). Rainfall here manifests largely similar patterns as in the highlands but the long-rains here are much smaller in amount and reliability, sometimes commencing well after April. Evaporation is very high within the Rift Valley and rates calculated for Naivasha amounted to a mean annual value of 1793 mm/yr. The short rains in October-November are less pronounced but the area is reported to be under the influence of the Zaire monsoons from the south which cause some light rains during the months of June and July (Ojany and Ogendo, 1973).

2.5.0: <u>GEOLOGY</u>

Much of the highland areas across Ndunduri, Ngorika and Nyaituga are composed of an assortment of vitric pumice tuffs, part of the Mau-Bahati-Kinangop tuffs,(McCall 1967). Around Ndunduri and Bahati forest, interruptions are common with the occurrence of the Rumuruti phonolites in some places while across Gitare and Northern Gilgil, the tuffs are also widely replaced by surficial deposits of volcanic origin which cover lowland areas around Kariandus, Mbaruk and Lanet. The narrow belt along Mbaruk fault is characterized by porphyritic olivine-basalt which constitute the Mbaruk basalt (Fig. 3).

At various places in the low-lying areas, the existence of the Gilgil trachyte is evident. These are particularly widespread along the Gilgil escarpment, Soysambu estate and some parts of Mbaruk. The trachyte might also overly the Mbaruk basalt at several places. McCall (1967) suggests that Pliocene fissure eruptions may have resulted in the emission of the basaltic lavas, trachytes and phonolites in many places across the catchment.

Much of the southern and western sides of the lake is covered by what McCall terms 'Elementeita badlands' which form into basalt-cinder cones at various places the most distinguishable being the cone at the southern shores of the lake. Some very recent tuff cones can also be identified south of Lake Elementeita.

Around Kariandus area, diatomite forms layers separating the Gilgil trachyte to form the Kariandus lacustrine sediments purportedly formed during lower or middle Pleistocene. This deposition is believed to have occurred within a larger basin of the joint ancient Nakuru-Elementeita lake.

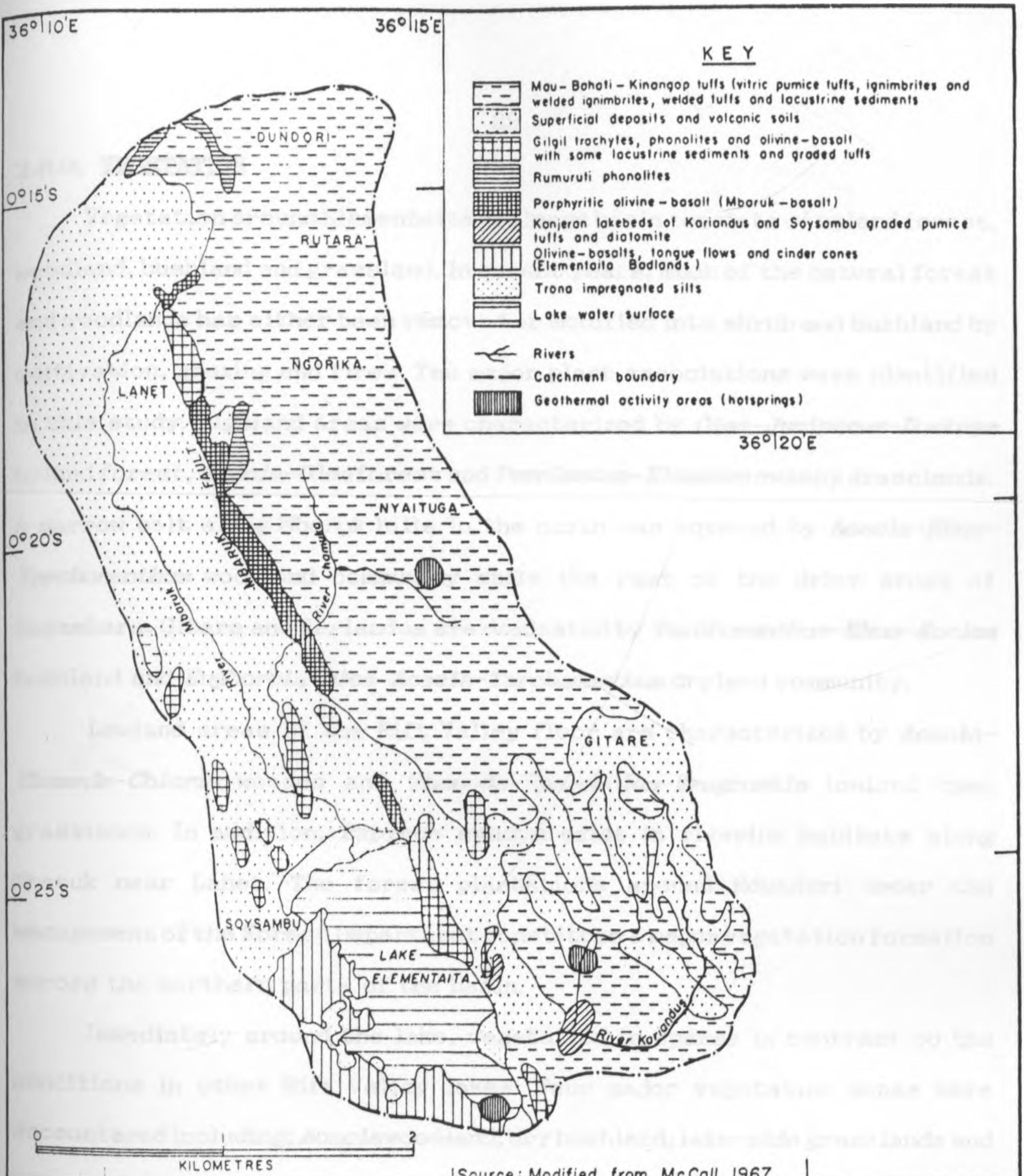


Fig. 3: The Geology of the Elementeita drainage basin.

2.6.0: VEGETATION

Vegetation around Elementeita drainage basin consists of upland forest, woodland, bushland and grassland. In recent years, much of the natural forest and woodlands has either been removed or modified into shrub and bushland by cultivation, grazing and fires. Ten major plant associations were identified in this study. Highland areas were characterized by ***Olea-Juniperus-Dombeya*** upland forest, ***Acacia-Olea*** forest and ***Pennisetum-Eleusine*** swampy grasslands. A narrow belt along Mbaruk hills in the north was covered by ***Acacia-Rhus-Tarchonanthus*** woodland community while the rest of the drier areas of Kasambara, Gitare and Kariandus are dominated by ***Tarchonanthus-Rhus-Euclea*** bushland and ***Euphorbia-Olea-Acacia-Tarchonanthus*** dryland community.

Lowland areas of the Rift Valley floor are characterized by ***Acacia-Themeda-Chloris*** wooded and ***Themeda-Sporobolus-Eragrostis*** lowland open grasslands. In addition, Papyrus swamps exist in riverine habitats along Mbaruk near Lanet. The forest plantations around Ndunduri under the management of the Forest Department constitute a major vegetation formation across the northern parts of the basin.

Immediately around the lake, vegetation is sparse in contrast to the conditions in other Rift Valley lakes. Four major vegetation zones were encountered including; ***Acacia*** woodland, dry bushland, lake-side grasslands and swamps. ***Acacia xanthophloea*** is the sole woodland tree species while bushlands are dominated by the species ***Rhus natalensis, Sesbania sesban, Lantana trifolia*** and ***Tarchonanthus camphoratus***. There are several grass species but the most dominant are ***Sporobolus spicatus*** and ***Chloris gayana***, the latter mostly restricted to the western parts of the lake. Swamps around the lake are characterized by ***Typha domingensis, Cyperus laevigatus, Cyperus immensus*** and

Cyperus papyrus but the latter restricted to a few places in the north.

2.7.0: LANDUSE

Agriculture is a major activity across the catchment, with greatest concentration in the northern moister belts of Ndunduri, Ngorika and Nyaituga. Maize is a major crop, but beans, cabbages, carrots and potatoes are also grown. Most of the agriculture is rain-fed and irrigation is rare. Currently, agricultural development is rapidly penetrating into previously reserved forest zones particularly in the upper catchment.

Livestock husbandry is a major occupation throughout the basin. In most places, this is combined with small scale cultivation. However, some farms across Ngorika notably Waiyaki, Mahihu and Kiringa specialize in large scale dairy farming and maize is mainly grown as a fodder crop. Milk production is high around this area and most of this is sent for processing to the Kenya Cooperative Creameries, Nakuru plant. Ranching is restricted to the drier belts around the lake (Soysambu, Kekopey and Nderit estates) where raising of beef cattle is a prominent undertaking. Pastoralism is common around the southern fringes of Lake Elementeita, which constitute dry season grazing for the Maasai who are assured of watering points along the Kariandus quasi-delta zone.

Urban centres are restricted to a few market points at Ndunduri, Ngorika, Kanjuiri and Lanet where a variety of commercial activities are taking place. Ndunduri, the largest of these, is traversed almost in the middle by Bonde river, a tributary of Mbaruk. The level of urban effluent disposal into the stream is noticeable, particularly in the absence of any kind of sewage treatment. The population of the centre is increasing and a number of small-scale industries mostly involved with saw-milling are emerging.

The diatomite mines at Kariandus exploit ancient diatomaceous earths. Currently, the factory is bringing in its raw material from diatomite deposits located to the west of Lake Elementeita within Soysambu estate.

Lake Elementeita is a major tourist attraction for visitors who wish to view the Rift Valley alkaline lakes, the Flamingos or just the Rift Valley. A major viewpoint exists off the Trans-African highway which transverses the basin. Further, the National Museums of Kenya operate an anthropogenic pre-historic site at Kariandus which displays certain historical aspects of the Stone Age Man.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1.0: INTRODUCTION

This chapter describes materials and methods used in this study. The study utilized both primary and secondary data but the latter were largely restricted to records on lake level and climatic variables. LANDSAT data were used as a measure of spatial dynamics in forest and woodland belts while population census records for 1962, 1969 and 1979 were also used.

Primary data involved field measurements of water, soil and vegetation. The latter parts of this chapter describe methodologies involved in data analysis.

3.2.0: SAMPLING STRATEGY

Stratified random sampling was used to avoid clustering effects of simple random sampling (Smartt *et al.* 1974). Stratification was primarily based on vegetation belts across the basin which was found vital in order to facilitate a comparison between vegetation structure and environmental gradients.

Sample stratification was implemented through the use of both topographic maps and LANDSAT images. The sampling was essentially based on a 0.5 km x 0.5 km grid system drawn on topographic sheets where the coordinate axes delineating the study area were divided into equal portions across major vegetation strata or blocks categorized as forest, woodland, bushland, grassland and swamps. Sample points were then located within each stratum by selection of random coordinate values. All the strata were sampled and every possible coordinate pair within a stratum had an equal chance of selection.

Field location of sampling points was aided by the direction of major stream profiles.

3.2.1: VEGETATION SURVEY

For each site, a 10 m x 2 m plot was established for an examination of plant species and number. For sites around the lake, vegetation profiles and related zonation was examined from transects laid down orthogonally to the water edge on stabilized zones.

For bushland and open vegetation, small quadrats 0.5 m x 1.0 m were drawn from the 10 m x 2 m plots. The latter were mainly used for woodland sites. In some instances notably the upland forests in the upper catchment, it was necessary to extend into plots 20 m x 5 m, in order to facilitate more complete sampling of large heterogeneous stands.

For all sites, existing plant species were identified, coded and counted. Topographic, hydrologic and land-use characteristics were entered in a recording schedule (see Appendix II). Field transect data from each station was used to compute estimates of stand plant diversity and cover abundance, while the measurement of trunk diameter and height was limited to a few cover types. A similar approach to the one used in this study has been discussed in detail by Cain and Castro, (1959).

Vegetation community classification was based on both plant structure and the aggregation of particular species (Frenkel & Harrison, 1974; Perera, 1975). The unit of classification in this study was the "association" identified here as a group of plants of different species and growth forms but ecologically related, to the extent that they share the same habitat.

3.2.2: HYDROCHEMICAL SURVEY

Water sampling was done during both wet and dry spells between October 18th, 1988 and 3rd February, 1989. Samples were collected from the top 20 cm in 2 litre polyethylene bottles and stored at room temperature prior to laboratory analysis.

3.2.3: SOIL SURVEY

Soil samples were collected between the 8th and 16th of February, 1989. They were taken at each sampling site from 30 cm depths at 25 m intervals along 100 m transects and the four quarters per site merged and thoroughly mixed to give representative site samples (Freeze, 1962; Cochran, 1963; Titus, 1979). The samples were sieved and stored at room temperature prior to laboratory analysis.

3.3.0: HYDROCHEMICAL ANALYSIS

Analysis was done at the Water Quality and Pollution Control Laboratory in Nairobi which was preceded by sample filtration through glass-fiber filters.

pH was estimated colorimetrically with bromthymol blue indicator (Talling and Talling 1965), while colour was measured on centrifuged samples by the Platinum-Cobalt Method. Turbidity values were read directly from a Hack Turbidimeter Model 2100 A (Bierhurzen & Prepas, 1985).

Electrical conductivity values were read directly from an Industrial Instruments conductivity meter corrected for temperature to 25°C and expressed as specific conductance (Golterman *et al.*, 1978). Total dissolved solids (TDS) were estimated from conductivity levels by multiplying the latter with a constant factor (k = 0.6) and expressed as mg/l to facilitate comparisons with past records. Alkalinity (mg $CaCO_3$/l) was measured by titration with standardized H_2SO_4 with bromocresol green-methyl red indicator while total hardness of water was also estimated by EDTA titration (Amer. Pub. Health Assoc., 1965).

Sodium and potassium were measured through flame photometry (Talling and Talling, 1965), using an E EL flame photometer, while calcium and magnesium were measured by EDTA titration using glyoxalbis and eriochrome black (Golterman *et al.*, 1978). Iron and manganese were measured through Atomic Absorption Spectrophotometry (Cooke, 1973).

Chloride was measured titrimetrically using silver nitrate and potassium chromate indicator after washing with sodium bicarbonate and dissolving in nitric acid (Horowitz, 1970). Nitrogen, was measured from nitrite (NO_2-N) by formation of an Azo dye (Saunders *et al.*, 1988) while sulphate was estimated by formation of the barium salt with spectrophotometric estimation of turbidity (Mackereth, 1963). Ascorbic acid colorimetric method (Anon, 1971) was used in the estimation of phosphorus in the orthophosphate form (PO_4-P), while fluoride was measured colorimetrically using alizarin-S and Zirconyl oxychloride (Mackereth, 1963). Free Carbon dioxide was measured titrimetrically using sodium hydroxide and phenolphthalein indicators (Golterman *et al.*, 1978). In addition, Permanganate Number (P.V. NO.) expressed as mgO/l was used as an indicator of oxidizable materials in water (Klein, 1959) where samples were oxidized with potassium permanganate and boiled for 20 minutes and P.V. NO. measured titrimetrically using iodine and sodium thiosulphate.

3.4.0: SOIL ANALYSIS

All soil analyses were done at the National Agricultural Laboratory, Nairobi. Soluble ions of sodium, potassium, calcium, magnesium and manganese were extracted with dilute acid (0.1N HCL + 0.025N H_2SO_4) and determined with reference to Lind & Visser, (1962) and Hesse, (1971).

pH was measured with a Marconi pH meter while sodium, potassium and calcium were determined by flame photometry. Magnesium was determined colorimetrically using thiazol yellow while manganese was similarly determined after oxidation with periodate. Total nitrogen was determined through micro-kjeldahl distillation while total organic carbon was estimated by oxidation with chromic acid.

3.5.0: VEGETATION ANALYSIS

Two methods were employed in vegetation data analysis for the estimation of plant abundance and plant diversity.

Plant abundance

A relative measure of abundance was taken as the estimate of plants (irrespective of species) occupying plots 10 m x 2 m or 20 m x 5 m in area. Measurement was done under an arbitrary 5-cover abundance class system through which vegetation in a sampling site was classified as rare, sparse, frequent, abundant or numerous on the basis of estimated plant coverage in every plot (Cain & Castro, 1959).

Plant diversity

Diversity indices have been studied by many scientists (Simpson, 1949; Kullberg, 1968; Williams *et al.*, 1969; Fager, 1972; Green, 1979). The Shannon-Weiner index was selected for use in this study on the basis of the fact that plant diversity estimation was from sample populations representing large communities (Pielou 1975 and 1977).

Shannon-Weiner index is expressed as follows:

$$H_i = -\Sigma[(n_i/N)\ Log_e\ (n_i/N)]$$

where;

H = Shannon-Weiner index.

n_i = Number of individuals of the i^{th} species in the sample.

N = Total number of individuals.

n_i/N = Proportion of the i^{th} species represented in sample.

3.6.0: LANDSAT DATA ANALYSIS

Materials used for this analysis include three LANDSAT scenes as follows; 1:1 000 000 multi-band (MSS) 9 x 9 cm prints (Bands 4,5 and 7), scene E-1192-07174 of January 31, 1973 and scene E-2368-07031 of January 25, 1976 and 1:000,000 LANDSAT-4 (TM), 9 by 9 cm prints (Bands 1,2 and 4), scene E-50122-07172 of January 1, 1984. These imageries were made available by the Regional Centre for Services in Mapping and Remote Sensing, Nairobi, Kenya. Bands 4,5 and 7 are particularly good for ecological studies (Ondenyo, 1979; Maher *et al.*, 1980; Ringrose & Large, 1983; Aleong-Mackay, 1987).

The three LANDSAT scenes were enhanced by the Spectral Data Series 70 Colour Additive Viewer that provides a selective enhancement technique for multispectral and/or multitemporal differences in imagery, yielding simulated

Colour Infra-Red (CIR) prints. The procedure simultaneously enlarged these false colour composite images to the scale of 1:250 000 which were then subjected to visual interpretation. Boundaries around water surfaces, woodlands, forest and bushlands were identified on the CIR imagery and transferred to a 1:250 000 map of the area (Nyeri; 1:250 000 series Y503 sheet SA-37-1 edition 3-SK, Kenya Government 1973) with the guidance of ground truth data. The integration of map data, satellite information and ground reconnaissance survey (ground truthing) for a common geographic data base permitted investigation of intended relationships.

Identification of forest and woodland belts was based on visible colours on the CIR LANDSAT imageries coupled by ground truth data. Largely undisturbed forest appeared deep red, compared to lighter red to brown in areas of disturbance whilst bushland and open grasslands varied between grey and dirty white coloration on LANDSAT TM. Lakes and dams appeared black and the high concentration of salts together with predominantly shallow water zones at Lake Elementeita resulted in light blue colours.

Forest/woodland area determination and related dynamics was achieved through ordinary geographic methods involving multitemporal LANDSAT imagery and topographic map overlays.

3.7.0: STATISTICAL ANALYSIS

Multiple linear regression analysis and Principal Component Analysis were used examine various interrelationships between both physical and biological variables. The related analysis has also used several tests of significance including the F-test for the analysis of variance and the t-statistic to determine the strength of the relationships. All statistical computations were done using STATVIEW+ 512 computer package (Fieldman *et al.*, 1986).

3.7.1: MULTIPLE LINEAR REGRESSION ANALYSIS

The multiple linear regression model was adopted for use in this study as a means of investigating two major sets of relationships. First, the relationships between hydrochemical and vegetational variables and secondly, relationship between lake levels and climatic variables. A detailed discussion of multiple regression analysis can be found elsewhere (Chatterjee, 1977; Draper & Smith, 1966). The description provided here is restricted to only those areas of the model that are of particular interest as far as this work is concerned.

Multiple linear regression aims at explaining the values of a variable Y (dependent) by means of other variables X_1, X_2,.....X_q (independent or explanatory). The general model by which it is often postulated that a relationship is linear is represented as follows;

$$Y_i = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} +,\ldots\ldots +\beta_m X_{mi} + \epsilon_i$$

Where;

Y_i = An estimate of the i^{th} dependent variable from the independent variables X_1, X_2,.....X_m

X_i = the i^{th} observation of the independent variable

β_o = the y-intercept (a regression constant)

β_1 = Slope of the regression relationship between Y_i and X_i (Regression coefficient)

ϵ_i = Stochastic or error term (disturbance value)

In the above model, β_o, β_1, β_2.......β_m are population parameters which cannot be obtained unless the whole population is measured. From a sample taken from the population however, the best estimates of these parameters will be b_o, b_1, b_2, ... b_m. Consequently, the sample regression equation is expressed as follows (Draper & Smith, 1966; Chatterjee, 1977; Harnett, 1982)

$Y = b_o + b_1x_1 + b_2x_2 + ... + b_mp_m$.

A major objective of regression is to minimize the sum of the squared deviations of the individual values y_i about the predicted values of y_i. Normal procedures can be used for the partition of total variation in the regression problem into sums of squares of regression (SS_{reg}) and sum of squares of residuals (SS_{res}). From a ratio of the two, the multiple coefficient of determination (R^2) can be calculated, from which correlation coefficients (**r**) values can also be computed. Ranging between the two extreme levels of zero and one, **r** provides a measure of the degree of correlation between **X** and **Y** variables. An analysis of variance table can also be drawn from the regression results.

A variety of test procedures have been developed to test the strength of the relationship between **Y** and **Xs** in multiple regression model and for this study, the **F** and **t**-statistics were used (Chatterjee, 1977). The **t** - statistic was particularly selected to determine the significance of individual coefficients in the model, with a null hypothesis that the variable x_i has no linear relationship with y_i holding the effect of the other independent variables constant.

3.7.2: PRINCIPAL COMPONENT ANALYSIS

Principal Component Analysis was selected for application in this study as a means of classification for major hydrochemical variable groupings in Lake Elementeita. The aim was to isolate outstanding or dominating chemical constituents of water in order to determine dominant chemical substances in the lake. Principal Component Analysis was favoured here because while producing results that do not differ widely from those of Common Factor Analysis, its results are more objectively interpretable. Further, it avoids the problem of having to compute communalities which is a requirement in Common Factor Analysis. PCA techniques have been used in many studies for an assessment of vegetation-environment relationships (Barkham & Norris, 1970; Caldas & White, 1983; Morgan, 1987; Smith *et al.*, 1987). In Kenya, Barkham & Rainy (1976) used the technique to determine relationships between biogeochemical gradients and vegetation variation in Samburu-Isiolo Game Reserve.

Principal Component Analysis (PCA) and Common Factor Analysis are multivariate techniques whose basic problem is to determine whether **n** variables in a set, exhibit patterns of relationship with one another, such that the set could be broken down into say **m** subsets each consisting of a group of original variables tending to be more highly related to each other within the subset than those in others. The major purpose is to determine whether, a set of variables can be described in terms of a number of factors and to determine what these factors are. For a detailed description of the PCA and other multivariate techniques, the reader is referred to Lindeman (1980).

The basic Component Analysis model is expressed compactly as follows;

$$Z_{j1} = a_{j}iC_{11} + a_{21}C_{21} + \ldots\ldots, + a_{j}nC_{n1}$$

Where;

a_{ji} = The i^{th} component loading for the j^{th} principal component

C_{1i} = The first principal component for all $i = 1,2,....n$.

In this study, Kaiser's criterion (Kaiser, 1960) which is based on components having eigenvalues greater than one was used to determine the number of components to extract. Other criteria include the scree test (Cattel, 1966). Naming or defining of factors was based on the values of the variables to which the factor made the greatest contribution (Lindeman, 1980).

3.8.0: RESEARCH LIMITATIONS

This exercise was coupled by several problems. Most significant was the limited funds available, whereby the whole exercise had to be sufficiently organized around a stiff budget of K.sh 18000 (US $857). Consequently, sampling was restricted to four months in the field with remarkable limitations on long-term evaluation of most environmental variables. In addition, lack of various equipment prohibited some intended biogeochemical and vegetation evaluations particularly within the lake.

Movement across the watershed was not an easy task and related transportation of samples from various points to the labs in Nairobi presented some very difficult problems. Research assistance was mostly restricted to one field assistant which was insufficient particularly for the vegetation survey. To this can be added a number of other limitations emanating from bad weather conditions and insecurity in some remote parts of the basin.

CHAPTER FOUR

VEGETATION

4.1.0: INTRODUCTION

The major objective in this chapter is to analyse vegetation structure in the Lake Elementeita drainage basin. The chapter therefore describes vegetation characteristics across the drainage basin in terms of major species and the distribution of various plant associations. Later sections provide an analysis of vegetation in terms of cover abundance and diversity.

4.2.0 VEGETATION STRUCTURE

Vegetation around the Elementeita drainage basin is diverse. Over 150 different species were encountered during this study and a checklist of common plants is provided in Appendix I. Nine broad plant associations were identified in the watershed (Fig.4).

Olea-Juniperus-Dombeya upland forest association

This forms the vegetation in upper catchment belts of Ngorika-Nyaituga hills across Ndunduri, Rutara and Kanjuiri. Around Kiringa valley, this vegetation prevails at lower altitude. Human encroachment is rapidly replacing this vegetation mainly with maize fields. Dominant trees include ***Olea africana*, *Juniperus procera*** and ***Dombeya goetzenii*** while notable species along streams include ***Olea hochstetteri*, *Polyscias kikuyuensis*, *Ficus thonningii*** and ***Nuxia congesta***. Some trees rise up to 20 m in height and devoid of a true canopy formation observed in many forest ecosystems. Bush and shrub plant species include ***Rhus natalensis*** around Nyaituga and Rutara and ***Euclea*** *divinorum* in parts of Chamuka. Notable herbs include ***Trifolium cryptopodium, Galinsoga parriflora, Hypoestes verticillaris*** and ***Urtica masaica*** which are intermingled with the grass species ***Pennisetum clandestinum*** and ***Panicum spp.*** Rocky environments, particularly near water points, are characterized by mosses and ferns.

***Acacia-Olea* forest association**

Occupying the intensively cultivated belts across Ngorika plateau (elevation 2170-2256 m) from Nyaituga to Ndunduri, this formation is almost completely replaced by human settlements and agro-ecosystems except for a few lines along major streams. This generally flat landscape with fertile grey soils is particularly favourable for agriculture and livestock husbandry. ***Acacia tortilis*** and ***Olea africana*** constitute dominant tree species but ***Dombeya goetzenii*** is also common. Both ***Olea africana*** and ***Dombeya goetzenii*** have now been replaced by ***Acacia tortilis*** to the subdominant level. Apart from the fact that the latter is not a common source of fuel-wood in the area, ***Acacia tortilis*** is also more tolerant to drier conditions and is favoured by dairy farmers because it also allows the development of good pastures. Major grasses include the nuisance species ***Cynodon dactylon, Pennisetum clandestinum*** and ***Panicum spp*** with herb species such as ***Trifolium usambarense*** and ***Geranium arabicum.*** Along streams, ***Kyllinga aurata, Rotala apetala*** and ***Cyperus rigidifolius*** constitute salient aquatic sedge species.

***Pennisetum-Eleusine* swampy grassland association**

This occupies most of the Ngorika swamps where soils are predominantly vertisols but with a low content of montmorillolite clays in comparison to the levels associated with planosols that occupy many parts of the Nyandarua plateau. ***Pennisetum clandestinum*** is rapidly being replaced by ***Eleusine jaegeri*** because the latter being hardy and unpalatable is disfavoured by livestock hence its dominance with increased grazing. In some places, ***Eragrostis tenuifolia*** is fairly abundant. The swamps are characterized by ***Acacia tortilis*** as the sole tree species with ***Trifolium cryptopodium, Solanum incanum***, and ***Geranium arabicum*** as major herbs. Highly waterlogged environments are dominated by ***Kyllinga aurata, Cyperus rigidifolius*** and ***Potamogeton spp.***

***Acacia-Rhus-Tarchonanthus* woodland association**

This formation is restricted to a narrow belt along Mbaruk hills in the north (Fig 4). Lying at approximately 2134 m, the soils of this belt show higher proportions of sands. The area is reasonably well conserved, under the auspices of a Government research farm at Lanet, and the belt has fairly dense tracts of ***Acacia tortilis*** with ***Teclea simplicifolia*** and ***Warburgia salutaris*** alongside streams. ***Stephania abyssinica*** and ***Achyranthes aspera*** constitute the middle canopy and undergrowth. Overgrazing and fuel-wood cutting especially in areas bordering human settlements is now converting this woodland into a bushland dominated by ***Tarchonanthus camphoratus*** and ***Rhus natalensis***.

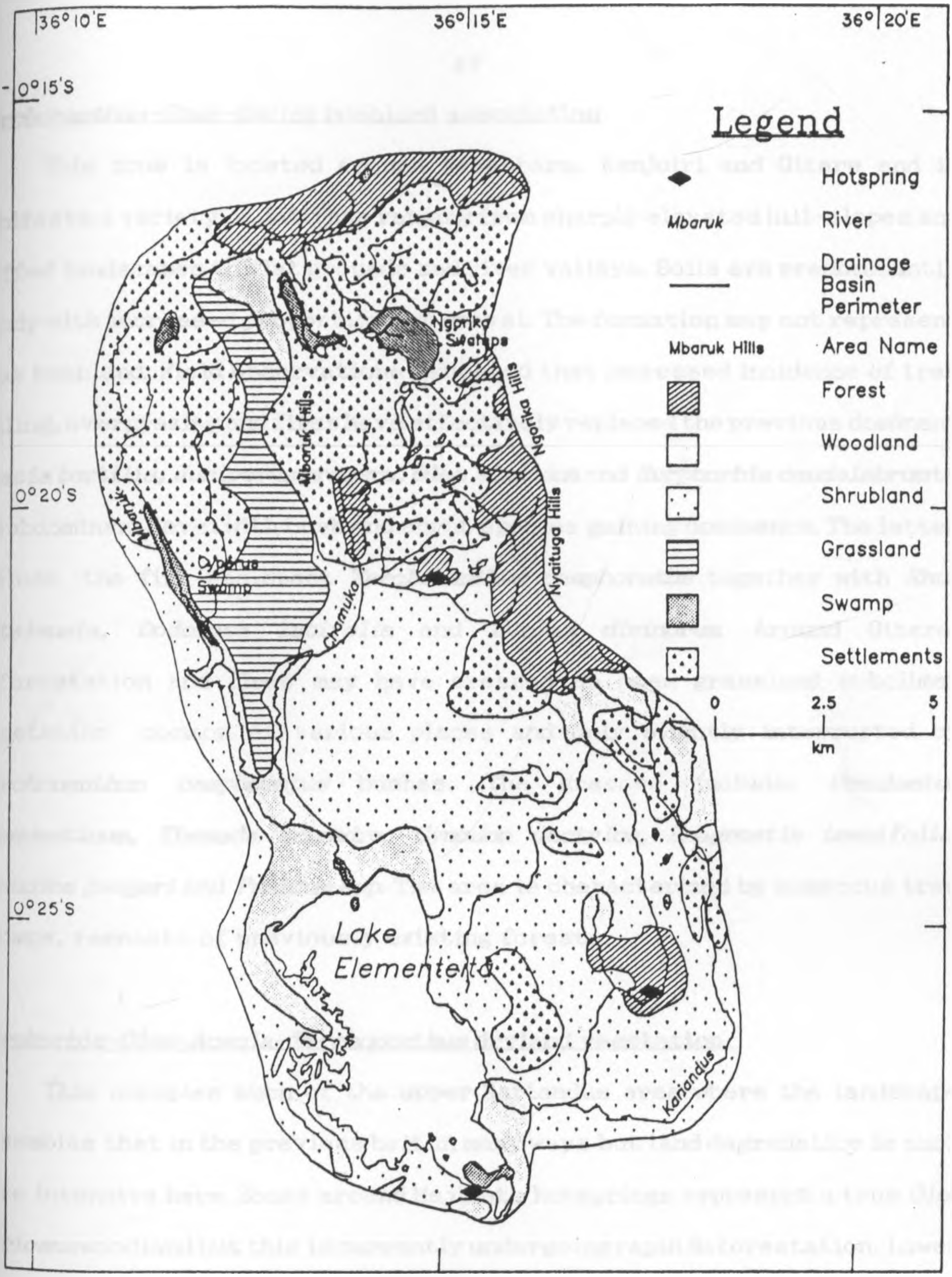


Fig. 4: Vegetation distribution in the Elementeita drainage basin.

Source: Field Survey

Tarchonanthus-Rhus-Euclea bushland association

This zone is located around Kasambara, Kanjuiri and Gitare and it manifests a variety of habitats ranging from sharply elevated hill-slopes and cliffed landscapes to flat grounds and river valleys. Soils are predominantly sandy with increased proportions of gravel. The formation may not represent true bushland. Field observations indicated that increased incidence of tree felling, overgrazing and fires have effectively replaced the previous dominant ***Acacia tortilis, Juniperus procera, Olea africana*** and ***Eurphorbia candelabrum*** to a subdominant level with bush and shrub species gaining dominance. The latter include, the fire resistant ***Tarchonanthus camphoratus*** together with ***Rhus natalensis, Dodonaea latifolia*** and ***Euclea divinorum***. Around Gitare, deforestation and fires may have created an open grassland subclimax vegetation common at various places and only slightly interrupted by ***Tarchonanthus camphoratus*** bushes. The grasses include; ***Pennisetum clandestinum, Themeda triandra, Cynodon dactylon, Eragrostis tenuifolia, Eleusine jaegeri*** and ***Panicum spp***. The area is characterized by numerous tree stumps, remnants of previously existing forests.

Eurphorbia-Olea-Acacia-Tarchonanthus dryland vegetation

This occupies much of the upper Kariandus area where the landscape resembles that in the previous belt in many ways but land degradation is much more intensive here. Zones around Majimoto hotsprings represent a true ***Olea africana*** woodland but this is currently undergoing rapid deforestation. Lower down around Kariandus, the vegetation suddenly grades into dry ***Tarchonanthus camphoratus*** and ***Euclea divinorum*** shrubland with both ***Aspilia pluriseta, Acacia drepanolobium*** and ***Vernonia spp***. forming less dominant shrubs. ***Acacia*** *xanthophloea* is largely restricted to riverine habitats together with *Setaria chevaleri, Hyparrhenia hirta* and *Panicum* species. Elsewhere, *Themeda triandra* and *Sporobolus spp* constitute a major source of livestock forage.

<u>*Acacia-Themeda-Chloris* lowland wooded grassland association</u>

This covers large parts of Soysambu estate north of lake Elementeita which lie at approximately 1880 m. *Acacia xanthophloea* is the dominant tree with *Ficus sur, Warburgia salutaris* and *Teclea simplicifolia* restricted to riverine habitats. Bushes and shrubs are rare. The grasses *Chloris gayana* and *Themeda triandra* are widespread together with the much more localized *Setaria chevaleri, Sporobolus* and *Panicum Spp. Senecio petitianus, Commelina africana, Tagetes minuta, Achyranthes aspera* and *Bidens pilosa* constitute major herbs. This vegetation formation collectively supports very successful ranching operations across Delamere's Soysambu Estate.

<u>*Themeda-Sporobolus-Eragrostis* lowland open grassland association</u>

This extends from southern Lanet to Mbaruk railway station in the low-lying flat areas across both the Trans-African Highway and the Great North Road. *Acacia xanthophloea* exists in restricted habitats and the grassland is dominated mainly by *Themeda triandra, Sporobolus fimbriatus, Eragrostis tenuifolia* (very dominant), *Eragrostis exasperata, Pennisetum catabasis* and *Cynodon dactylon.*

<u>*Cyperus* swamps</u>

These are restricted to riverine habitats along Mbaruk river between Lanet Government farm and the Trans-African Highway for a distance of well over 2 km (Fig. 4). The swamps are fairly dense and the vegetation rises up to 3.5 m in height. They are composed of both ***Cyperus papyrus*** and ***Cyperus immensus*** intermingled at various places with the grasses ***Cynodon dactylon*** and ***Hyparrhenia spp***.

Four major vegetation zones were identified around Lake Elementeita including ***Acacia*** woodland, dry bushland, lake-side grasslands and swamps.

The woodlands are concentrated around the mouths of rivers (Fig. 5) with ***Acacia xanthophloea*** as the sole tree species. In some places, these trees rise up to 25 m in height with clear vertical stratification. Below the upper canopy is a zone dominated by various climbers including ***Senecio petitianus, Commicarpus pedunculosus*** and ***Ipomoea cairica*** (Figs. 6 & 7). Herb species are dominated by the species ***Achyranthes aspera*** (very dominant), ***Hypoestes verticillaris*** (dominant), ***Conyza floribunda*** (dominant), ***Solanum incanum, Urtica masaica*** and ***Gutenbergia cordifolia***. The ground layer is dominated by the grass species ***Cynodon dactylon*** and ***Pennisetum clandestinum*** with ***Oplismenus compositus, Setaria chevaleri*** and ***Panicum spp*** restricted to specific habitats close to the water.

The dry bushlands cover parts of the eastern and much of the southern and western parts of the lake where dominant tree species include ***Acacia xanthophloea*** and ***Eurphorbia candelabrum***. Bush species are dominated by ***Rhus natalensis, Sesbania sesban, Lantana trifolia***, and ***Vernonia spp*** while ***Cynodon dactylon, Chloris gayana*** and giant ***Panicum*** grass species are also very common.

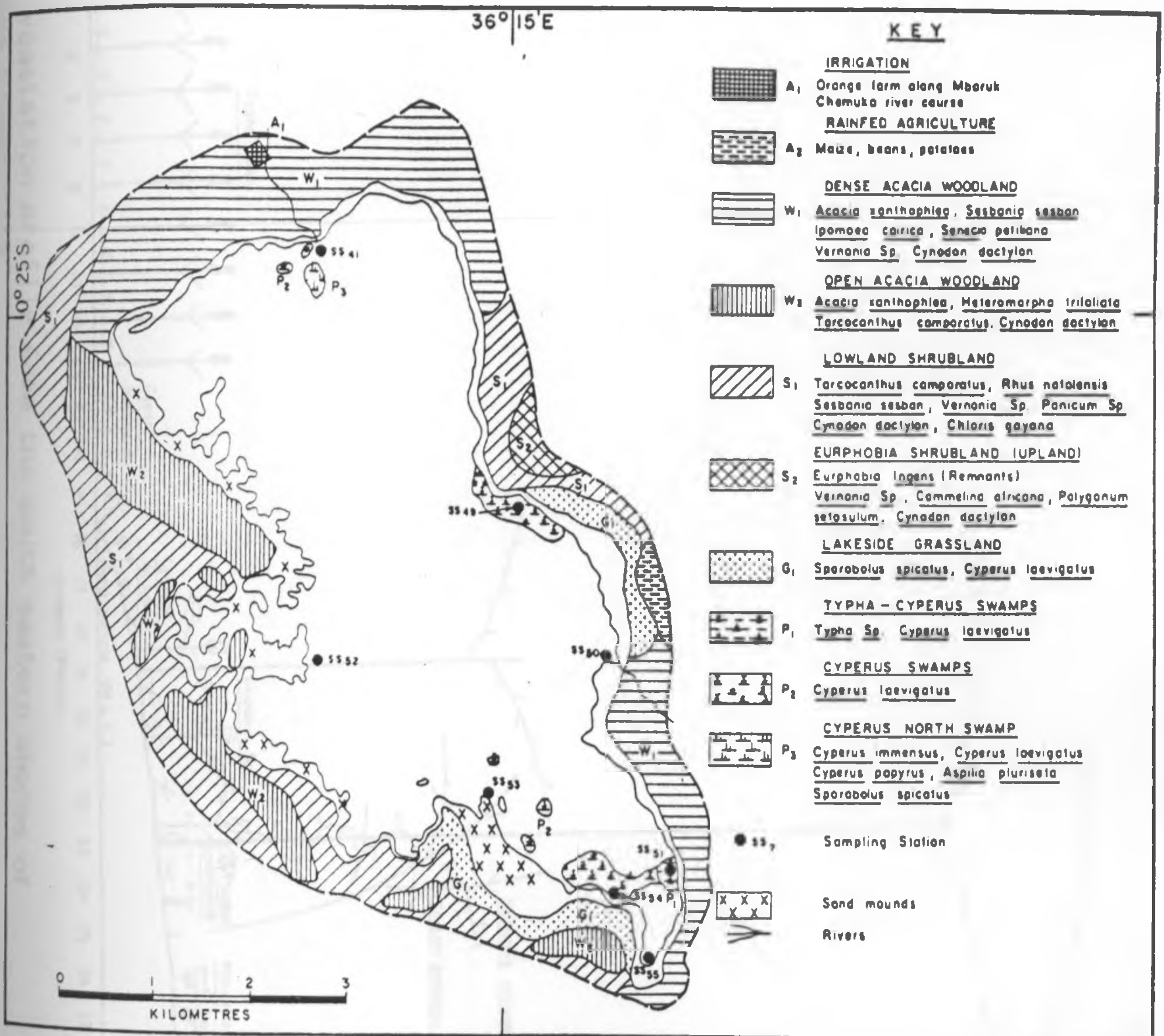


Fig. 5: Vegetation zones around Lake Elementeita.

Source: Field Survey

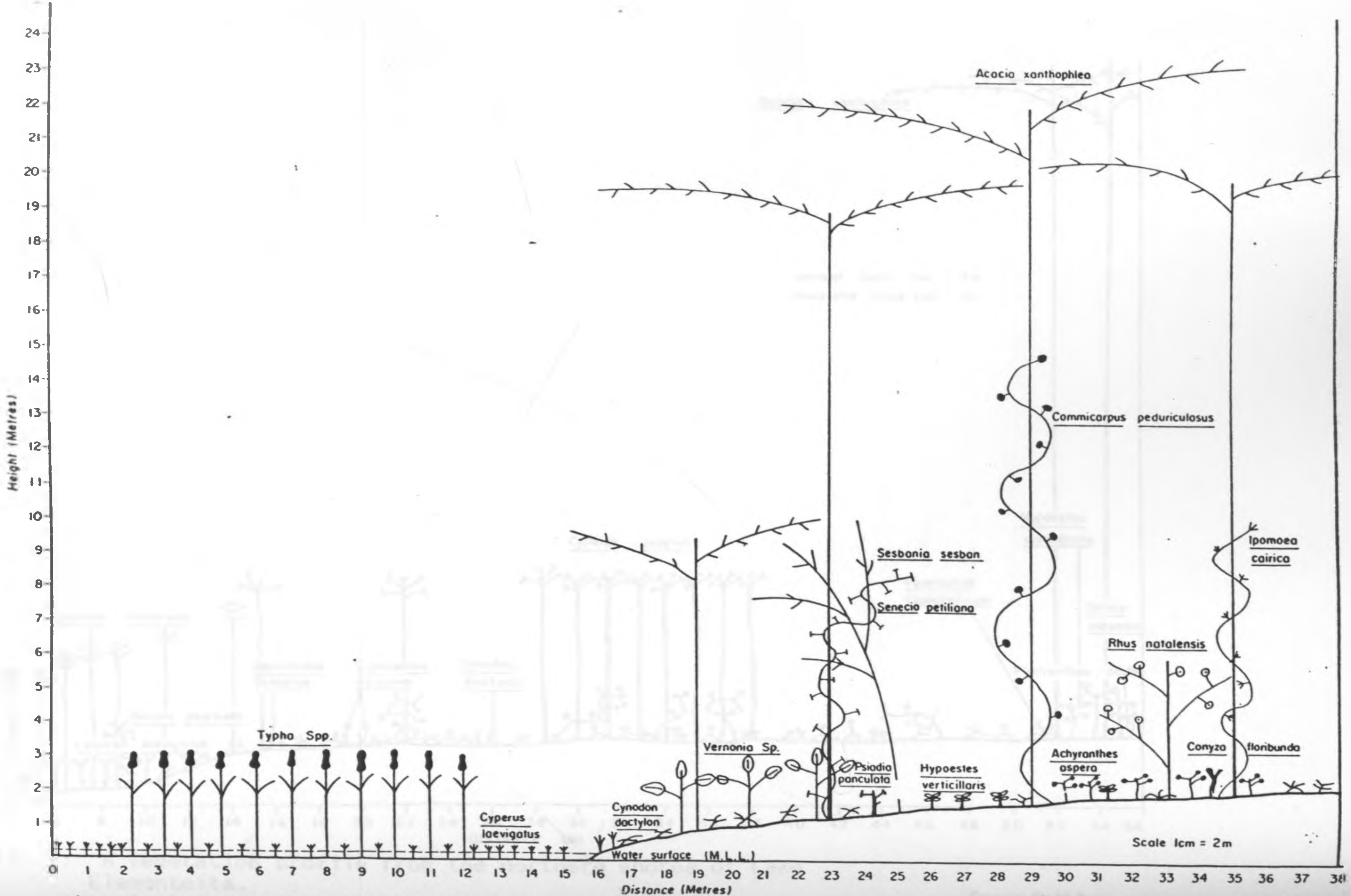


Fig. 6: A vegetation profile from the south eastern shores of Lake Elementeita.

Source: Field Survey

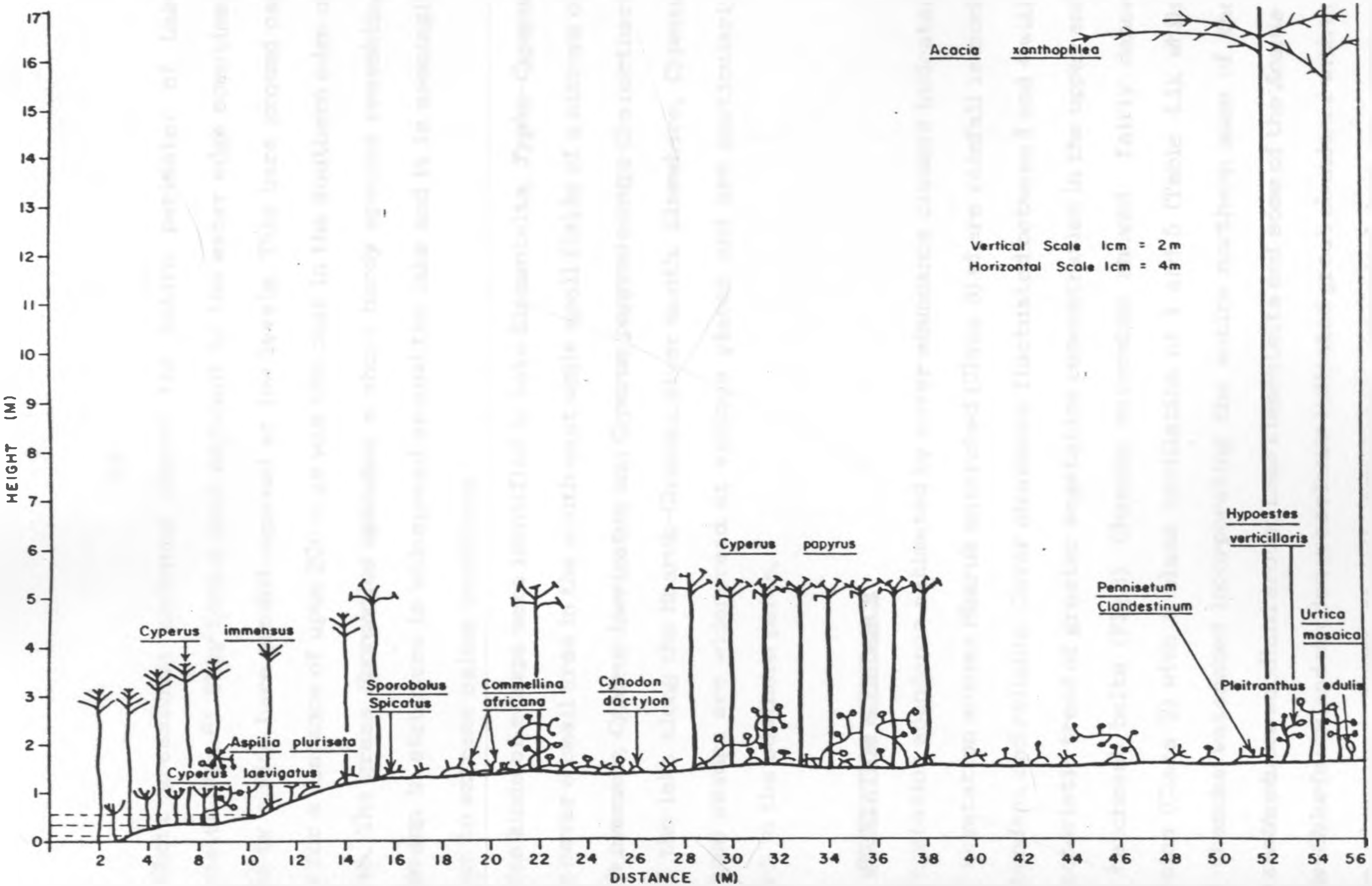


Fig. 7: A vegetation profile from the northern shores of Lake Elementeita.

Source: Field Survey

Short grasslands surround almost the entire perimeter of Lake Elementeita (Fig. 5). They form a zone adjacent to the water edge sometimes bridged by a wide bare ground exposed at low levels. This bare ground can extend for a distance of upto 200 m as was the case in the southern edge of the lake. The grass ***Sporobolus spicatus***, a short hardy species resembling ***Cynodon spp.*** in structure is widespread around the lake and it is seemingly tolerant to extreme saline conditions.

Three kinds of swamps were identified in Lake Elementeita. ***Typha-Cyperus*** swamps cover a small area in the south east while small fields of a mixture of ***Cyperus immensus, Cyperus laevigatus***, and ***Cyperus papyrus*** occupy the northern part of the lake along the Mbaruk-Chamuka river mouth. Elsewhere, ***Cyperus laevigatus*** swamps are widespread at various places and are particularly dominant in the southern parts.

4.3.0: VEGETATION ABUNDANCE

Vegetation abundance estimated by cover abundance classes indicated denser vegetation across Mbaruk watershed (Class 3) where rainfall is much more abundant and reliable. Cover abundance fluctuated between 1 and 4 with a characteristic trend of greater vegetation concentration in the upper and middle catchment belts (Fig.8). Chamuka watershed showed fairly dense vegetation (Class 2) with a class oscillation of 1 and 5 (Table 4.1), while Mbaruk-Chamuka watershed incorporating the entire northern zone of the ***Acacia xanthophloea*** woodland around Lake Elementeita and some of the ***Acacia-Themeda-Chloris*** lowland wooded grasslands indicated great abundance with an average abundance class of 2.0. Kariandus watershed had an average abundance class of 2 and unlike the other two subcatchments, vegetation abundance was here much more uniform (Fig.8). The upper parts including deforested hills of Gitare and Kanjuiri showed low plant abundance. Vegetation in the basin showed some conformity with prevailing climatic conditions and a declining trend in vegetation abundance was observed in relation to declines in rainfall amount and reliability.

Around the lake, cover abundance was generally low with an exception of river mouth areas. Most vegetation profiles were characterized by grounds sparsely covered with ***Sporobolus spicatus*** as the single species.

The highest spatial variations in vegetation abundance were observed across Chamuka whose location in an eco-climatic transition zone bridging a wet environment to the north and a dry one to the south might result to greater diversity in terms of plant habitats.

Table 4.1.0 Plant abundance classes in Elementeita basin

Catchment	Abundance class	Average class	Standard Deviation
Mbaruk	1-4	2.4	1.0
Chamuka	1-5	2.3	1.1
Mbaruk-Chamuka	2	2.0	0.0
Kariandus	1-2	1.6	0.5

(Field data)

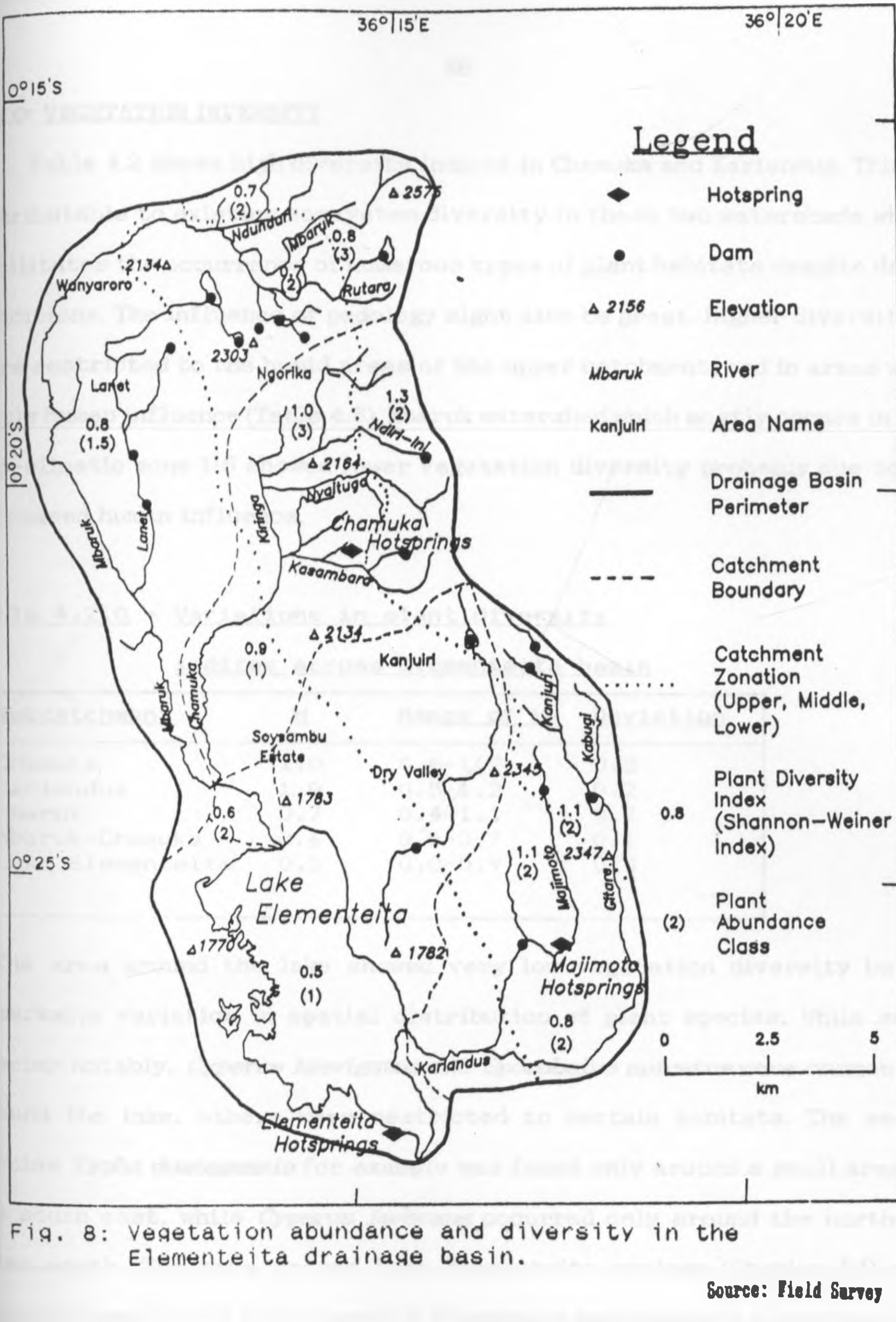


Fig. 8: Vegetation abundance and diversity in the Elementeita drainage basin.

Source: Field Survey

4.4.0: VEGETATION DIVERSITY

Table 4.2 shows high diversity indices in Chamuka and Kariandus. This is attributable to existing ecosystem diversity in these two watersheds which facilitates the occurrence of numerous types of plant habitats despite drier conditions. The influence of pedology might also be great. Higher diversities were restricted to the humid areas of the upper catchment, and in areas with little human influence (Table 4.3). Mbaruk watershed which mostly occurs in the eco-climatic zone II6 showed lower vegetation diversity probably due to an increased human influence.

Table 4.2.0 - Variations in plant diversity indices across Elementeita basin

Subcatchment	H	Range of H	Deviation
Chamuka	1.0	0.6-1.2	0.2
Kariandus	1.0	0.5-1.2	0.2
Mbaruk	0.7	0.4-1.1	0.2
Mbaruk-Chamuka	0.6	0.5-0.7	0.1
Lake Elementeita	0.5	0.0-0.9	0.3

The area around the lake showed very low vegetation diversity but a remarkable variation in spatial distribution of plant species. While some species notably, *Cyperus laevigatus* and *Sporobolus spicatus* were common all around the lake, others were restricted to certain habitats. The sedge species *Typha domingensis* for example was found only around a small area in the south east, while *Cyperus immensus* occurred only around the northern river mouth. The area around Lake Elementeita springs (Station 54) was characterized by the grass species *Sporobolus spicatus* as a single species thus providing an index of 0 (Table 4.4).

Table 4.3.0 Quantative plant diversity index (H) results for sampling stations on a source-mouth profile of Chamuka

Sampling station	Number of species	Total count	Diversity Index (H)
23(U)	28	209	1.204
24(U)	29	367	1.013
19(U)	29	298	1.551
21(U)	33	268	1.201
8(U)	21	628	1.055
9(U)	19	214	1.035
10(U)	16	529	0.587
20(U)	22	392	0.587
25(M)	36	258	1.228
22(M)	20	197	1.152
26(M)	22	157	0.865
27(M)	20	80	1.173
28(M)	21	195	0.972
29(M)	17	178	0.980
30(L)	13	124	0.852
40(L)	14	108	0.873

U = Upper catchment
M = Middle catchment
L = Lower catchment
Field Data)

Hotspring areas outside the lake were characterized by fairly high diversities. At Chamuka, 33 different plant species were identified including ***Ficus sur, Geranium arabicum, Pennisetum clandestinum, Rotala apetala, Achyrospermum schimperi*** and ***Tarchonanthus camphoratus*** as the most dominant. At Majimoto springs a total of 26 different species were identified, the most dominant including; ***Olea africana, Rhus natalensis, Digitaria velutina, Panicum spp, Adiantum thalictroides*** and ***Solanecio spp.***

Table 4.4.0* Plant diversity indices (H) results for stations around Lake Elementeita

Sampling Station	Number of species	Total count	H
41	7	193	0.573
49	6	224	0.421
50	6	25	0.528
51	14	146	0.877
54	1	40	0.000
55	2	30	0.276
53	2	13	0.235
52	15	126	0.840

* - See Fig. 9 (Field Data)

In summary, this chapter has discussed the nine major plant associations identified in the catchment of Lake Elementeita and outstanding vegetation zones around the lake ecosystem. The discussion on the spatial distribution of different plant species in the region indicates a remarkably high degree of heterogeneity in vegetation distribution which is evident from quantative records on both plant diversity indices and abundance classes. This is mostly attributed to both climatic and human factors.

CHAPTER FIVE

HYDROCHEMISTRY

5.1.0 INTRODUCTION

Two major objectives are examined in this chapter. The first aim is to analyse the hydrochemistry of Lake Elementeita and its river systems, including an investigation into the significance of thermal springs to water chemistry to the lake ecosystem. The second objective is to examine the relationship between plant communities and prevailing hydrochemical conditions around Lake Elementeita. The first two sections dwell therefore on the hydrochemistry in the drainage basin while a latter section discusses water conditions in thermal springs. Results of statistical analyses and vegetation-environmental relationships are also discussed.

5.2.0 THE RIVERS

Hydrochemistry around the basin manifested marked variations with some remarkable similarities across a spectrum of habitats. Water pH varied slightly across the watershed with Mbaruk recording lowest mean values at pH 6.9 while in Kariandus it was 7.5. Higher fluctuations occurred across agricultural and livestock production areas. The average turbidity in the basin was 47 mg/l but it exhibited high variations, with Mbaruk recording the highest mean levels at 54 mg/l. Apart from stream-bed characteristics, this may be attributed to a higher intensity of agriculture and livestock husbandry in the upland areas of Ngorika and Nyaituga.

High conductivity levels were common throughout the basin which implies a high concentration of mineral salts. The highest conductivity was measured in Kariandus at 267 μS/cm and lowest in Mbaruk at 137 μS/cm. Chamuka recorded mean conductivity at 171 µS/cm. Great fluctuations in conductivity along river profiles were observed with forested belts around Ngorika, Rutara, Kanjuiri and Kariandus generally recording lower levels in contrast to farming areas, swamps and bushlands. A similar trend was manifested in total dissolved solids (TDS).

Alkalinity across the basin was also high. Average basin levels were estimated at 608 mg $CaCO_3$/l, with highest and lowest mean levels at 101 and 43 mg $CaCO_3$/l for Kariandus and Mbaruk respectively (Table 5.2.1). Greater alkalinity variations existed within Kariandus while Chamuka exhibited much more stable conditions. Densely vegetated belts recorded low alkalinity in contrast to the fire prone and deforested areas of Kasambara and Gitare. Riverine swamps and agricultural belts indicated higher alkalinity.

The level of iron across the basin was relatively stable with the concentration ranging between 1.4 mg/l in Kariandus to 1.7 mg/l in Mbaruk and Chamuka (Table 5.2.1). Lower levels existed in forested and bushland areas while agricultural belts generally recorded higher iron. Within Mbaruk for example, iron concentration increased sevenfold from 1.0 mg/l in forests above Wanyororo to 8.0 mg/l below Lanet across an intensively cultivated and grazed landscape. Manganese was similarly low and stable across the basin at approximately 0.1 mg/l.

Table 5.2.1 - Water chemistry in the Lake Elementeita catchment(mg $CaCO_3$/l & mg/l)

	River			
Parameter (mg/l)	Mbaruk	Chamuka	Mbaruk-Chamuka	Kariandus
Alkalinity	42.7	54.3	54.0	100.8
Iron	1.7	1.7	1.3	1.4
Potassium	3.3	4.5	2.2	5.9
Fluoride	0.6	0.9	0.3	1.6
Chloride	9.2	11.8	10.0	9.5

(Field data)

Average calcium concentration across the basin was 9 mg/l with highest levels existing in Kariandus at 11.5 mg/l and lowest around Chamuka at 8.6 mg/l. Concentration of calcium showed great variations along Mbaruk where higher levels were observed across farming areas and across deforested fire prone areas of Gitare and Kasambara valley. On the other hand magnesium was generally low, with great spatial uniformity although slightly higher concentrations existed across Kariandus at 3.67 mg/l.

Sodium was generally high, with mean basin level at 303 mg/l. Highest sodium concentration was measured in Kariandus. Potassium concentration was remarkably low across the basin with average concentration at 7.7 mg/l.

Chloride concentration in rivers across the basin ranged between 11.8 mg/l for Chamuka and 9.2 mg/l for Mbaruk which marked a great contrast with prevailing conditions around the lake. Spatial variations in chloride concentration were small but agricultural belts and swamps generally recorded higher levels while largely undisturbed forests measured low chloride levels. Fluoride on the other hand was generally below 1.5 mg/l except in Kariandus where it slightly exceeded this level. The latter maybe explained by the weathering of alkaline lavas in the area.

Sulphate concentration in the watershed did not exceed 100 mg/l and in Chamuka it was measured at 1.9 mg/l. Higher sulphate concentration was found across the agricultural belts of Ngorika as well as in swampy areas notably with in the ***Cyperus papyrus*** vegetation near Lanet.

Phosphorus concentration was low and remarkably stable with average basin phosphorus level calculated at 0.07 mg/l (Table 5.2.1). Kariandus recorded highest concentration at 0.12 mg/l while both Mbaruk and Chamuka had mean levels at 0.01 and 0.02 mg/l respectively. Nitrogen concentration was also low and relatively stable at 0.01 mg/l, with only small oscillations across intensive agricultural belts. High Permanganate number was encountered across small areas of undisturbed forest where detritus was more abundant.

An analysis of Variance (ANOVA) on hydrochemical data across the basin showed significant variation for all variables with an exception of iron, manganese, nitrogen and fluoride. This test particularly indicated greater spatial variation in the concentrations of sodium, potassium and chloride, with F values computed at 12.22, 10.86 and 12.37 respectively which were significant at $P < 0.01$ and 54 degrees of freedom.

For rivers within the East African Rift Valley, water pH ranges between 6.5 and 7.5 except in a few cases like that of Njoro river (Table 5.2.2). Ugandan rivers are however much more alkaline and those that drain Mount Elgon, Ruwenzoris, Karamoja and Kigezi regions have water pH mostly above 7.0 while some like Semliki and Mpanga in the west have even higher pH levels. Sodium concentration in Semliki river has been measured at 79.7 mg/l which is high in contrast to Kenyan rivers. Ugandan rivers also indicate high calcium, magnesium, potassium, phosphorus, nitrogen and sulphate (Viner, 1975). The high salinity in Ugandan rivers is said to arise from high carbonate levels which, according to some Viner (1975) may encourage silica to dissolve rapidly from the surroundings under much higher pH conditions. For many parts of East Africa however, the influence of geology is great, particularly in areas of considerable volcanic activity given that related volcanic deposits are particularly rich in alkalis.

Table 5.2.2 - Water chemistry (mg/l & pH scale) in some East African rivers

River	pH	Na	K	Cl^{--}	SO_4^{--}
Mbaruk[3]	6.9	12.7	3.3	9.2	2.0
Chamuka[3]	7.0	16.0	4.5	11.8	1.9
Kariandus[3]	7.5	40.9	5.9	9.5	3.7
Molo[2]	7.3	12.7	0.7	5.0	nd
Malewa[2]	6.5	11.4	nd	3.0	T
Njoro[2]	8.9	13.2	nd	4.0	T
Malaba[1]	7.3	9.2	4.1	2.2	8.2
Locheman[1]	6.5	3.9	5.0	1.0	4.1
Semliki[1]	8.7	79.7	60.2	44.2	95.7
Nyamweru[1]	7.6	6.0	7.1	1.4	21.6
Mpanga[1]	8.2	16.8	2.7	4.7	23.1

1 - Talling & Talling, (1965)
2 - McCall, (1967), 3 - Author (nd = Not determined, T = Trace)

The higher turbidity levels observed across agricultural and livestock production areas of Ndunduri, Ngorika and Nyaituga may indicate some consequences of improper soil and water management. The extent of eutrophication of rivers in the basin is difficult to estimate because of a high geological influence. Slightly higher oscillations in the concentrations of some minerals notably iron, calcium, nitrogen and sulphate in cultivated areas may indicate the effect of agriculture on hydrochemistry across agro-ecosystems mainly through fertilizer application, nature of tillage, water management and cropping systems.

The industrial process at Kariandus Diatomite mines did not at the moment indicate any significant incidence of water pollution although the lower section of Kariandus river below the industry showed a continuous deposition of whitish rock particles on river beds as a result of earthworks at the factory.

5.3.0 THE LAKE

Lake Elementeita manifested some extreme hydrochemical conditions and the average total dissolved solids (TDS) level at 7703 mg/l was 70 times higher around the lake than in the watershed (Table 5.3.1). Average water pH was 8.8 with a high of 10.2 in the western parts of the lake (Fig. 9). Both Sodium and chloride were 50 times higher in the lake than in the catchment while alkalinity and conductivity levels estimated at 3832 mg $CaCO_3$/l and 12842 μS/cm respectively was about 60-70 times higher than in rivers. Sulphate around the lake was also remarkably higher.

Calcium, potassium and magnesium indicated some accumulation in the lake. Permanganate number was high indicating abundance in organic matter especially for areas in the lake attracting large avian populations. The accumulation of minerals and salts in the lake can be attributed to evaporative concentration especially with the lack of a direct water outlet.

Table 5.3.1 - Average hydrochemical conditions around Lake Elementeita in comparison to the catchment

Parameter	Lake	Catchment
pH (pH scale)	8.8	7.1
Turbidity (mg/l)	67.9	34.8
Conductivity (µS/cm)	12842.0	183.0
Iron (mg/l)	1.5	1.5
Manganese (mg/l)	0.1	0.1
Calcium (mg/l)	55.0	9.1
Magnesium (mg/l)	17.6	3.6
Sodium (mg/l)	1966.5	13.0
Potassium (mg/l)	27.9	4.0
Phosphorus (mg/l)	0.3	0.04
Alkalinity (mg $CaCO_3$/l)	3832.4	63.0
Chloride (mg/l)	1543.4	10.1
Sulphate (mg/l)	53.1	2.0
Fluoride (mg/l)	1.05	1.55

(Field data)

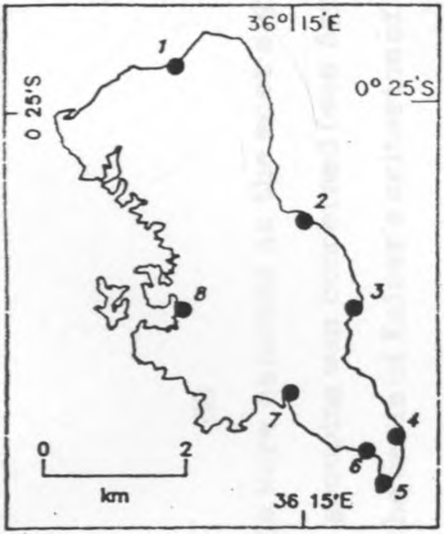
Some minerals however did not show any remarkable change between the lake and the rivers notably the concentrations of both iron and manganese (Table 5.3.1). Fluoride concentration was also much lower in the lake at 1.05 mg/l in contrast to average conditions around Kariandus (Table 5.2.1).

Significant spatial variation was evident in the concentration of most dissolved solids. Thus while conductivity in the Northern Mbaruk-Chamuka river mouth was only 156 µS/cm, levels in the western parts of the lake were as high as 20400 µS/cm. Total alkalinity was also much lower around the northern river mouth, due to the dilution effect from stream-water. The concentration of potassium, sodium and magnesium was much lower around river mouths and highest in the southern and western parts of the lake while that of calcium was much higher around river mouths and low elsewhere except in the extreme south. The concentration of iron was almost sevenfold higher around Kariandus river mouth at 6.0 mg/l in comparison to other areas (Fig. 9).

Chlorides, carbonates and sulphates constituted important salt substances in the lake. While chloride and sulphate concentrations were remarkably lower around river mouths, the situation changed rapidly in the other parts of the lake with highest chloride concentration for example existing in the eastern, southern and south eastern parts of the lake (Fig. 9).

Phosphorus levels varied slightly mostly between the river mouths and was highest in the eastern river mouth at 0.5 mg/l. Nitrogen concentration was mostly stable at 0.01 mg/l while fluoride was lower in the eastern and south eastern parts of the lake (Fig. 9). Kariandus river mouth recorded highest fluoride concentration in the lake at 2.0 mg/l.

Principal Component Analysis was applied on hydrochemical data to isolate dominant hydrochemical variable groupings within the lake. PCA procedures on an initial correlation matrix (Table 5.3.2) provided 12 components which together accounted for 92.8% of the total variation (see Appendix III). By use of the Kaiser's criterion of an eigenvalue of one or greater than one (Kaiser, 1960), only the first 7 components were considered with the remaining 5 components representing non-significant variance. The 7 components together accounted for 76.9% of the system variance. The varimax method of orthogonal rotation was used to give a set of loadings such that the variance of the square of the loadings is a maximum (Kaiser, 1958).



Legend

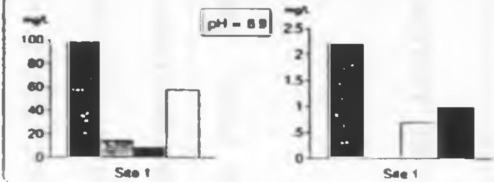
● Sampling Site

N.B.: The legend on the left corresponds to the left graph, and the legend on the right to the right graph for each site.

	TDS	Na	Cl	CaCO3
Site 1	98	15	8	58

	K	PO4-P	SO4	F
Site 1	2.2	0.01	0.7	1

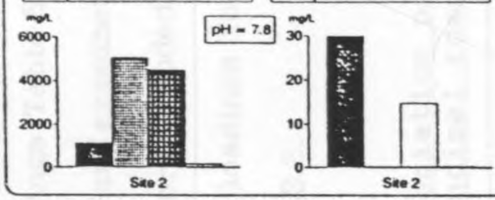
pH = 6.9



	TDS	Na	Cl	CaCO3
Site 2	1160	5040	4500	186

	K	PO4-P	SO4	F
Site 2	30	0.08	14.7	0.1

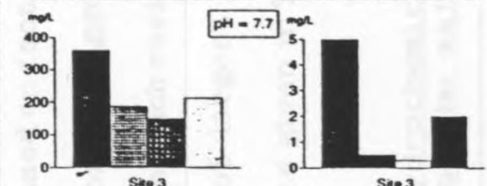
pH = 7.8



	TDS	Na	Cl	CaCO3
Site 3	361	189	150	214

	K	PO4-P	SO4	F
Site 3	5	0.5	0.3	2

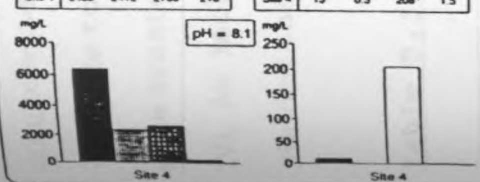
pH = 7.7



	TDS	Na	Cl	CaCO3
Site 4	6408	2415	2700	218

	K	PO4-P	SO4	F
Site 4	13	0.5	206	1.5

pH = 8.1



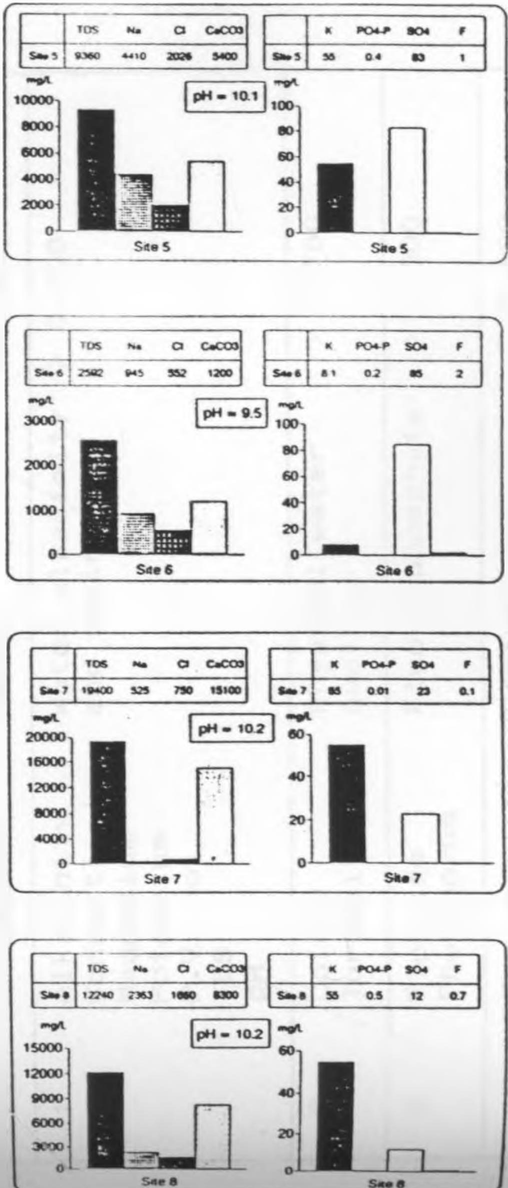


Fig. 9: Water chemistry in Lake Elementeita.

Source: Field Survey

The first four components were selected as the most significant in so far as hydrochemical variable grouping was concerned (see Appendix IV). The selection was accomplished on the basis of Kaiser's criterion of an eigenvalue of one or greater than one (Kaiser, 1960). The definition of individual components was based on factor loadings (Table 5.3.3.). Contributions of each variable to a factor were aggregated and examined after which critical values were created above which variables were included in a component (see Appendix IV). An isolation of largest factor loadings for all the four components yielded the results given in Table 5.3.3.

Table 5.3.3 - Hydrochemical association patterns as isolated for the major principal components

Major P.C.	Hydrochemical variables	Descriptive Label	Factor loading cut-off
1	Alkalinity Conductivity Magnesium Potassium P.V. No. TDS pH	Water alkalinity and salinity	> 0.700
2	Colour Turbidity	Physical water quality	> 0.700
3	Fluoride Phosphorus	Fluoro-phosphate	> 0.500
4	Sodium Chloride Sulphate	Sodium salts	> 0.600

In the first major principal component (C1), 89.4% of total variation in electrical conductivity was explained by all the other 6 variables (Table 5.3.4), but potassium and alkalinity together accounted for 87.1% of this variation. This component suggests the significance of water salinity and alkalinity in as far as water chemistry in Lake Elementeita is concerned.

Table 5.3.3 - Correlation matrix for conductivity (C) Alkalinity (A), Permanganate Number (P), Potassium (K), Magnesium (M) and pH (H) in Lake Elementeita

	C	A	M	K	H	P
C	1.000					
A	0.883	1.000				
M	0.628	0.726	1.000			
K	0.908	0.848	0.666	1.000		
H	0.781	0.781	0.560	0.850	1.000	
P	0.691	0.593	0.824	0.754	0.622	1.000

Both water colour and turbidity constituted major component C which was collectively labelled "physical water quality". Both these factors were high in Lake Elementeita and would seem to highlight the "dirt" element of water in the lake. In C3, both fluoride and phosphorus were positively correlated (Table 5.3.2), except in river mouths and the lake-bed springs where phosphorus was much lower in comparison to fluoride. For the fourth major component, sodium had a strong positive correlation with chloride as compared to sulphate (Table 5.3.5). The results in C_3 might indicate the dominat source of salinity in Lake Elementeita, and we may therefore conclude that PCA results highlighted the high salinity in the lake and showed the significance of the concentrations of sodium, chloride, carbonate and sulphate as far as this is concerned. In addition, the low level of phosphorus and the poor physical water conditions are also very significant.

	pH.	Colour	Turbiditu	Conducti	Fe.	Mn.	Ca.	Mg.	[illegible]	[illegible]	Total Ha...	Total A...	Chlorid...	Flourid...	Sulphate	Orthoph...	T.D.S.	B.O.D.	Free Co2	20 Min.	Nitrite
pH.	1																				
Colour	.092	1																			
Turbidity	.032	.378	1																		
Conducti...	.781	.322	.039	1																	
Fe.	-.3	.519	.406	-.168	1																
Mn.	.029	.113	.085	-.051	.116	1															
Ca.	-.199	.073	.024	-.234	.174	-.005	1														
Mg.	.683	.413	.165	.629	-.059	-.071	-.038	1													
Na.	.582	.235	.101	.698	-.092	-.051	-.174	.591	1												
K.	.85	.318	.107	.908	-.17	.047	-.182	.812	.708	1											
Total Har...	.625	.459	.183	.546	.018	-.062	.064	.973	.528	.744	1										
Total Aka...	.761	.333	.04	.883	-.168	-.038	-.157	.667	.345	.848	.608	1									
Chloride	.493	.182	.051	.71	-.085	-.043	-.228	.384	.95	.621	.306	.304	1								
Flouride	.211	-.2	-.068	-.17	.004	-.071	.124	-.051	-.061	-.138	.023	-.156	-.088	1							
Sulphate	.462	-.051	-.025	.4	-.162	-.048	-.184	.25	.541	.324	.183	.181	.575	.227	1						
Orthopho...	.61	.002	.106	.349	-.063	.069	-.11	.413	.452	.436	.383	.241	.416	.464	.511	1					
T.D.S.	.781	.322	.039	1	-.168	-.051	-.234	.63	.699	.909	.547	.883	.711	-.169	.4	.35	1				
B.O.D.	-.069	.089	-.041	-.042	.107	-.024	.016	-.031	-.04	.081	-.017	-.032	-.039	-.161	-.03	-.057	-.042	1			
Free Co2	-.55	.137	-.045	-.35	.354	-.152	.203	-.19	-.333	-.382	-.122	-.264	-.329	-.055	-.283	-.353	-.35	.031	1		
20 Min. P...	.622	.289	.128	.691	-.054	.005	-.202	.679	.602	.754	.606	.593	.577	-.079	.248	.507	.691	.004	-.319	1	
Nitrite	-.127	-.006	-.094	-.101	-.085	-.055	-.142	-.055	-.095	-.147	-.088	-.076	-.094	-.064	-.091	-.124	-.101	-.044	.005	-.084	1

Table 5.3.4: A correlation matrix of hydrochemical variables.

A comparison of Lake Elementeita with other African lakes shows a high concentration of dissolved solids (average of 7703 mg/l) in the lake. In Lake Chad, mean alkalinity is estimated between 50 and 70 mg/l (Carmouze *et al.*, 1983) which is low in comparison to Lake Elementeita. In the Naivasha basin lakes, alkalinity has been measured at 3.4, 7.2 and 86.8 meq/l respectively for Main lake, Oloidien and Sonachi (Njuguna, 1982).

Average conductivity in Lake Elementeita at 12 842 µS/cm was lower than in Lake Nakuru where conductivity varies between 10 000 and 162 000 µS/cm (MacIntyre, 1981). Lakes Magadi, Bogoria and Manyara also have high conductivity in comparison to Lake Elementeita (Table 5.3.6).

Table 5.3.5 - A correlation matrix for sodium, chloride and sulphate concentrations in Lake Elementeita.

	Sodium	Chloride	Sulphate
Sodium	1.000		
Chloride	0.950	1.000	
Sulphate	0.541	0.515	1.000

A classification of lakes on the basis of their conductivity levels by Talling & Talling (1965) indicated an average of between 6000 and 160 000 µS/cm for highly saline lakes. Table 5.3.6 shows the contrasting picture of conductivity between saline and freshwater lakes. In Lake Chad which is located in the southern fringes of the Sahara, conductivity is recorded at 296 µS/cm (Carmouze *et al.*, 1983) despite the expected high evaporative concentration which means that conductivity differnces between lakes might mainly be a factor of their geology.

The water chemistry at Lake Elementeita somehow indicates sulphato-chloride conditions is however a rare occurrence in East Africa. Studies in a lake situated in Western Uganda revealed that nearly equal amounts of chloride and sulphate accounted for about 90% of the anionic composition of water which was attributed to evaporative concentration within a closed basin but might also have been enhanced by hotsprings (Melack & Kilham, 1971). Visser (1973) has also made mention of a high sulphate:chloride ratio in East African waters associated with past incidence of vulcanism.

Table 5.3.6 - Levels of sodium, potassium, chloride, sulphate and conductivity (EC) in some African lakes (mg/l and µS/cm)

Lake	Na	K	Cl^{--}	SO_4^{--}	EC
Victoria[1]	12	4	6.8	7	97
Naivasha[4]	42	22	14	2	282
Baringo[2]	1584	15	37	32	416
Tanganyika[3]	87	35	144	1	612
Kivu[3]	130	85	220	15	1240
Turkana[3]	810	21	475	64	2900
Elementeita[5]	1967	30	1543	53	12845
Bogoria[2]	6712	304	3400	181	35700
Magadi[3]	38000	537	22600	900	160000
Nakuru[4]	38000	1312	13000	1800	19000
Katwe[3]	156500	45	148	42	296
Manyara[3]	215000	94	8670	1056	94000

1 - Kendall, (1968)
2 - McCall, (1967)
3 - Talling and Talling, (1965)
4 - Kalff, (1983)
5 - Author

A high concentration of sodium in relation to potassium in some saline lakes of Eastern Africa may arise from a higher retention in the biota of potassium. In Lake Elementeita, this also arises from the surrounding volcanic hills particularly those around Kariandus. Tables 5.3.7 and 5.3.8 show the chemical analyses of rock and soil samples from the study area. Table 5.3.7 particulary indicates a higher degree of mineralization for the Olivine basalts which cover parts of the basin. Soils across the basin also showed a pH range from slightly acid to alkaline, with potassium, calcium, iron and magnesium as major minerals. Volcanic soils in the lower parts of the basin had a higher sodium content in contrast to the vitric pumice tuffs of upland areas.

Some mineral concentrations are lower in Lake Elementeita in contrast to other tropical lakes. At Lake Victoria for example, magnesium concentration has been recorded at above 30 mg/l (Kendall 1968) as compared to average levels in Lake Elementeita at 2.8 mg/l. According to Talling & Talling (1965), nitrate is not found in measurable amounts in most African lakes, which may also apply in the case of nitrite. Generally, variability in nitrogen concentration in aquatic ecosytems is not easily explainable because of the intricate nature of the nitrogen cycle. It is not right, for example, to infer low nitrogen level after measurement of only one nitrogen form without any estimate of total nitrogen. Kalff (1983) has demonstrated that Lake Elementeita exhibits a high phosphorus demand with short phosphorus turnover times similar to most phosphorus deficient temperate lakes. It seems however that total combined nitrogen and phosphorus must be present in large amounts in most of the saline lakes in Kenya and Tanzania given the dense populations of ***Spirulina platensis*** which constitute the major primary producer in many of these lakes.

Table 5.3.7 - Results of the chemical analyse of some rock samples from the Rift Valley of Kenya

Parameter	Concentration (%) in samples				
Fe_2O_3	3.28	7.79	8.01	3.50	4.77
FeO	7.84	2.56	3.88	5.70	1.97
MgO	4.89	2.55	2.40	0.31	0.75
CaO	8.66	9.74	7.82	0.99	1.41
Na_2O	3.85	3.50	4.25	7.95	6.85
K_2O	1.75	0.90	1.50	4.55	5.00
P_2O_5	0.42	0.88	0.65	0.10	0.06
MnO	0.24	0.16	0.19	0.40	0.28
Total	30.9	28.1	28.7	23.5	21.1

1 - Olivine basalt, Elementeita.
2 - Olivine basalt, Mbaruk.
3 - Vitrophyric olivine basalt, Malewa.
4 - Pantellerite trachyte, Menengai.
5 - Lake Bogoria phonolite, Ol Punyata.

Source - Saggerson (1970)

At Lake Sonachi, despite prevailing high alkalinity in the small alkaline crater lake, both phosphorus and nitrogen concentrations are high in co parison to the other freshwater ecosystems of Naivasha basin lakes (Njuguna 1982). This can be attributed to lower demands for these elemente as a result of reduced levels of primary productivity such that input generally overrides output.

Table 5.3.8 - Results of the chemical analyses (in meq and %) of soil samples from the Elementeita basin

Area	Na	K	Ca	Mg	Mn	N%	C%
Kariandus	1.2	1.4	8.6	0.6	0.3	0.1	0.8
Chamuka Bridge	1.7	1.4	53.0	1.6	0.1	0.1	0.3
Mbaruk Bridge	1.0	1.3	45.0	1.9	0.03	0.2	1.3
Mbaruk-Bonde	0.6	1.5	19.0	3.0	0.7	0.4	3.3
Mahihu farm	0.5	1.2	15.2	3.3	0.7	0.3	2.8
Gichure farm	0.5	0.9	15.0	2.2	0.8	0.3	2.7
Ndiri-ini	0.6	1.3	3.1	0.8	0.3	0.3	2.3
Nyaituga hills	0.5	1.2	19.5	5.5	0.6	0.3	2.3
Chamuka hotsprings	0.6	1.6	20.0	4.8	0.4	0.3	2.7
Ngorika hills	0.7	1.7	20.0	4.0	0.6	0.4	3.7
Rutara hills	0.5	1.1	26.0	4.7	0.42	0.4	2.9
Kasambara valley	0.5	0.9	9.0	3.9	0.7	0.2	2.1
Kiringa farm	0.6	1.4	16.6	4.3	0.6	0.3	2.6
Ndunduri centre	0.4	0.6	17.7	2.6	0.8	0.2	2.5
Mbaruk station	1.5	0.7	7.0	2.0	0.7	0.1	1.5

(Field Data)

5.4.0 THERMAL SPRINGS

Three areas of geothermal activity were encountered and hydrochemically examined. Chamuka hotsprings exist on the lower fringes of Nyaituga hills while Maji Moto hotsprings occur within the lower Kariandus *Juniperus procera* woodland above the Nakuru-Nairobi railway line. Elementeita hotsprings are located south of the lake next to the basaltic-cinder volcanic cone (Fig. 2).

The water chemistry in springs varied from one spring to another (Table 5.4.1). Samples from the lake-bed springs indicated high sodium and low potassium concentrations. Manganese was very low in all springs while fluoride was high. The springs exhibited high chloride levels and were major sources of sulphate. Low concentration was found for some elements notably iron, calcium and magnesium.

Table 5.4.1 - Results of chemical analysis of hotspring water around Elementeita basin

Parameter	Area			
	(1)	(2)	(3)	(4)
pH (pH Scale)	7.2	8.1	9.5	7.3
Turbidity (mg/l)	7.0	3.5	6.1	46.6
Conductivity(µS/cm)	228.0	300.0	4300.0	2019.0
Alkalinity(mg$CaCO_3$/l)	76.0	144.0	1200.0	608.2
Iron (mg/l)	0.7	0.2	0.1	1.6
Manganese (mg/l)	0.1	0.1	0.1	0.1
Calcium (mg/l)	4.0	8.8	0.8	8.8
Magnesium (mg/l)	2.4	2.4	0.1	5.3
Sodium (mg/l)	13.0	44.0	945.0	303.1
Potassium (mg/l)	3.6	14.0	8.1	7.7
Chloride (mg/l)	14.0	8.0	552.0	233.2
Fluoride (mg/l)	1.5	2.0	2.0	0.91
Sulphate (mg/l)	5.0	10.0	85.0	9.6
Phosphorus (mg/l)	0.08	0.08	0.2	0.07
Nitrogen (mg/l)	0.01	0.01	0.01	0.01

1 - Chamuka hotsprings
2 - Majimoto hotsprings
3 - Elementeita hotsprings
4 - Average value in the rest of the basin (Field data)

Thermal springs within the basin seem therefore to constitute sources of minerals and salts, notably sodium, potassium, sulphate and chloride. In Majimoto, this account for a high total dissolved solids (TDS) level in Kariandus river below the springs which contrasts with the results from upper catchment areas. The chemistry of the Elementeita lake-bed springs shows some similarities with the rest of the lake, particularly with respect to concentrations of sodium, sulphates and chlorides (Table 5.4.2). The conductivity measurement at 4300 µS/cm in these springs is high in relation to levels around the drainage basin which may indicate a major source of water chemicals.

The chemical conditions of hotsprings in Elementeita are similar to other occurrences across a spectrum of saline, alkaline lakes along both flanks of the Great Rift Valley. Around Lake Magadi for example, alkaline saline springs with water of temperatures ranging between 36 and 68° C have been known to release up to 4300 tons of Na_2CO_3 daily into the lake (Coe, 1960). Mineral springs with water pH ranging between 8-11 and temperatures between 31 and 97° C have also been found in Western Uganda (Arad and Morton, 1969).

Table 5.4.2 - Water chemistry in Elementeita Lake-bed springs compared to conditions in the lake

Parameter	Springs	Lake
Potassium (mg/l)	8.1	28.0
Sodium (mg/l)	945.0	67.0
Calcium (mg/l)	0.8	55.0
Magnesium (mg/l)	0.1	18.0
Iron (mg/l)	0.1	1.5
Manganese (mg/l)	0.1	0.1
Sulphate (mg/l)	85.0	53.0
Chloride (mg/l)	552.0	1543.0
Fluoride (mg/l)	2.0	1.05
pH (pH scale)	9.1	8.8
Conductivity (µS/cm)	4320.0	12842.0

(Field data)

The analyses of water from several thermal springs in the Rift Valley of Kenya show marked similarities in chemistry (Talling and Talling, 1965; McCall, 1967). Cases in Western Uganda indicate slightly higher concentration for sulphate and chloride (Arad and Morton, 1969). In Tanzania, many springs resemble Ugandan examples except those in the north around Lake Manyara which largely resemble Kenyan examples (White, 1957). At Elementeita, comparisons of field data with past hydrochemical records (McCall, 1967) shows periodic shifts with regard to the output of sodium, chloride and sulphate.

Jones *et al.* (1977) have also measured higher concentrations in spring-water at Lake Magadi in comparison to previous reports.

Various theories have been advanced for the occurrence of thermal springs. In Lake Magadi for example, the existence of a hot ground-water reservoir has been postulated as a principal source of spring water (Coe, 1960). Talling and Talling (1965) however, disagree with the deep-seated reservoir hypothesis and instead relate saline springs to ancient Pleistocene greater Rift Valley lakes, whereby alkaline ground-water has accumulated in areas previously occupied by such lakes. Deep-seated alkaline ground-water under high pressure seems feasible an explanation for occurrences at Lake Bogoria where geysers in the south west near Kwaibeipei eject clouds of water and steam up to 4 m at short intervals, and are relatively similar to the steam jets south of Lake Naivasha currently being harnessed for geothermal energy. In Tanzania, thermal springs have been associated with vulcanism whereby pressure resulting from up-warping and faulting constitute a driving force (White, 1957).

Water recirculation between lakes and springs has been suspected in western Uganda, with water purportedly moving continuously from the lake down into the nearby water table to return to the surface through springs. It is generally argued that lack of extensive connections result in escalating concentration of salts around these areas.

In Lake Elementeita, it might be possible that a substantial amount of water is seeping into the ground-water reservoir from Gilgil river. The latter which empties into Lake Naivasha flows for some distance alongside Elementeita basin just some 5-10 Km away. Seepage through largely alkaline rocks could be supplying the springs situated to the east of the lake. The nature of the lake-bed springs however resembles the accounts given for similar occerrences in Lakes Magadi and Bogoria.

5.5.0 VEGETATION AND WATER CHEMISTRY

In the *Cyperus papyrus* vegetation along lower Mbaruk, chemical nature of stream-water showed significant changes (Table 5.5.1). While calcium, iron and phosphorus showed a marked rise, both sodium and nitrogen indicated some decline. Potassium, magnesium and chloride did not show much change.

Table 5.5.1 - Nutrient changes in the *Cyperus papyrus* swamps near Lanet

Variable	Above swamps	Within swamps	Below swamps
pH (pH scale)	7.1	7.0	7.2
Nitrogen (mg/l)	0.04	0.01	0.02
Sodium (mg/l)	14.0	13.0	19.0
Phosphorus (mg/l)	0.01	0.02	0.01
Sulphate (mg/l)	1.3	3.0	0.3
Calcium (mg/l)	6.4	13.0	8.0
Iron (mg/l)	1.0	1.5	0.8
Potassium (mg/l)	2.0	2.0	2.0
Fluoride (mg/l)	0.5	0.7	0.7
Chloride (mg/l)	9.0	9.0	10.0

(Field data)

In wetlands, the mass of some nutrients in litter may increase over time causing net accumulation and thus offsetting the general picture in the region. This will depend on mineralization rates through microbial degradation. Wetlands have been found to influence the concentration of some minerals notably; nitrates, sulphates and phosphorus. The role of **papyrus** swamps as sediment and mineral traps along streams has been widely documented (for example, Gaudet, 1977, 1978 & 1979). Gaudet (1977) particularly observed low sulphur (SO_4-S) in the **papyrus** swamps north of Lake Naivasha which was attributed to either adsorption or binding by nutrients to sediments. His study also concluded that nitrogen fixation within the swamps was much higher, resulting in nitrogen exports into the lake. Across the "Sudd", Gaudet (1979) has also reported falls in pH due to increased biological processes.

The observation by Kilham and Hecky (1973) about the absence of ***Cyperus papyrus*** in high fluoride waters was true around Lake Elementeita. ***Cyperus papyrus*** existed only along the lower parts of Mbaruk river, and in all instances fluoride concentration in such habitats did not exceed 1.0 mg/l. Near Lanet where **papyrus** vegetation is most abundant, fluoride was estimated at 0.7 mg/l, but apart from fluoride, this sedge species was also clearly absent in highly saline water. Near the northern Mbaruk-Chamuka river mouth where the last few traces of the species were encountered, electrical conductivity was measured at 150 μS/cm. Elsewhere around the lake, higher fluoride and conductivity levels were marked by replacement of ***Cyperus papyrus*** by ***Cyperus immensus*** and ***Cyperus laevigatus***, the latter is also widespread around such saline alkaline lakes as Nakuru (Kilham, 1971), Chad (Carmouze ***et al.*** 1983) and Sonachi (Njuguna, 1982).

The effects of high fluoride concentration on ***Cyperus papyrus*** is not understood. However, high conductivity in water means high water salinity which may result in physiological stress for the sedge plant hence its absence in such areas.

High chemical concentration of water in Lake Elementeita showed some relationship with vegetation diversity. High concentration was coupled by very few species in many places. These comprised salinity-tolerant species such as the sedge ***Cyperus laevigatus*** and the grass ***Sporobolus spicatus*** both of which are known to withstand high alkaline conditions particularly prevalent under arid and semi-arid conditions. These were wholly restricted to highly alkaline lake margin areas. On the other hand, ***Typha domingensis*** was absent from all other parts of the lake except in the south west where salinity is fairly high. In Lake Chad, ***Typha australis*** is said to dominate the highly alkaline northern parts of the lake and is absent around the Shari delta in the south where mineralization is much lower (Carmouze ***et al.***, 1983).

A regression analysis between plant diversity (PLD) and all hydrochemical variables exhibited a weak relationship accounting for only 53.5% of total variation in PLD. Water pH alone accounted for 17% of this variation and the t-statistic computed for the latter was significant at $P < 0.01$ (Table 5.5.2).

Table 5.5.2 - Stepwise regression results for a relationship between Plant Diversity (PLD) and hydrochemical variables in Lake Elementeita

Last step (STEP NO. 1): VARIABLE ENTERED: X1 pH					
Parameter	Partial r	Regression coefficient	S_e	t	α
Intercept	1.896				
pH	-0.146	-0.410	0.283	3.275	0.01
n = 55, R^2 = 0.168, Se = 0.283, $P < 0.01$					

S_e = Standard error of estimate Y at (N - 1) degrees of freedom (df)
t = t-statistic

In a multiple regression between plant abundance (PLA) and all twenty hydrochemical variables, the latter accounted for only 58% of the variation in the former and the computed F statistic at 1.847 was significant at $P < 0.05$. But the results from a related stepwise regression showed significance only with regard to fluoride (FL) and total dissolved solids (TDS), at $p < 0.001$ and 0.01 respectively (Table 5.5.3). An improvement in explanation power by 12% was realized with the addition of TDS onto an initial 19.2% explainable variance by fluoride. These results are complicated by TDS which is in itself a whole array of hydrochemical variables and individual contribution in the regression are difficult to estimate. While both fluoride and TDS accounted for only 32% of total variation in plant abundance, fluoride showed a stronger inverse relationship with plant abundance ($r = -0.44$).

Table 5.5.3 – Regression results for a relatioship between Plant abundance (PLA), Fluoride (FL) and Total Dissolved solids (TDS) in Lake Elementeita

Variable	Partial r	Regression coefficient	S_e	t	α
Intercept	2.928				
FL	0.438	-8.500	0.197	4.307	0.001
TDS	0.566	-9.66E-5	3.085E-5	3.132	0.01
$n = 55$	$R^2 = 0.320$		$S_e = 0.808$	$P < 0.001$	

S_e = Standard error of estimate Y at (N - 1) df
t = t-statistic

The account for only 54 and 53.4% of total variation in plant abundance and diversity, respectively by hydrochemical variables indicates the significant role played by other factors [not included in the regression equation] in vegetation structure.

In summary, the findings in this chapter shows the nature of water chemistry in Lake Elementeita and the major mineral constituents accounting for to this. A comparison with other tropical lakes in Africa shows Lake Elementeita as a major alkaline saline lake in the Rift Valley with much of the mineralization arising from Kariandus river as a result of a strong geologic influence. The contribution of thermal springs to the water chemical conditions in the lake is also great. Extreme lake water chemical conditions have had some influence on the distribution of plant species around the lake notably ***Cyperus papyrus*, *Sporobolus spicatus*** and ***Typha domingensia*.**

CHAPTER SIX

LAKE LEVEL DYNAMICS

6.1.0 INTRODUCTION

Two major objectives are examined in this chapter. The first aim is to establish the role of climate in lake level fluctuations at Lake Elementeita while the second is to estimate rates of forest and woodland depletion in relation to human population growth and distribution in the watershed and to examine possible hydrological implications of this with respect to Lake Elementeita.

The review and analysis of lake level trends at Elementeita was restricted to the period (1963-87) in conformity with available data. Examination of lake level figures between 1963 and 1987 shows great fluctuations. Higher levels seem to have existed in the years prior to 1971, with low levels in subsequent years except for 1977 to 1979 (Fig 10). High water level years include 1964 (2.9 m), 1965 (2.8 m), 1968 (2.6 m) and 1978 (2.4 m) while low water level was recorded in the years 1974 (1.2 m), 1975 (1.2 m), 1983 (0.8 m) 1984 (1.1 m) and 1985 (0.9 m) (see Appendix V).

6.2.0 ATMOSPHERIC TEMPERATURE

An examination of atmospheric temperature records showed that the period 1963 to 1971 was characterized by low temperatures rising slightly from a mean value of 14° C (1963-1964) to 15° C (1965-1970). This corresponds to a high water level period in Lake Elementeita.

The period between 1972 and 1985 recorded mean annual temperatures above 15° C, although between 1972 and 1976 atmospheric temperature was fairly constant at about 16° C. The relatively higher mean annual temperatures in the 1970s and 1980s were matched by low water levels in comparison to the 1960s.

6.3.0 EVAPORATION

Apart from direct water uptake from aquatic systems for domestic, livestock and agricultural uses, evaporation losses of water may have significant impact on eventual water storage at the lake. Evaporation is subject to weather fluctuations, including those of temperature. Pan evaporation trends at Elementeita showed a strong correlation to temperature trend. Periods of low atmospheric temperatures were characterized by low rates of evaporation (Appendix V).

A period of fairly low evaporation rates characterized the period between 1964 and 1968 and might have contributed to increased water storage at Lake Elementeita between these years. But evaporation data for the years between 1972 and 1987 shows little consistency in relation to water levels. The period between 1980 and 1987, for example, was generally a low water level period in the lake despite much lower evaporation rates. Some years of very high evaporation figures, notably 1982, also indicate fairly high lake water level. The reliability of available evaporation data and the accuracy of methods used for measurement are therefore questionable.

6.4.0 RAINFALL

Much of the area comprising the basin is situated in a rain-shadow from the Nyandarua ranges (The Aberdares). Areas located close to these highlands are wetter. On the other hand, areas in the Rift Valley are drier because winds blowing into these areas have already deposited much of their moisture in the upland areas (Fig. 10).

An examination of rainfall data for five upland stations since 1959 showed a mean annual rainfall of 1066 mm (Ndunduri forest station, Ndunduri administrative HQs, Elementeita highlands, Oljoro-orok agricultural station and Wanjohi Chief's camp). Similarly, an annual mean value of 733 mm was computed for a set of seven stations in the Rift valley for the last 30 years (1957-87). These stations included Soysambu estate, Gilgil Kekopey estate, Elementeita Nderit estate, Winston estate, Chokora farm (Mbaruk), Lanet police station and Naivasha Water Station.

The years between 1963 and 1971 were generally wetter representing a period of high rainfall with 1963 recording a high basin mean annual value at 1191 mm and was consequently matched by some of the highest water levels at Lake Elementeita (Fig.10). Between 1972 and 1976, rainfall was generally below 955 mm and with prevailing high temperature lake levels declined in comparison to preceding years. Fig 10 however shows increased inconsistency between rainfall and lake level trends after the 1960s.

The available records indicate that rainfall amount in the basin has declined within the last few years. Since 1983, the basin has rarely received mean annual precipitation above 900 mm.

During the drought of 1984 for example, the basin received only 539 mm while in 1987 records showed only 559 mm of mean annual rainfall. Consequently, lake levels indicate a declining trend at least up to 1987 when data were available although field observations showed an improved situation by 1988. The drought years of 1983, 1984 and 1985 were marked by some low water levels at Lake Elementeita (Fig.10). In 1983, water level averaged at 0.8 m was the lowest in the last 25 years.

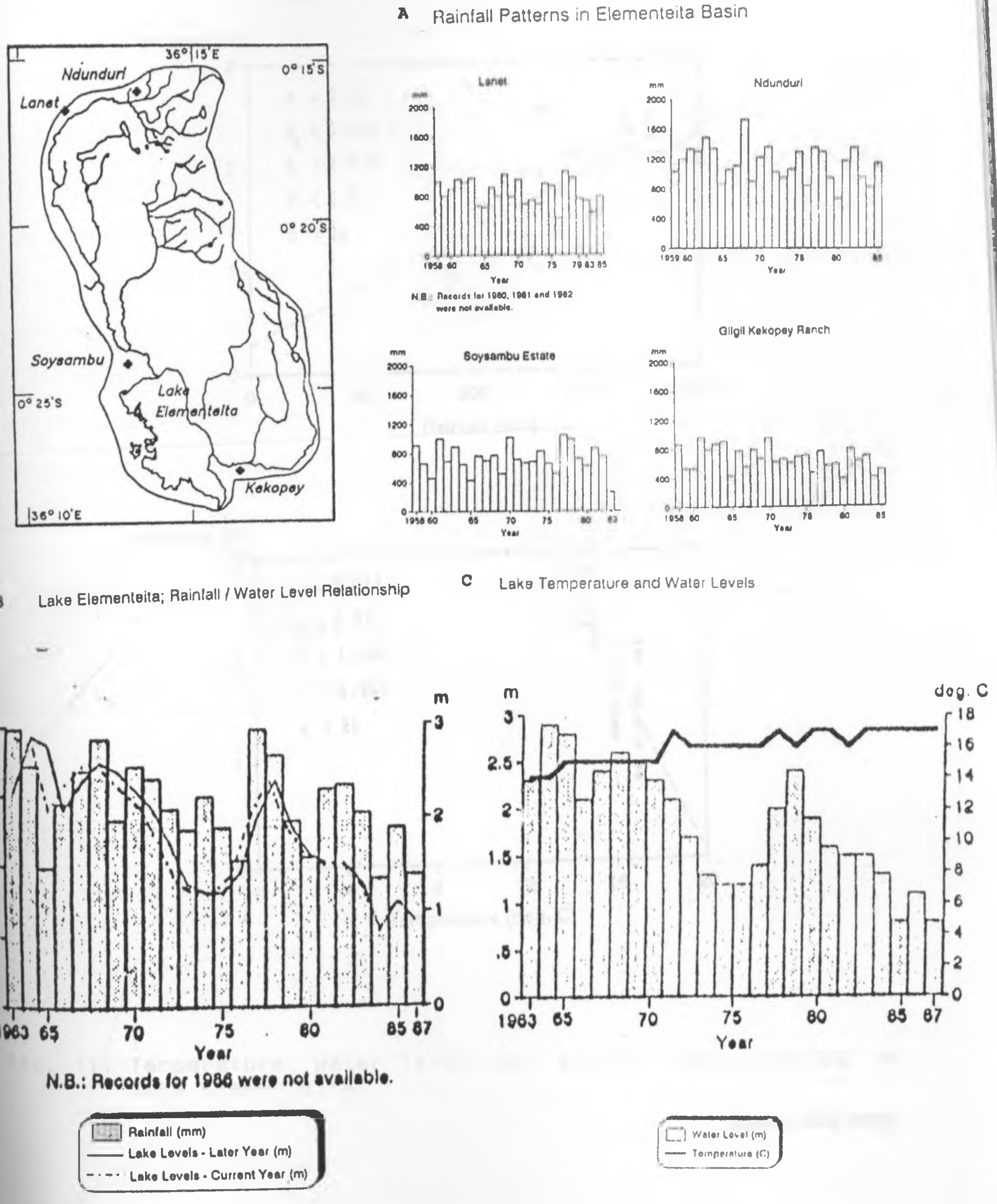


Fig. 10: Climate and water level trends in Elementeita (1958-87).

Source: Field Survey

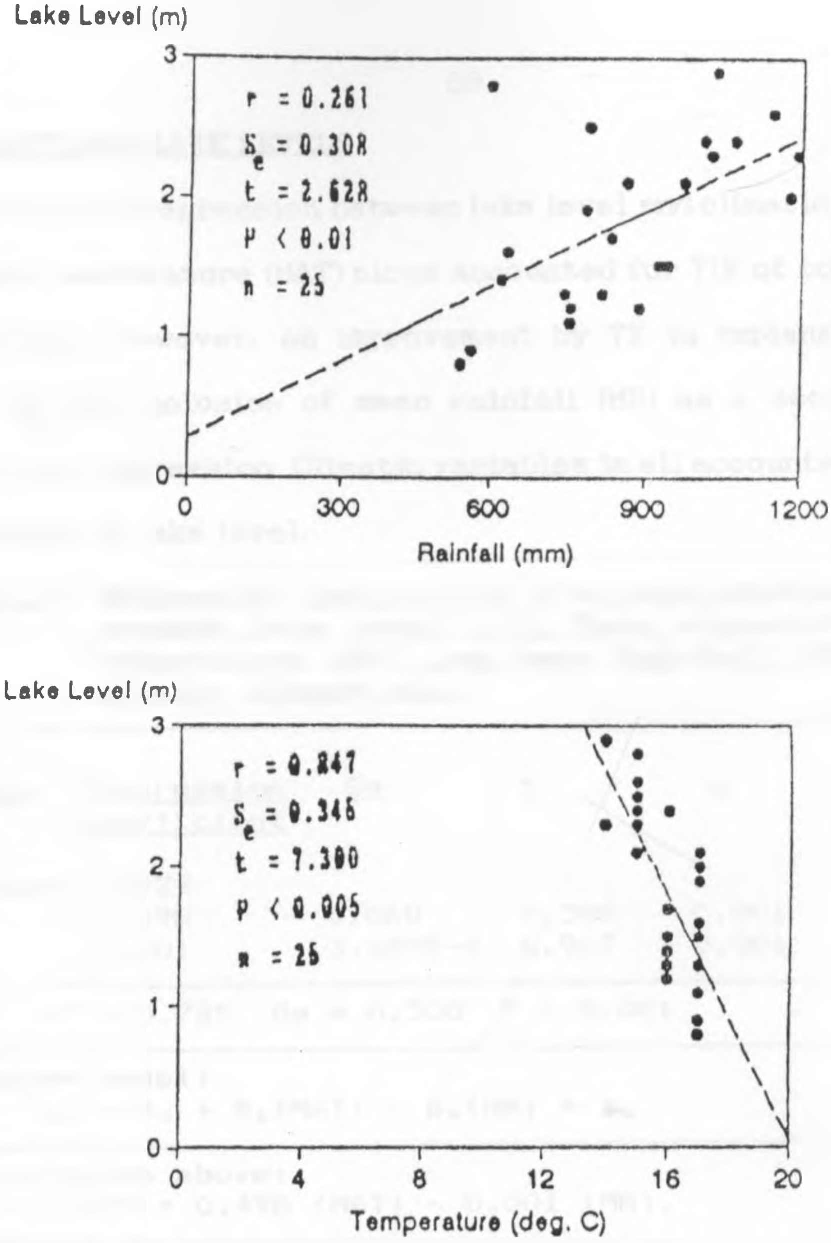


Fig. 11: Temperature, water level and rainfall relationships at Lake Elementeita.

Source: Field Survey

6.5.0 CLIMATE AND LAKE LEVELS

In a stepwise regression between lake level and climatic variables, Mean atmospheric temperature (MAT) alone accounted for 71% of total variation in lake level (LL). However, an improvement by 7% in explanation power was achieved by the inclusion of mean rainfall (MR) as a second independent variable in the regression. Climatic variables in all accounted for 85% of the total variance in lake level.

Table 6.5.0 Regression results for the relationship between Lake level (LL), Mean atmospheric Temperature (MAT) and Mean Rainfall (MR) at Lake Elementeita

Variable	Regression coefficient	Se	t	α
Intercept	9.029			
MAT	-0.498	0.068	7.300	0.001
MR	0.001	3.057E-4	6.907	0.001

n = 25 $R^2 = 0.785$ Se = 0.308 $P < 0.001$

Regression model:

$$LL = \beta_0 + \beta_1(MAT) - \beta_2(MR) + \epsilon_1$$

Equation given above:

$$LL = 9.029 + 0.498\ (MAT) - 0.001\ (MR).$$

Se = Standard error of the estimate Y at (N-1) degrees of freedom

t = t-statistic

The regression results revealed that 15% of the variance in lake level was unexplainable by factors of climatic change and could only be accounted for by factors not included in the regression equation. Rapid population growth together with human concentration within one part of the watershed might be one of these factors. The latter may have some disastrous impacts on natural vegetation in the area particularly in forest and woodland belts in upper and middle catchments which constitute a major source of water into the lake during periods of low rainfall.

6.6.0 MANKIND AND THE FORESTS: Results from LANDSAT data analysis

The population of Ndunduri and Ngorika has risen from 17,424 people in 1962 to 26,087 in 1969 and 27,526 by 1979 (Table 6.3.1). The 1962-69 annual growth rate averaged 5.7%, explained by increased immigration into the area by people from the highly populated districts of Kiambu, Muranga and Nyeri after independence. This may have been prompted by resultant occupation of former White (European) settler farms around Nyandarua, Nakuru and Naivasha by Africans mostly through cooperative efforts and settlement schemes. By 1979, population in the area had increased by 58% and 5.5% over the 1962 and 1969 figures respectively. Assuming an average and constant growth of 3.1%/yr (1962-79), population reached about 32,926 in 1989.

In 1962, 83% of the population in the drainage basin was concentrated in the upper and middle catchment areas of Ndunduri, Ngorika and Nyaituga, where climate and soils are more favourable for commercial crop and livestock farming and this had risen by 2% in 1969. These more humid parts cover only 187 km^2 or 37.4% of the total basin area. The concentration of people within one part of the watershed coupled with a high population growth rate has affected vegetation in the area, particularly within the forests and woodlands.

Analysis of LANDSAT images for the watershed between 1973 and 1984 indicates a rapid disappearance of trees in forests and woodlands previously covering most of the Ndunduri and Ngorika areas (Fig. 12). Much of the *Juniperus procera* and *Olea africana* forest belts previously dominating most of Ngorika plains have now been replaced by agro-ecosystems. This replacement is penetrating into the isolated forest remnant stands on the hills.

Table 6.6.0 – Human population statistics for Ndunduri and Ngorika (1962-79)

NDUNDURI (Formerly Dundori forest)			
Year	Population	Area(km^2)	Population density (km^2)
1962	16221	232	70
1969	20911	232	90
1979	21521	210	102
NGORIKA (formerly Dundori ward)			
1962	1203	53	23
1969	5176	70	73
1979	6005	70	85

Results of the analysis of a LANDSAT imagery taken in January, 1973 shows an approximate 152 km^2 of forest and woodlands around the watershed representing about 45% of total area of the drainage basin (Table 6.4.1). In 1976, the LANDSAT picture shows a reduction of this area to 95 km^2 which is only about 28% of total basin area. By 1984,the satellite imagery shows that only 19% of the watershed was covered by any significant forest or woodland, representing an area of about 64 km^2 (Fig. 12). In the period between 1976 and 1984, a total of 31 km^2 of forest and woodland had been cleared representing a loss of about 32% of total cover in 1976.

Table 6.6.1 – Forest and woodland cover estimation in the Klementeita watershed from LANDSAT imagery

Year	Area (km^2)	% of catchment
1973	152	45
1976	95	25
1984	64	19

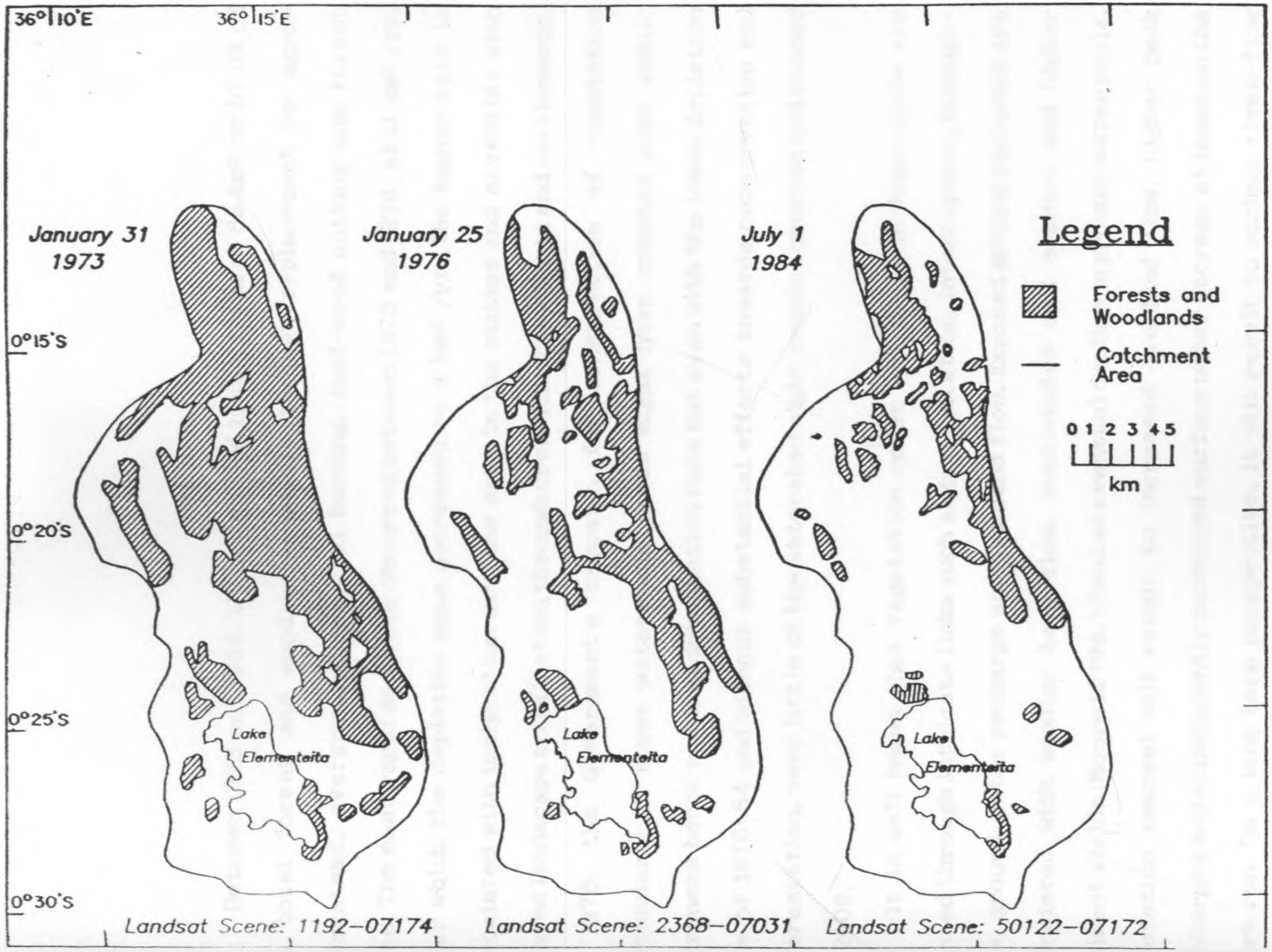


Fig. 12: Forest and woodland belt depletion in the Elementeita catchment.

Between 1973 and 1984, the watershed lost a total of 88 km^2 or 57.9% of the total forest and woodlands, mostly through replacement by agro-ecosystems, overgrazing, charcoal burning, fuel-wood cutting and forest fires. The most rapid decrease occurred between 1973 and 1976, at 11 km^2 /yr, after which the depletion rate decreased to 4 km^2 /yr. The higher rate is associated with immigration into the area in the sixties and seventies with related landscape modification through creation of new farms and settlements. By 1976, the Government's campaign for conservation of vegetation particularly in upper watersheds areas might have created some public awareness hence reduced devastation rate but even with the lower depletion rate of 1976-84 and without substantial efforts towards conservation and afforestation, very little of the watershed might remain forested and wooded by 2000.

It is well known that vegetation cover and the hydrologic cycle are related through intricate links such as precipitation, interception, through-flow, ground-water recharge and overland flow. Exposed ground surfaces are associated with smaller base-flow, accelerated soil erosion and higher sediment yields (Moore 1979a, b) and an eventual decline in ground-water pools. Vegetation removal will result to increased overland flow, higher peak discharges and consequently increased surface water storage at least on the short run. On a long term perspective, it will result to minimal river-flow during periods of low precipitation when water supply is normally restricted to ground-water recharge areas in forested and wooded belts where infiltration is enhanced. In such circumstances, any substantial stream-flow into Lake Elementeita would be limited only to a few rainy months in April, May and November with dry streams for the rest of the year and given high evaporation rates in the area averaged at 1592 mm (1963-87), this will doubtlessly affect water storage in the lake.

All springs and streams feeding the major inflows into lake Elementeita originate in the highland areas within the forested belts of Rutara, Ndunduri, Ngorika, Nyaituga and Gitare. In areas where deforestation has been particularly severe, such as in the zone extending between Kasambara, Kanjuiri and Gitare, higher incidence of dry streams was observed. Although it is difficult to disassociate this phenomenon from climatic influences, rapid deforestation might have resulted in reduced ground-water recharge. Figure 11 shows significant declines in water levels at Lake Elementeita after the sixties with particularly low levels in the early seventies and late eighties. The drought of 1984 was particularly marked by some of the lowest lake levels at Elementeita in the last two decades and the higher rainfall of 1978 and 1979 did not achieve as higher a lake level as was prevalent in the sixties when much of the basin was still largely unsettled. Thus the increasing disparity between rainfall amount and lake level trend since the sixties might have resulted partly from increased human influences in core watershed areas.

In summary, findings in this chapter show that the periodic water level fluctuations in Lake Elementeita have mainly responded to changes in the climatic factors of precipitation and temperature. However, such fluctuations may also be attributed to mankind through the continued depletion of forest and woodlands in the region.

CHAPTER SEVEN
SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

7.1.0: INTRODUCTION

As a result of rejection strength for the null hypotheses postulated in this study, accepted alternative hypotheses can therefore be stated as follows:

1. That the hydrochemistry of thermal springs manifests significant variation from the general water chemical conditions in rivers and lake.
2. That plant communities around Lake Elementeita manifest significant variation with varying hydrochemical conditions within the lake.
3. That rainfall, temperature and evaporation trends in the drainage basin do correspond to lake level trends at Elementeita.

On the basis of above accepted alternative hypotheses together with other results from this study, major findings and conclusions are outlined below from which recommendations have also been made.

7.2.0: SUMMARY OF FINDINGS

The following constitute major research findings from the Lake Elementeita drainage basin study, based on results from chapters Four, Five and Six.

VEGETATION

(1). Vegetation survey in the catchment realized nine different plant associations as follows:

(a) ***Olea-Juniperus*** upland forest

(b) ***Acacia-Olea*** forest

(c) ***Pennisetum-Eleusine*** swampy grassland

(d) ***Acacia-Rhus-Tarchonanthus*** woodland

(e) ***Tarchonanthus-Rhus-Euclea*** bushland

(f) ***Euphorbia-Olea-Acacia-Tarchonanthus*** dryland vegetation

(g) ***Acacia-Themeda-Chloris*** lowland wooded grassland

(h) ***Themeda-Sporobolus-Eragrostis*** open grassland

(i) ***Cyperus*** swamps

The ***Tarchonanthus-Rhus-Euclea*** bushland in Kasambara, Kanjuiri and Gitare represents an area where increased deforestation through overgrazing, tree felling and fire has effectively replaced the previously dominant ***Acacia-Juniperus-olea*** forest.

(2). Four vegetation zones were identified around Lake Elementeita including; ***Acacia xanthophloea*** woodland, dry bushland (Dominant species are:***Rhus natalensis, Sesbania sesban, Lantana trifolia*** and ***Tarcochanthus camphoratus***), Lake-side grasslands (Dominant species: ***Sporobolus spicatus***) and swamps (Dominant species: ***Cyperus laevigatus*** and ***Cyperus immensus***).

(3). Vegetation abundance estimated by cover abundance classes indicated greater vegetation concentration within Mbaruk watershed and low abundance around the lake except in river mouths where ***Acacia xanthophloea*** woodlands flourish. Higher plant diversity indices were encountered in Chamuka and Kariandus. Plant diversity indices were equally low around the lake with some areas occupied only by the salinity tolerant grass species, ***Sporobolus spicatus.***

HYDROCHEMISTRY

(4). The hydrochemistry in rivers of the Lake Elementeita drainage basin showed high mineral and salt concentration in river Kariandus where average electrical conductivity and alkalinity were computed at 267 µS/cm and 101 mg$CaCO_3$/l respectively. Kariandus river also displayed high levels of potassium, sodium, calcium, magnesium, iron and fluoride in comparison to Mbaruk and Chamuka, thus making it a major input of minerals and salts into Lake Elementeita. The high mineralization in Kariandus was attributed to a strong geological influence in the area. Forested and wooded parts of the watershed showed a higher stability in mineral concentrations. Higher oscillations in mineral concentrations was observed in areas of deforestation and intensive agriculture. The latter particularly showed high levels of calcium, phosphorus, nitrogen and sulphate.

(5). Lake Elementeita was found to be highly saline and alkaline with electrical conductivity and total alkalinity averaged at 12842 µS/cm and 3832 mg CaCO3/l respectively. Both sodium and chloride were 50 times higher in the lake than in the catchment while sulphate was also high. The lake was also an accumulation point for potassium, calcium and magnesium while some minerals notably iron and manganese did not show much change between the lake the rivers. A significant spatial variation was evident within the lake in terms of concentration of most dissolved solids.

(6). Thermal springs within the basin particularly the lake-bed springs south of Lake Elementeita were found to constitute major point sources of minerals and salts into the lake notably; sodium, potassium, sulphate and chlorides. The concentration of sodium in the lake-bed springs for example was found to be fourteen times higher than the average concentration within the rest of the lake.

(7). Hydrochemical conditions around the lake were found to influence the distribution of major plant species notably; ***Cyperus papyrus, C. laevigatus, Sporobolus spicatus*** and ***Typha domingensis***.

LAKE LEVELS

(8). Water level fluctuations at Lake Elementeita were found to be strongly linked with changes in climatic factors. Rainfall records in the region showed a declining trend in amount after the mid-seventies while average atmospheric temperature records indicated an increase since the sixties. This state of affairs must have affected water balance in the lake. Lake level fluctuations at Elementeita were also associated with increased human activities in the upper watershed areas after the 1970s due to increased human population growth. Results from LANDSAT imageries showed that between 1973 and 1984, the watershed lost a total of 88 km^2 or 57.9% of the total forest and woodlands, mostly through replacements by agro-ecosystems, overgrazing, charcoal burning, fuel-wood demands and forest fires. In areas where deforestation has been particularly severe like in the zone extending between Kasambara, Kanjuiri and Gitare, higher incidence of dry streams was observed.

7.3.0: CONCLUSION

Vegetation in the Lake Elementeita drainage basin is quite diverse with over ten different plant associations identified. Vegetation distribution in the area is mainly a factor of topography, climate, soils and water chemistry. In many places. human influence has changed natural vegetation structure in terms of both lifeform and species types. Thus much of the previously dominant ***Olea-Juniperus-Dombeya*** upland forest has now been replaced by a few remnant stands of ***Olea africana*** and ***Acacia tortilis*** while the ***Tarchonanthus-Rhus-Euclea*** bushland in certain parts of the basin is a replacement of previously dominant ***Acacia-Juniperus-Olea*** forests.

Lake Elementeita is a saline alkaline lake mainly as a result of high concentrations in sodium, chlorides, carbonates and sulphate. The prevailing hydrochemical conditions are attributed to both the surrounding geology, thermal springs and the influence of climate. Alkaline volcanic rocks around Kariandus are particularly rich in sodium, potassium, iron and calcium oxides and river Kariandus is consequently a major source of mineral salts into the lake. But the lake has lower concentrations of calcium, magnesium, phosphorus (PO_4-P) and nitrogen (NO_2-N).

Land management particularly for steep slope and river bank cultivation is affecting water quality through increased turbidity. Such influence also emanate from forest and bush fires, charcoal burning and uncontrolled grazing particularly around Kanjuiri, Kasambara and Gitare. In such places, deforestation and related landscape modification results in increased land degradation and soil erosion as more and more land is left with little vegetation cover.

Eutrophication of water systems in the watershed is difficult to estimate because higher concentrations of calcium, sulphate, phosphorus (PO_4-P) and nitrogen (NO_2-N) across some agricultural belts could not entirely be attributed to the management of agro-ecosystems in an area where geological influence is generally quite strong.

There is a relationship between water chemistry and the distribution of some plant species around Lake Elementeita. While a few species notably ***Cyperus immensus, C. laevigatus, Typha domingensis*** and ***Sporobolus spicatus*** are tolerant of extreme conditions, most others are not. High values of fluoride concentration and electrical conductivity showed inverse relationship with the distribution of ***C. papyrus*** hence its general absence around the lake except for a few areas in the northern river mouth where water conditions are less saline.

Water fluctuations at Lake Elementeita were found to emanate mainly from changes in climatic factors. However, loss of forest and woodlands in the basin appears to have been particularly rapid in the seventies with increased human settlement of the area. Between 1976 and 1984, destruction of forest and woodlands was occurring at an approximate rate of 4 km^2/yr. Field observations in 1988/89 showed that destruction is continuing. Disappearance of forests and woodlands in the watershed may result in lower water levels at Lake Elementeita particularly in times of drought. In addition, the environment in the watershed is quite fragile and will not easily tolerate excessive abuse and further removal of vegetation will probably exacerbate soil erosion on steep slopes and around other parts of the basin especially around Kariandus where soils are generally shallow.

The rivers across the catchment provide a suitable water resource for domestic and alternative uses including fish farming but for strict human consumption treatment is required in some places for excessive iron, manganese and fluoride removal. In Kariandus for example fluoride was generally above standard levels of 1.5 mg/l.

The lake is an important ecosystem and its destruction would be disastrous to the hundreds of Lesser and Greater Flamingos (***Phoeniconaias minor*** and ***Phoenicopterus ruber***) together with other bird species which have either temporary or permanent habitats within and around the lake. Increased salt concentration in the lake will probably result to lesser diversities and abundance in vegetation because few species maybe well adapted to tolerate extreme conditions. A restricted flora might further accelerate chemical concentrations in the lake due to limited biological uptake.

The existence of lake Elementeita depends naturally on the continued flow of major rivers. This will require preservation of remaining forest and woodland belts in the upper catchment which constitute major ground water recharge areas. Ecological protection is also vital around Lake Elementeita probably through a multiple landuse approach whereby for example the ***Acacia xanthophloea*** woodlands will be saved from any further destruction through charcoal burning. But wholescale preservation of the lake ecosystem is unrealistic in the face of a rapid population growth in the area. Many parts of the basin are confronted with development problems that may require some immediate attention. Communication is particularly a major drawback to the farmers and during the rains, when transportation of agricultural and dairy products to the market is almost impossible on often impassable roads. This occasionally culminates in great financial losses. Conditions could be improved favourably if major feeder roads were upgraded. Agricultural extension services in the area are also not efficient hence some appalling land management practices in most places. There is need for farmers to become more vigorously involved in soil and water conservation through agricultural management and this should particularly involve a reforestation program which apart from restoring lost ground cover in degraded areas will also prepare the area for the expected increase in fuelwood demands.

The drainage basin seems to hold a good unexploited potential in fishery in several large dams, while the possibility of establishing a permanent fishery at Lake Elementeita does exist.

7.4.0: RECOMMENDATIONS

The following recommendations for conservation and further research based on the study are made.

(1). The need for conservation of the remaining tracts of *Olea-Juniperus-Acacia* forests around Rutara, Ngorika, Nyaituga and Gitare as major sources of domestic water supply and also for the maintenance of Lake Elementeita. The utilization of *Acacia xanthophloea* woodlands around the lake should probably be restricted to controlled grazing in order to preserve major wild habitats in the area.

(2). The need for improved land management in the catchment to reduce soil erosion and ensure the rehabilitation of such degraded areas like Kanjuiri, Kasambara, Gitare and Kariandus. This can be achieved by the promotion of increased soil conservation and reforestation campaigns through agricultural extension. But for any success, the implementation of such environmental controls will have to be reconcilable with local conditions and with real and growing needs of the rural people.

(3). Further research is required to determine the hydrochemical, hydrologic and ecologic implications of thermal springs to aquatic ecosystems within the Rift Valley.

(4). The need to research and experiment on the existing fishery potential in the area. This can boost biological production in Lake Elementeita particularly with regard to avian populations, while fish farming in the catchment can form a salient alternative source of protein and income. As far as fish introductions is concerned, the following areas demand some research attention:

   (i). Determine long term limnological conditions in the related aquatic habitats,

   (ii). Experiment on suitable fish species

   (iii). Investigate into possible social implications.

(5). Further research is required to ascertain hydrological implications of dams and stream diversions on river discharge, nutrient budgets and water levels for Lake Elementeita.

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APPENDICES
APPENDIX I

LIST OF PLANT SPECIES

The checklist presented below is based on personal collections from most areas across the Elementeita drainage basin between October 1988 and February 1989. Plant names reported here are those in current usage at the Herbarium of Botany Department, University of Nairobi, Kenya.

Acacia xanthophloea
Acacia tortilis
Croton megalocarpus
Dombeya goetzennii
Dovyalis abyssinica
Eurphorbia candelabrum
Ficus thonningii
Ficus sur
Heteromorpha trifoliata
Juniperus procera
Maytenus senegalensis
Nuxia congesta
Olea africana
Olea hochstetteri
Polyscias kikuyuensis
Prunus africanus
Syzygium guineense
Stephania abyssinica
Teclea simplicifolia
Warburgia salutaris
Aspharagus sp
Aspilia pluriseta
Aloe spp
Achyrospermum schimperi
Adiantum thalictroides
Carpunia aurea
Cyphostemma orondo
Commicarpus pedunculosus
Crotalaria axillaris
Cassia didymobotrya
Cyathula polycephala
Cordia ovalis
Crassocephalum picridifolium
Crassocephalum mannii
Clutia abyssinica
Dodonaea latifolia
Drouguetia debilis

Desmodium repandum
Euclea divinorum
Echinops hoehnelii
Helichrysum maranguense
Hibiscus diversifolius
Hibiscus spp.
Hypericum spp.
Helichysum spp.
Indigofera spp.
Isoglossa gregorii
Impatiens elegantissima
Kalanchoe spp.
Lantana trifolia
Microgrossa pyrifolia
Maytenus heterophylla
Ochna insculpta
Pavonia patens
Pavonia urens
Plectranthus barbatus
Phaulopsis imbricata
Pterolobium stellatum
Psiadia punctulata
Rhus natalensis
Rhamnus priniodes
Sesbania sesban
Solanum aculeastrum
Solanum incanum
Solanecio spp.
Sida ternata
Sida rhombifolia
Sida spp.
Tarchonanthus camphoratus
Urtica masaica
Vernonia auriculifera
Vernonia spp.
Acalypha volkensii
Australina acuminata
Ipomoea cairica
Leucas mollis
Periplocca spp.
Rubia cordifolia
Senecio petitianus
Thunbergia gibsonii
Thunbergia alata
Achyranthes aspera
Acanthaceae
Bidens pilosa
Conyza floribunda
Commelina africana
Dyschhoriste radicans
Fuerstia africana
Gutenbergia cordifolia

Galinsoga parriflora
Geranum arabicum
Hypoestes verticillaris
Kalanchoe densiflora
Plectranthus edulis
Plantago palmata
Papilionaceae
Rorippa nasturtium aquaticum
Ranunculus multifidus
Sida masaica
Spiranthes mauritiana
Sphaeranthus suaveoleons
Trifolium usambarense
Trifolium cryptopodium
Tagetes minuta
Andropogon spp.
Cyperus rigidifolius
Cynodon dactylon
Cynodon spp.
Chloris gayana
Digitaria velutina
Eleusine jaegeri
Eragrostis tenuifolia
Eragrostis superba
Eragrostis exasperata
Hyparrhenia rufa
Hyparrhenia spp.
Oplismenus compositus
Panicum spp.
Rhychlytrum repens
Pennisetum clandestinum
Pennisetum sphacelatum
Pennisetum catabasis
Sporobolus fimbriatus
Sporobolus spp.
Sporobolus spicatus
Themeda triandra
Cyperus immensus
Cyperus laevigatus
Cyperus papyrus
Impatiens elegantissima
Kyllinga aurata
Polygonum setulosum
Potamogeton richardii
Rotala apetala
Rumex bequaertii
Setaria chevaleri
Stephania abyssinica
Sphaeranthus suaveoleons

APPENDIX II

TENTATIVE RECORDING SHEET

I - SITE DESCRIPTION

(1) Location

Site No...........
Date..............
Weather...........

(a) Direction.......................
(b) Approximate distance from stream..........................
(c) Approximate distance from Lake.....
(d) Approximate distance from Kariandus river mouth............
(e) Approximate distance from Mbaruk-Chamuka river mouth........
(f) Others (Specify)................

(2) Stream Channel physical characteristics

(a) Approximate stream width........
(b) Approximate stream depth........
(c) Channel structure
 Winding slightly
 Winding greatly
 Straight
(d) Ground character across which a stream runs
 Rocky
 Non-rocky
(e) Others (Specify).............

(3) Physical characteristics at Lake edge

(a) Topography
 Cliffed
 Smooth
(b) Baseline Material
 Rock
 Sand
 Silt
(c) Approximate distance from water edge......................
(e) Others (Specify).........

(4) Vegetation

(a) Vegetation type
- Forest
- Woodland
- Bushland
- Grassland
- Swamp

(b) Vegetation structure
- Rare
- Sparse
- Abundant

(c) For (a):
- (i) Vegetation type restricted to area around site or is a general occurrence?.........

(d) Nature of disturbance around site?
- Cutting
- Burning
- Trampling
- Grazing
- Others (Specify)

(5) <u>Soil</u>

(a) Ground cover structure
- Soil bare
- Soil well covered

(b) Soil layer (structure)
- Deep
- Thin

(c) Soil texture
- Sandy
- Clayey
- Loamy
- Silty
- Rocky

(d) Soil minerals (Soil sample)
- Potassium (K).......
- Sodium (Na).........
- Phosphorus (P)......
- Nitrogen (N)........
- Carbon (C)..........
- Iron (Fe)...........
- Magnesium (Mg)......
- Manganese (Mn)......
- pH..................
- Others (Specify)....

(6) <u>Topography</u>

(a) Surface gradient
- Steep
- Gentle

Flat

(b) Is (a) Localized or Extensive?........

(c) Others (Specify).......................

(7) Fauna

(a) Common animals, their habitats and approximate populations at or around the site (Biological names not necessary)

Animal	Habitat	Total count
(1).............	....	....
(2).............	....	....
(3).............	....	....
(4).............	....	....
(5).............	....	....
(6).............	....	....
(7).............	....	....
(8).............	....	....
(9).............	....	....
(10)...........	....	....

II SITE PLANT SPECIES STRUCTURE

(8) (a) Plant species by name and code.

Indicate total number of each from which allocate plant abundance class and compute site plant diversity index.

Species (Name or code)	Total count	Shannon-weiner Index (H)
1.	....	....
2.	....	....
3.	....	....
4.	....	....
5.	....	....
6.	....	....
7.	....	....
8.	....	....
9.	....	....
10.	....	....
11.	....	....
12.	....	....
13.	....	....
14.	....	....
15.	....	....

Site Plant Abundance Class...............

Site Plant Diversity Index...............

(9) Landuse

(a) Observed landuse at and around site. (Note the magnitude of this)

Landuse	Magnitude
1.	....
2.	....
3.	....
4.	....
5.	....

(b) Observe the impacts of each of this particularly with regards to aquatic ecosystems

Landuse	Environmental impacts
1.	....
2.	....
3.	....
4.	....
5.	....

III - SITE WATER QUALITY CHARACTERISTICS

(a) Physical characteristics

1. Colour..................
2. Turbidity...............

(b) Chemical characteristics

3. pH.......................
4. Electrical conductivity....
5. T.D.S....................
6. K........................
7. Na.......................
8. Mg.......................
9. Fe.......................
10. Mn.......................
11. Ca.......................
12. P........................
13. N........................
14. F........................
15. Permanganate Number........
16. Cl.......................
17. SO_4.......................
18. Free CO_2..................
19. Total alkalinity..........

20. Total hardness.............

APPENDIX III

Proportion of variance accountedfor by the the first 12 principal components from PCA

P.C. number	Eigen value magnitude before rotation	% variance extracted	cumulative % total variance
1	8.302	36.1	36.1
2	2.469	10.7	46.8
3	1.949	8.5	55.3
4	1.568	6.8	62.1
5	1.219	5.3	67.4
6	1.114	4.8	72.2
7	1.077	4.7	76.9
8	0.961	4.2	81.1
9	0.772	3.4	84.5
10	0.764	3.3	87.8
11	0.640	2.8	90.6
12	0.513	2.2	92.8

APPENDIX IV

Factor loadings for the first four principal components.

Hydrochemical variable	Components C1	C2	C3	C4
pH	0.790	-0.166	0.388	0.247
Colour	0.402	0.720	-0.217	0.015
Turbidity	0.066	0.730	0.103	0.014
Conductivity	0.828	-0.058	-0.103	0.456
Fe	-0.178	0.832	-0.039	-0.025
Mn	-0.053	0.199	-0.071	-0.092
Ca	-0.074	0.142	0.083	-0.260
Mg	0.879	0.176	0.165	0.077
Na	0.490	0.090	0.059	0.795
K	0.915	-0.001	0.015	0.309
Total hardness	0.839	0.243	0.204	-0.003
Total alkalinity	0.917	-0.073	-0.078	0.013
Cl	0.363	0.032	-0.026	0.902
F	-0.137	-0.065	0.856	-0.045
SO_4	0.132	-0.113	0.394	0.696
PO_4-P	0.319	0.059	0.728	0.341
T.d.s.	0.828	-0.057	-0.103	0.457
Free CO_2	-0.284	0.283	-0.260	-0.214
P.V. NO.	0.721	0.089	0.079	0.322
NO_2-N	-0.055	-0.015	-0.042	-0.187

APPENDIX V

Climatic and lake level trends at Elementeita between 1963 and 1985

Year	Mean annual Temperature (Deg.C)	Mean annual Evaporation (mm)	Mean annual Rainfall (mm)	Mean annual Lake level (m)
1963	14	1524	1191	2.3
1964	14	901	1031	2.9
1965	15	1062	593	2.8
1966	15	1686	862	2.1
1967	15	1615	1007	2.4
1968	15	1333	1142	2.6
1969	15	1315	789	2.5
1970	15	1600	1022	2.3
1971	17	1515	969	2.1
1972	16	1862	833	1.7
1973	16	1931	743	1.3
1974	16	1774	886	1.2
1975	16	1646	955	1.2
1976	16	1811	617	1.4
1977	17	1867	1177	2.0
1978	16	1213	1068	.4
1979	17	1812	783	1.9
1980	17	1482	629	1.6
1981	16	1386	921	1.5
1982	17	2167	939	1.3
1983	17	1571	816	0.8
1984	17	2169	539	1.1
1985	17	1488	754	0.9
1986	-	1269	-	-
1987	-	1792	559	

Lake level figures from station 2FAG near Mbaruk Chamuka river mouth. Data from Hydrology section, Ministry of water Development and Meteorology Department, Nairobi, Kenya.

APPENDIX VII

Rainfall records (mm) for upland stations of the Lake Elementeita drainage basin between 1959 and 1985

Year	1	2	3	4
1959	1044	-	-	-
1960	1209	-	-	-
1961	1345	-	-	-
1962	1313	-	-	-
1963	1501	-	1154	-
1964	1351	-	1089	-
1965	877	-	667	-
1966	1064	-	851	-
1967	1121	-	1493	-
1968	1730	-	1088	-
1969	913	-	815	-
1970	1229	1234	891	1091
1971	1371	1333	1408	966
1972	1036	1063	814	835
1973	961	852	716	785
1974	1074	1003	857	910
1975	1305	1366	1061	959
1976	847	760	736	756
1977	1364	1547	1247	144
1978	1303	1481	1131	1080
1979	961	-	740	892
1980	678	-	687	843
1981	1183	1201	923	882
1982	1368	1366	753	1020
1983	967	1257	973	1202
1984	833	657	412	600
1985	1153	948	952	583

1 - Ndunduri forest
2 - Ndunduri Admin. H.Q.
3 - Oljoro orok Government Farm
4 - Wanjohi Chief's Camp.

Source: Hydrology Section, Ministry of Water Development, Nairobi.

APPENDIX VIII

Rainfall records (mm) for lowlands stations in the Lake Elementeita drainage basin (1958-1987

Year	1	2	3	4	5
1958	918	1000	1101	883	1015
1959	668	808	974	537	674
1960	467	905	1148	538	707
1961	1011	1033	1210	964	1285
1962	695	994	1190	1800	922
1963	894	1047	1339	884	1100
1964	654	677	1104	915	855
1965	434	653	-	437	409
1966	776	916	-	785	638
1967	702	810	-	564	784
1968	775	1089	-	799	958
1969	524	795	-	672	670
1970	1021	1024	-	957	977
1971	714	697	-	633	688
1972	670	747	-	664	651
1973	689	692	-	615	738
1974	837	973	-	696	826
1975	668	941	-	714	-
1976	520	504	-	474	-
1977	1060	1133	-	768	-
1978	1001	1050	-	570	-
1979	731	760	-	592	652
1980	625	-	-	392	650
1981	885	-	-	806	922
1982	763	-	-	634	766
1983	263	730	-	707	725
1984	-	577	-	408	398
1985	-	783	-	509	666

1 - Kekopey Ranch, Gilgil
2 - Lanet Police Station
3 - Winston, Estate, Gilgil
4 - Soysambu Estate, Elementeita
5 - Chokora Farm, Mbaruk

Source: Hydrolgy Section, Ministry of Water Development, Nairobi.

Appendix VI: Hydrochemical and vegetation data for Lake Elementeita drainage basin.

Subcatchment	Station No.	Ph.	Colour	Turbidity	Conductivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Alkalinity	Chloride	Fluoride	Sulphate	Orthophosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abundance	Plant Diversity
Lake-Elementeita	41	6.9	175	23.0	155	1.5	0.1	9.6	1.5	[illegible]	2.	[illegible]	53	9	1.00	0.7	0.01	99	5	4	5.7	0.00	2	0.5
Lake-Elementeita	45	7.9	200	46.0	18-00	1.5	0.1	2.4	0.50	[illegible]	[illegible]	[illegible]	154	4500	0.19	[illegible]	0.05	11160	5	0	24.1	0.01	2	0.4
Lake-Elementeita	50	7.7	750	210.0	[illegible]	4.0	0.1	13.0	1.	19.0	5.	56	219	159	2.00	[illegible]	0.59	[illegible]	5	0	15.9	0.00	1	0.5
Lake-Elementeita	[illegible]	9.1	84	22.0	[illegible]	[illegible]	0.1	[illegible]	[illegible]	[illegible]	13.	12	21	2700	1.50	[illegible]	0.01	[illegible]	5	0	21.0	0.00	1	0.7
Lake-Elementeita	55	[illegible]	550	154.5	1500	1.5	[illegible]	13.	55.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00	31.5	0.40	[illegible]	5	0	24.0	0.00	1	0.3
Lake-Elementeita	54	9.5	5	5.1	49	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12[illegible]	552	2.00	55.	0.0	2592	5	0	4.0	0.00	1	0.0
Lake-Elementeita	57	10.2	300	[illegible]	[illegible]	[illegible]	0.1	5.2	22.	[illegible]	5500	[illegible]	152[illegible]	720	[illegible]	23.	0.01	[illegible]	5	0	20.0	0.00	1	0.1
Lake-Elementeita	[illegible]	10.2	200	54.0	2040	[illegible]	0.1	[illegible]	46.	[illegible]	[illegible]	200	5100	4650	0.70	12.	0.50	12240	5	0	71.0	0.0	1	0.6
No. of observations:	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Mean:		8.8	203	67.9	1284	1.5	[illegible]	5.5	17.52	[illegible]	[illegible]	56.[illegible]	[illegible]	[illegible]541.4	1.05	[illegible]	0.25	77[illegible]	5.0	0.5	23.1	0.0	1.3	0.5
Standard deviation:	-	1.3	134.0	72.5	[illegible]	1.3	0.1	5.4	[illegible]	[illegible]45.5	[illegible]	104.0	[illegible]	1501.7	0.8	[illegible]	0.2	5672.[illegible]	0.0	1.4	20.7	0.0	0.5	0.3
Standard error:	-	0.47	43.93	25.65	[illegible]	0.68	[illegible]	1.91	[illegible]	497.16	9.4	73.55	1537.17	533.41	0.27	[illegible]	0.02	[illegible]	0.00	0.50	7.37	0.00	0.16	0.11

LAKE ELEMENTEITA [illegible]

Subcatchment	Station No.	Ph.	Colour	Turbidity	Conductivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Alkalinity	Chloride	Fluoride	Sulphate	Orthophosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abundance	Plant Diversity
Mbaruk	4	7.2	10	7.0	96	0.1	0.1	5.6	2.40	9.5	5.7	25	30	9	0.14	1.3	0.01	57	5	2	3.6	0.0	2	1.1
Mbaruk	[illegible]	7.1	70	20.0	74	0.7	0.1	6.4	1.50	6.3	4.1	22	26	6	[illegible]	0.7	0.01	44	5	2	5.1	0.0	3	0.9
Mbaruk	2	7.[illegible]	85	27.0	7[illegible]	[illegible]	0.1	5.9	0.97	[illegible]	4.5	2[illegible]	25	3	0.16	0.7	0.01	48	5	4	10.5	0.0	[illegible]	0.5
Mbaruk	1	7.1	60	19.0	84	1.5	0.1	5.5	0.97	5.3	4.4	18	32	6	0.14	0.7	0.01	50	5	4	9.9	0.0	3	0.7
Mbaruk	5	7.1	100	400.0	115	0.1	0.1	5.6	1.57	12.0	5.4	18	30	9	0.25	1.0	0.01	69	5	4	5.7	0.0	3	0.4
Mbaruk	6	6.5	85	34.0	105	1.9	0.1	5.6	0.97	12.5	5.4	18	30	5	0.18	0.3	0.01	63	5	14	5.2	0.0	2	0.6
Mbaruk	7	7.0	200	65.0	155	2.9	0.1	6.9	5.40	15.8	8.1	8	52	10	0.29	0.7	0.01	111	5	9	7.4	0.0	3	0.6
Mbaruk	19	6.4	200	29.0	240	4.0	0.1	10.0	5.30	17.0	1.7	48	60	16	0.70	1.5	0.01	144	5	36	0.1	0.0	4	0.4
Mbaruk	17	6.8	50	7.0	108	0.7	0.1	2.4	2.90	3.4	1.2	18	40	7	0.70	1.0	0.01	55	5	4	7.7	0.1	4	0.5
Mbaruk	16	6.6	70	8.0	132	0.8	0.1	4.8	3.40	9.5	1.7	26	48	8	0.70	0.7	0.01	79	5	12	8.9	0.0	3	1.0
Mbaruk	15	7.0	175	22.0	204	3.0	0.1	8.2	3.90	15.0	2.2	38	60	14	1.00	5.7	0.03	122	5	6	6.0	0.0	3	0.5
Mbaruk	14	6.9	200	39.0	192	2.0	0.1	8.0	3.30	14.0	2.3	42	6[illegible]	13	1.00	1.3	0.01	115	5	8	3.9	0.0	1	0.5
Mbaruk	13	6.6	70	18.0	114	1.0	0.1	4.0	2.40	9.5	2.0	20	70	9	0.70	1.[illegible]	0.01	68	5	4	5.1	0.0	1	1.0
Mbaruk	11	7.0	200	31.0	215	2.5	0.1	3.3	3.9	20.0	2.2	46	67	2	1.00	7.7	0.01	130	5	3	5.1	0.0	3	1.0
Mbaruk	12	6.3	72	16.5	122	1.0	0.1	48.0	[illegible]	13.0	2.6	26	36	10	0.70	0.7	0.01	72	5	6	4.6	0.0	1	1.0
Mbaruk	43	7.1	200	22.0	138	1.0	0.1	6.4	4.40	14.0	2.0	34	59	9	0.50	1.3	0.01	83	5	3	4.7	0.0	3	1.1
Mbaruk	32	6.6	200	220.0	132	8.0	0.1	13.0	4.40	18.0	3.7	50	46	12	1.00	0.3	0.01	79	5	15	12.0	0.0	1	0.6
Mbaruk	31	7.0	200	27.0	132	1.5	0.1	11.0	1.00	13.0	2.0	32	38	7	0.70	3.0	0.02	79	5	4	6.8	0.0	2	0.6
Mbaruk	39	7.2	150	26.0	150	0.8	0.1	8.0	4.90	19.0	2.0	46	56	10	0.70	0.7	0.01	90	5	4	9.8	0.0	1	0.9
No. of observations:	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Mean:		6.9	126	53.9	137	1.7	0.1	9.2	3.12	12.7	3.3	22.6	42.7	9.2	0.57	2.0	0.01	82.4	5.0	8.2	7.0	0.0	2.4	0.7
Standard deviation:	-	0.2	67.3	96.1	47.3	1.8	0.0	9.7	1.8	4.5	1.9	12.3	14.9	3.5	0.3	2.4	0.0	28.4	0.0	7.8	3.1	0.0	1.0	0.2
Standard error:	-	0.06	15.44	22.05	10.35	0.41	0.00	2.23	0.41	1.03	0.43	2.82	7.42	0.79	0.07	0.55	0.00	6.52	0.00	1.78	0.72	0.00	0.23	0.06

Appendix VI: Continued

Appendix VI: Continued

Subcatchment	Station No.	Ph.	Colour	Turb-idity	Conduc-ctivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Akalinity	Chloride	Flouride	Sulphate	Ortho-phosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abandance	Plant Diversity
Chemuka	23	7.2	5	9.8	144	0.3	0.1	5.6	2.40	14.0	2.4	24	36	10	0.70	5.1	0.06	96	5	4	1.1	0.0	2	1.2
Chemuka	24	7.2	200	41.0	156	1.0	0.1	11.0	2.00	10.0	2.2	40	52	11	0.70	1.0	0.01	97	5	8	4.5	0.0	3	1.0
Chemuka	19	5.6	150	26.0	156	1.6	0.1	9.6	2.44	10.0	1.7	34	62	11	0.70	0.3	0.01	97	5	16	6.6	0.0	2	1.6
Chemuka	21	7.2	5	7.0	229	0.7	0.1	4.0	2.40	13.0	3.5	20	76	14	1.30	5.0	0.08	137	5	3	7.1	0.0	2	1.2
Chemuka	8	7.2	200	34.0	156	2.6	0.1	6.0	2.90	16.8	10.5	32	49	15	0.28	0.3	0.01	94	5	6	9.2	0.0	5	1.1
Chemuka	9	7.4	159	35.0	132	1.5	1.0	7.2	0.97	17.0	15.0	22	42	9	0.24	1.3	0.01	79	5	2	7.6	0.0	2	1.0
Chemuka	10	6.7	200	27.[illegible]	162	2.8	0.1	9.6	2.30	12.0	15.0	36	45	11	0.25	2.9	0.01	101	10	8	9.5	0.0	4	0.6
Chemuka	25	6.8	200	29.0	156	1.5	0.1	5.6	2.90	16.0	2.1	25	46	11	0.70	4.0	0.01	59	5	8	8.5	0.0	2	1.0
Chemuka	22	6.4	200	4.6	139	2.5	0.1	10.0	3.40	9.5	2.5	40	59	12	1.00	6.3	0.01	108	5	12	5.7	0.0	2	1.2
Chemuka	20	7.0	200	67.0	216	4.0	0.1	13.0	4.90	13.0	2.5	52	72	12	1.00	0.3	0.03	130	5	8	7.5	0.0	3	0.8
Chemuka	26	7.0	200	60.0	192	2.0	0.1	7.2	1.50	22.0	3.0	24	64	13	1.50	1.0	0.04	115	5	12	8.1	0.0	2	0.9
Chemuka	27	5.8	200	82.0	156	0.1	0.1	8.0	4.60	28.0	2.6	38	50	11	1.90	0.3	0.01	99	5	8	9.2	0.0	1	1.2
Chemuka	28	5.9	200	65.0	156	1.5	0.1	8.8	1.90	17.0	2.5	30	46	12	1.40	0.3	0.01	99	5	8	8.5	0.0	2	1.0
Chemuka	29	5.9	200	58.0	156	1.3	0.1	8.3	3.40	16.0	2.4	36	48	15	0.70	0.3	0.01	95	5	8	3.4	0.0	2	1.0
Chemuka	30	7.5	200	57.2	156	2.0	0.1	9.6	3.40	16.0	2.6	38	56	7	0.70	0.3	0.01	100	5	4	7.0	0.0	1	0.9
Chemuka	40	7.4	200	37.0	216	1.0	0.1	11.0	2.50	20.0	3.9	46	74	13	1.00	2.3	0.01	130	5	4	5.1	0.0	1	0.9
No. of observations:	16	16	16	16	16	16	16	16	16	16	16	16	15	15	16	16	16	16	16	16	16	16	16	16
Mean:		7.0	159	43.1	171	1.7	0.2	8.6	2.82	15.0	4.5	33.3	54.3	11.3	0.85	1.9	0.02	104.6	5.3	7.8	7.1	0.0	2.3	1.0
Standard deviation:	-	0.3	66.4	25.4	27.9	1.0	0.2	2.3	1.0	4.8	4.2	8.5	12.0	2.2	0.4	2.1	0.0	15.9	1.3	3.5	2.2	0.0	1.1	0.2
Standard error:	-	0.07	16.59	6.35	6.97	0.25	0.05	0.55	0.26	1.19	1.05	2.13	2.99	0.55	0.11	0.52	0.01	3.98	0.31	0.87	0.54	0.00	0.27	0.05

1 - Subcatchment : Kariandus

LAKE ELEMENTEITA DRAINAGE BASIN

Subcatchment	Station No.	Ph.	Colour	Turb-idity	Conduc-ctivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Akalinity	Chloride	Flouride	Sulphate	Ortho-phosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abandance	Plant Diversity
Kariandus	36	7.0	200	38.0	144	2.0	0.1	11.0	6.39	9.5	2.0	56	54	9	1.00	1.0	0.01	96	5	16	5.9	0.0	1	1.2
Kariandus	35	7.9	200	130.0	96	6.9	0.1	6.0	5.30	12.0	2.1	44	34	7	1.00	0.3	0.01	57	5	4	6.6	0.0	2	1.1
Kariandus	34	7.0	200	22.0	144	2.0	0.1	13.0	1.59	8.4	3.0	40	59	15	1.00	0.3	0.02	86	5	16	8.9	0.0	2	1.0
Kariandus	33	7.2	70	16.0	204	1.0	0.1	21.0	1.49	10.0	3.0	58	60	11	1.59	0.3	0.01	122	5	9	6.1	0.0	1	1.1
Kariandus	37	7.1	200	35.0	150	1.5	0.1	14.0	6.89	15.0	2.6	72	56	8	1.30	0.3	0.01	90	5	8	7.3	0.	2	1.1
Kariandus	44	8.1	5	3.5	300	[illegible]	0.1	8.5	2.40	44.0	[illegible]	32	144	8	2.00	[illegible]	0.03	180	5	4	2.4	0.0	1	1.1
Kariandus	45	8.9	10	5.1	372	0.4	0.1	8.8	2.90	69.0	7.9	34	120	9	2.30	5.	0.20	223	5	4	7.1	0.0	2	1.0
Kariandus	46	8.2	20	9.9	396	0.3	0.1	8.8	2.90	67.0	7.9	34	156	9	2.00	5.4	0.70	238	5	4	5.5	0.0	2	0.5
Kariandus	47	7.9	20	7.4	432	0.7	0.1	10.0	1.40	105.0	8.1	32	152	9	2.09	5.2	0.09	259	5	4	8.7	0.0	2	0.9
Kariandus	48	7.9	20	13.0	432	0.3	0.1	12.0	2.40	69.0	8.7	40	162	10	1.70	7.0	0.10	259	5	2	10.0	0.0	1	0.9
No. of observations:	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Mean:		7.5	95	28.3	267	1.4	0.1	11.5	3.67	40.9	5.9	44.2	100.8	9.5	1.55	3.7	0.12	160.0	5.0	7.1	6.8	0.0	1.6	1.0
Standard deviation:	-	0.5	92.4	37.5	133.5	1.7	0.0	3.9	2.5	34.8	4.0	13.5	50.9	2.2	0.4	3.6	0.2	80.2	0.0	5.1	2.1	0.0	0.5	0.2
Standard error:	-	0.16	29.24	11.88	42.21	0.55	0.00	1.23	0.81	11.00	1.26	4.27	16.10	0.70	0.14	1.15	0.07	25.32	0.00	1.62	0.67	0.00	0.16	0.06

Appendix VI: Continued

LAKE ELEMENTEITA DRAINAGE BASIN

Subcatchment	Station No.	Ph.	Colour	Turbidity	Conductivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Alkalinity	Chloride	Floride	Sulphate	Orthophosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abundance	Plant Diversity
Mbaruk-Cheraka	39	7.0	100	2.6	155	1.5	0.1	8.0	5.80	17.0	2.2	44	54	10	1.00	0.3	0.01	99	5	8	0.1	0.0	2	0.7
Mbaruk-Chemuka	42	7.2	100	25.0	159	1.0	0.1	6.4	3.90	15.0	2.2	32	54	10	0.70	0.3	0.01	90	5	4	5.1	0.0	2	0.5
No. of observations:	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mean:		7.1	100	13.8	153	1.3	0.1	7.2	4.85	16.0	2.2	39.0	54.0	10.0	0.85	0.3	0.01	94.5	5.0	6.0	2.6	0.0	2.0	0.6
Standard deviation:	-	0.1	0.0	15.8	4.2	0.4	0.0	1.1	1.3	1.4	0.0	8.5	0.0	0.0	0.2	0.0	0.0	6.4	0.0	2.8	3.5	0.0	0.0	0.1
Standard error:	-	0.10	0.00	11.20	3.00	0.25	0.00	0.80	0.95	1.00	0.00	6.00	0.00	0.00	0.15	0.00	0.00	4.50	0.00	2.00	2.50	0.01	0.00	0.10

OVERALL SUMMARY

	Station No.	Ph.	Colour	Turbidity	Conductivity	Fe.	Mn.	Ca.	Mg.	Na.	K.	Total Hardness	Total Alkalinity	Chloride	Floride	Sulphate	Orthophosphate	T.D.S.	B.O.D	Free Co2	20 Min P.V.	Nitrite	Plant Abundance	Plant Diversity
No. of observations:	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Mean:		7.3	144	46.6	2019	1.6	0.1	8.8	5.30	705.1	7.7	41.5	608.2	233.2	0.91	9.6	0.07	1211.8	5.1	6.7	9.2	0.0	2.0	0.8
Standard deviation:	-	0.9	87.0	66.1	6057.4	1.5	0.1	6.5	10.6	985.2	12.5	44.9	2386.3	773.5	0.6	31.3	0.2	3616.2	0.7	5.9	9.8	0.0	1.0	0.3
Standard error:	-	0.12	11.74	8.91	813.55	0.21	0.02	0.88	1.43	132.85	1.68	6.06	321.77	104.29	0.08	4.22	0.02	487.61	0.09	0.80	1.32	0.00	0.13	0.04

Appendix VI: Continued

Chemuka	8	7.2	200	54.0	150	2.0	0.1	0.0	2.50	16.0	10.5	32
Chemuka	9	7.4	150	35.0	132	1.5	1.0	7.2	0.97	17.0	13.0	22
Chemuka	10	6.9	200	27.0	168	2.0	0.1	9.6	2.50	18.0	15.0	36
Chemuka	19	6.6	150	26.0	156	1.6	0.1	9.6	2.00	10.0	1.7	36
Chemuka	20	7.0	200	67.0	216	4.0	0.1	13.0	4.50	13.0	2.3	52
Chemuka	21	7.2	5	7.0	228	0.7	0.1	4.0	2.00	13.0	3.6	20
Chemuka	22	6.6	200	6.6	180	2.5	0.1	10.0	3.00	9.5	2.6	40
Chemuka	23	7.2	5	9.8	144	0.3	0.1	5.6	2.00	16.0	2.4	26
Chemuka	24	7.2	200	41.0	156	1.0	0.1	11.0	2.00	10.0	2.2	40
Chemuka	25	6.8	200	29.0	156	1.5	0.1	5.6	2.00	16.0	2.1	26
Chemuka	26	7.0	200	40.0	192	2.0	0.1	7.2	1.50	22.0	3.0	24
Chemuka	27	6.8	200	82.0	156	0.1	0.1	8.0	4.00	20.0	2.6	38
Chemuka	28	6.9	200	65.0	156	1.5	0.1	0.8	2.50	17.0	2.5	30
Chemuka	29	6.9	200	50.0	156	1.3	0.1	0.8	3.00	16.0	2.4	36
Chemuka	30	7.3	200	57.0	188	2.0	0.1	9.6	3.00	10.0	2.6	30
Chemuka	40	7.4	200	37.0	216	1.0	0.1	11.0	2.00	20.0	3.0	40
Kariandus	33	7.2	70	16.0	200	1.0	0.1	21.0	1.00	10.0	3.0	30
Kariandus	34	7.0	200	22.0	144	2.0	0.1	13.0	1.50	8.4	3.0	40
Kariandus	35	7.0	200	150.0	96	6.0	0.1	0.0	3.00	12.0	2.1	44
Kariandus	36	7.0	200	30.0	144	2.0	0.1	11.0	6.00	9.5	2.0	56
Kariandus	37	7.1	200	35.0	150	1.5	0.1	14.0	7.00	15.0	2.6	72
Kariandus	44	8.1	5	3.3	300	0.2	0.1	0.8	2.00	44.0	10.0	32
Kariandus	45	8.0	10	0.1	372	0.8	0.1	0.8	2.50	69.0	7.8	36
Kariandus	46	8.2	20	9.9	396	0.3	0.1	0.8	2.50	67.0	7.9	36
Karianous	47	7.9	20	7.4	432	0.7	0.1	10.0	1.00	105.0	0.1	32
Kariandus	48	7.8	20	13.0	432	0.3	0.1	12.0	2.00	69.0	8.7	40
Lake-Elementeita	41	6.9	175	25.0	156	1.5	0.1	9.6	1.50	15.0	2.2	30
Lake-Elementeita	49	7.8	200	40.0	10000	1.8	0.1	2.6	0.50	5000.0	50.0	8
Lake-Elementeita	50	7.7	350	200.0	800	6.0	0.8	15.0	1.00	18.9	3.0	30
Lake-Elementeita	51	8.1	80	22.0	10000	0.6	0.1	0.8	2.00	2015.0	13.0	12
Lake-Elementeita	52	10.2	200	56.0	20000	0.2	0.1	1.6	40.00	2363.0	55.0	200
Lake-Elementeita	53	10.2	300	32.0	32000	0.3	0.1	3.2	22.00	525.0	55.0	100
Lake-Elementeita	54	9.3	5	6.1	6300	0.1	0.1	0.8	0.10	965.0	8.1	2
Lake-Elementeita	55	10.1	350	150.0	15000	1.5	0.1	13.0	45.00	4400.0	55.0	300
Mbaruk	1	7.1	40	10.0	56	1.5	0.1	5.6	0.97	3.3	4.6	18
Mbaruk	2	7.1	85	27.0	79	0.8	0.1	6.4	0.97	6.3	4.3	20
Mbaruk	3	7.1	70	20.0	74	0.9	0.1	6.4	1.50	6.3	4.1	22
Mbaruk	4	7.2	10	7.0	96	0.1	0.1	3.6	2.50	9.5	3.7	26
Mbaruk	5	7.1	100	400.0	115	0.1	0.1	5.6	0.97	13.0	5.4	18
Mbaruk	6	6.5	85	34.0	105	1.0	0.1	5.6	0.97	12.6	5.4	18
Mbaruk	7	7.0	200	60.0	168	2.0	0.1	6.4	3.00	15.8	6.1	8
Mbaruk	11	7.0	200	31.0	216	2.5	0.1	8.8	3.00	20.0	2.2	40
Mbaruk	12	6.8	70	10.0	132	1.0	0.1	40.0	1.50	13.0	2.0	20
Mbaruk	13	6.6	70	18.0	114	1.0	0.1	4.0	2.00	9.5	2.0	20
Mbaruk	14	6.9	200	30.0	192	2.0	0.1	8.0	3.30	16.0	2.3	42
Mbaruk	15	7.0	175	22.0	200	3.0	0.1	8.0	3.00	15.0	2.2	38
Mbaruk	16	6.6	70	8.0	132	0.8	0.1	4.8	3.00	9.5	1.7	20
Mbaruk	17	6.8	50	7.0	100	0.7	0.1	2.4	2.50	8.4	1.2	18
Mbaruk	18	6.4	200	29.0	200	4.0	0.1	10.0	3.30	19.0	1.7	40
Mbaruk	31	7.0	200	27.0	132	1.3	0.1	11.0	1.00	13.0	2.0	32
Mbaruk	32	6.6	200	220.0	132	8.0	0.1	13.0	4.00	18.0	3.9	30
Mbaruk	38	7.2	150	26.0	150	0.8	0.1	8.0	4.50	19.0	2.0	40
Mbaruk	43	7.1	200	22.0	138	1.0	0.1	5.6	4.00	14.6	2.0	36
Mbaruk-Chemuka	39	7.0	100	2.6	156	1.3	0.1	0.0	3.00	17.0	2.2	44
Mbaruk-Cnemuka	42	7.2	100	25.0	150	1.0	0.1	6.4	3.50	15.0	2.2	32

Appendix VI Continued

			Sulphate	Phosphate	T.D.S.	B.O.D	Co2	P.V.	Nitrite	Abundance	Diversity
48	15	0.20	0.3	0.01	94	5	6	9.2	0.01	3	1.1
42	9	0.20	1.3	0.01	79	5	2	7.6	0.01	2	1.0
46	11	0.25	2.9	0.01	101	10	8	9.5	0.01	4	0.6
62	11	0.70	0.3	0.01	99	5	16	6.6	0.01	2	1.6
72	12	1.00	0.3	0.03	130	5	8	7.5	0.01	3	0.8
76	14	1.50	5.0	0.00	137	5	8	7.1	0.01	2	1.2
50	12	1.00	6.3	0.01	108	5	12	5.7	0.01	2	1.2
56	10	0.70	5.1	0.06	86	5	4	1.1	0.01	2	1.2
52	11	0.70	1.0	0.01	99	5	8	4.5	0.01	3	1.0
48	11	0.70	4.0	0.01	99	5	8	6.5	0.01	2	1.0
54	13	1.50	1.0	0.04	115	5	12	4.1	0.03	2	0.9
50	11	1.00	0.3	0.01	99	5	8	9.2	0.01	1	1.2
46	12	1.00	0.3	0.01	99	5	8	6.3	0.01	2	1.0
48	16	0.70	0.3	0.01	99	5	8	6.4	0.02	2	1.9
56	7	0.70	0.3	0.01	100	5	4	7.0	0.02	1	0.9
74	13	1.00	2.3	0.01	130	5	4	5.1	0.01	1	0.8
80	11	1.50	0.3	0.01	122	5	9	8.1	0.01	1	1.1
50	15	1.00	0.3	0.02	86	5	16	6.9	0.01	2	1.0
34	7	1.00	0.3	0.01	57	5	4	6.6	0.01	2	1.1
54	9	1.00	1.0	0.01	86	5	16	5.9	0.01	1	1.2
56	8	1.50	0.3	0.01	90	5	8	7.3	1.01	2	1.1
144	8	2.00	10.0	0.06	180	5	4	2.4	0.01	1	1.1
120	9	2.00	6.0	6.20	223	5	4	7.1	0.01	2	1.0
156	9	2.00	3.4	0.70	230	5	4	3.3	0.01	2	0.3
152	9	2.00	6.2	0.09	259	5	4	6.7	0.01	2	0.9
162	10	1.70	7.0	0.10	259	5	2	10.0	0.01	1	0.9
58	9	1.00	0.7	0.01	99	5	4	5.7	0.01	2	0.6
100	6500	0.10	14.7	0.06	11100	5	0	24.1	0.01	2	0.4
214	150	2.90	0.3	0.50	361	5	0	15.0	0.01	1	0.3
218	2700	1.50	200.0	0.50	6000	5	0	21.0	0.01	1	0.9
8500	1600	0.70	12.0	0.50	12240	5	0	71.0	0.01	1	0.8
15000	750	0.10	25.0	0.01	19000	5	0	20.0	0.01	1	0.2
1200	552	2.00	85.0	0.20	2592	5	0	4.0	0.01	1	0.0
5000	2026	1.00	85.0	0.40	9300	5	0	26.0	0.01	1	0.3
32	6	0.10	0.7	0.01	50	5	4	9.9	0.01	3	0.7
26	6	0.10	0.3	0.01	40	5	4	13.5	0.01	3	0.5
26	6	0.15	0.3	0.01	44	5	2	5.1	0.01	3	0.8
30	9	0.10	2.3	0.01	57	5	2	3.6	0.01	2	1.1
30	9	0.25	1.0	0.01	69	5	4	5.7	0.01	3	0.4
30	8	0.10	0.3	0.01	65	5	16	5.2	0.01	2	0.6
52	10	0.20	0.7	0.01	101	5	8	7.4	0.01	3	0.6
60	2	1.00	7.7	0.01	150	5	8	8.3	0.01	3	1.0
50	10	0.70	7.7	0.01	79	5	8	6.6	0.01	1	1.0
50	9	0.70	1.0	0.01	66	5	4	5.1	0.01	1	1.0
60	13	1.00	1.3	0.01	115	5	8	8.9	0.01	1	0.6
60	14	1.00	5.7	0.03	122	5	6	6.9	0.01	3	0.5
40	8	0.70	0.7	0.01	79	5	12	8.9	0.01	3	1.0
40	7	0.70	1.0	0.01	65	5	4	7.7	0.03	4	0.5
80	18	0.70	1.8	0.01	144	5	36	6.1	0.01	4	0.4
38	9	0.70	3.0	0.02	79	5	4	6.8	0.01	2	0.6
40	12	1.00	0.3	0.01	79	5	16	12.0	0.01	1	0.6
50	10	0.70	0.3	0.01	90	5	4	9.0	0.02	1	0.9
58	9	0.50	1.3	0.01	83	5	8	4.7	0.00	3	1.1
54	10	1.00	0.3	0.01	99	5	8	0.1	0.02	2	0.7
54	10	0.70	0.3	0.01	90	5	4	3.1	0.01	2	0.5

Appendix VI: Continued

TWO-WAY FACTORIAL EXPERIMENT

DATASET : LAKE--

TREATMENT MEANS OVER TIME

OBSERVATION	Mbaruk	Chemuka
pH	6.9	7.013
Colour	126.053	169.375
Turbidity	53.789	43.088
Conductivity	137.421	171.00
Fe.	1.721	1.663
Mn.	0.1	0.15625
Ca.	9.2	8.5625
Mg.	3.12	2.816875
Na.	12.6947368	16.01875
K.	3.3052631	4.48125
Total Hardness	28.6315789	33.25
Total Alkalinity	42.7368421	54.25
Chloride	9.2105263	11.75
Flouride	0.5652631	0.860625
Sulphate	1.9652631	1.9375
Orthophospahte	1.15789474D-02	0.020625
T.D.S.	82.3684210	104.625
B.O.D	5	5.3125
20 Min P.V.	7.0157894	7.1
Nitrite	1.42105263D-02	0.0125
Plant Abundance	2.4210526	2.25
Plant Diversity	0.7315789	1.0375

MEAN FOR TRTMNT	23.6168192	28.4491032
No. IN TRTMNT. GROUP	19	16

Produced on 10/06/89 at 10:01

TREATMENTS

Mbaruk-Chemuka	Kariandus	Lake-Elementeit	MEAN FOR TIME
7.1	7.53	8.8125	7.3327272
100	94.5	207.5	143.8181818
13.8	28.29	67.8875	46.6363636
153.0	267.0	12842.125	2019.2727272
1.25	1.44	1.5	1.6036363
0.1	0.1	0.1375	0.1218181
7.2	11.54	5.55	8.8363636
4.85	3.67	17.5625	5.2954545
16	40.89	1966.4875	303.0963636
2.2	5.92	27.9125	7.6618181
38	44.2	86	41.4909090
54	100.8	3832	603.2181818
10	9.5	1543.375	233.1818181
0.85	1.55	1.05	0.9110909
0.3	3.68	53.0875	9.6443636
0.01	0.123	0.275	7.27272727D-02
94.5	160	7702.5	1211.7818181
5	7.1	0.5	6.6727272
2.6	6.85	23.1	9.1890909
0.015	0.01	0.01	1.23636364D-02
2	1.6	1.25	2.0363636
0.6	0.99	0.4625	0.8236363
22.5815217	34.8818695	1234.5254347	203.1652806
2	10	8	55

APPENDIX VII

Rainfall records (mm) for upland stations of the Lake Elementeita drainage basin between 1959 and 1985

Year	1	2	3	4
1959	1044	-	-	-
1960	1209	-	-	-
1961	1345	-	-	-
1962	1313	-	-	-
1963	1501	-	1154	-
1964	1351	-	1089	-
1965	877	-	667	-
1966	1064	-	851	-
1967	1121	-	1493	-
1968	1730	-	1088	-
1969	913	-	815	-
1970	1229	1234	891	1091
1971	1371	1333	1408	966
1972	1036	1063	814	835
1973	961	852	716	785
1974	1074	1003	857	910
1975	1305	1366	1061	959
1976	847	760	736	756
1977	1364	1547	1247	144
1978	1303	1481	1131	1080
1979	961	-	740	892
1980	678	-	687	843
1981	1183	1201	923	882
1982	1368	1366	753	1020
1983	967	1257	973	1202
1984	833	657	412	600
1985	1153	948	952	583

1 - Ndunduri forest
2 - Ndunduri Admin. H.Q.
3 - Oljoro orok Government Farm
4 - Wanjohi Chief's Camp.

Source: Hydrology Section, Ministry of Water Development, Nairobi.

APPENDIX VIII

Rainfall records (mm) for lowlands stations in the Lake Elementeita drainage basin (1958-1987

Year	1	2	3	4	5
1958	918	1000	1101	883	1015
1959	668	808	974	537	674
1960	467	905	1148	538	707
1961	1011	1033	1210	964	1285
1962	695	994	1190	1800	922
1963	894	1047	1339	884	1100
1964	654	677	1104	915	855
1965	434	653	-	437	409
1966	776	916	-	785	638
1967	702	810	-	564	784
1968	775	1089	-	799	958
1969	524	795	-	672	670
1970	1021	1024	-	957	977
1971	714	697	-	633	688
1972	670	747	-	664	651
1973	689	692	-	615	738
1974	837	973	-	696	826
1975	668	941	-	714	-
1976	520	504	-	474	-
1977	1060	1133	-	768	-
1978	1001	1050	-	570	-
1979	731	760	-	592	652
1980	625	-	-	392	650
1981	885	-	-	806	922
1982	763	-	-	634	766
1983	263	730	-	707	725
1984	-	577	-	408	398
1985	-	783	-	509	666

1 - Kekopey Ranch, Gilgil
2 - Lanet Police Station
3 - Winston, Estate, Gilgil
4 - Soysambu Estate, Elementeita
5 - Chokora Farm, Mbaruk

Source: Hydrolgy Section, Ministry of Water Development, Nairobi.