# CHAPTER 1

# An introduction to Lake Victoria catchment, water quality, physical limnology and ecosystem status (Kenyan sector)

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## Background

Lake Victoria is the world's second largest lake and the largest in the developing world. Lake Victoria covers an area of 68,800 km$^2$, spanning 400 km north-south and 240 km east-west. The lake is shared by Kenya, Tanzania and Uganda with only 6% of the surface area of the lake within the Kenyan territory, while Tanzania and Uganda have 51% and 43% respectively. Lake Victoria touches the equator in its northern reaches, and is a relatively shallow lake for its area, with an average depth of only 40 m, and a maximum depth of 79 m. The lake's shoreline is long (about 3,500 km) and convoluted, enclosing innumerable small, shallow bays and inlets, many of which include swamps and wetlands, which differ a great deal from each other and from the lake itself. The lake has a wide land catchment area, which is almost three times the size of the lake, and extends over the three East African countries together with Rwanda and Burundi. This is the area from which rivers carry water, nutrients, sediments and pollutants into the lake and is about 193000 km$^2$; of which the catchment area in Kenya covers 42460 km$^2$ (Fig. 1). The land catchment among the East African states is distributed as follows:

***TABLE 1. Land catchment area in the Lake Victoria Basin***

| **Country** | **Catchment area** | **Catchment area %** |
|---|---|---|
| Tanzania | 84920 | 44% |
| Kenya | 42460 | 22% |
| Uganda | 30880 | 16% |
| Rwanda | 21230 | 11% |
| Burundi | 13510 | 7% |
| **Total** | **193000** | **100** |

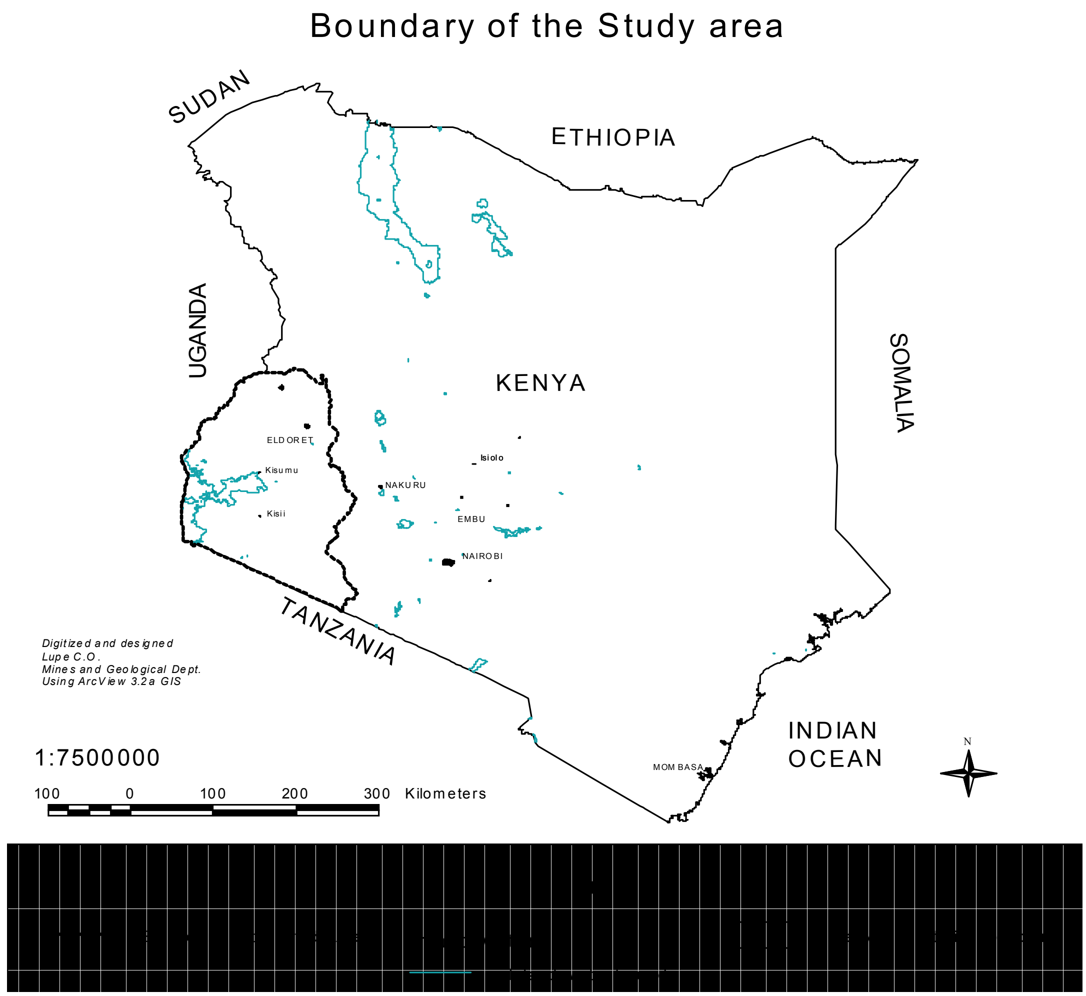



***FIG. 1. Map of the study area.***

Thus, over 30 million people in five countries share and effect the resources of the Lake Victoria basin. Harmful activities in the catchment area ultimately have an effect on the lake, and thus affect the livelihoods of people throughout the basin; these developments are already disrupting the current fishing activities in the area and grossly affect the livelihood of the local people. It is important, therefore, that the people of the region, through their governments and civil society organizations, cooperate through multilateral coordinated action to ensure a healthy Lake Victoria environment. Kenya, Tanzania and Uganda have founded the East African Community (EAC) and are supporting the Lake Victoria Development Programme within the EAC. Rwanda and Burundi have also expressed interest in joining the EAC in future.

Among the five drainage basins in Kenya, Lake Victoria drainage basin is of special interest: Nearly half of the country's population lives in this basin, which is endowed with abundant water and other natural resources, e.g. drinking, domestic, agricultural and industrial water use, fisheries, biodiversity, hydropower, among others. While some of the resources have been exploited, many are still undeveloped. However, the lower reaches of the basin have serious environmental and health problems that affect development.

Development in agriculture, industry and urban centers has had adverse effects on water resources in the basin. Consequently, the lake ecosystem has undergone significant changes, particularly during the last five decades.

**Beneficial uses of Lake Victoria dependent on water quality**

The Lake Victoria basin is used as a source of food, energy, domestic drinking and irrigation water and agricultural production, for shelter and transport, recreation and as a repository for human, agricultural and industrial waste. It is also a biodiversity conservation and tourism site. The basin supports large populations that depend on it for farming activities and fishing for subsistence, sale and export, and industrial development.

Lake Victoria has numerous wetlands on the edges of its shore as well as open beaches and islands. The coastline ranges from papyrus swamps to rocky and sandy beaches. The wetlands are important for fish breeding and growth; for filtering river waters; the wetlands plants are harvested for building materials by the riparian communities and are food for wildlife. The scenic beaches and islands are unique touristic features; in fact Kisumu is an important tourist destination due to its uniqueness and close proximity to the Ndere Islands managed by Kenya Wildlife Service. Recreational uses of the lake area include for swimming, sport fishing, boating, hippo watching and bird watching. In addition, Kisumu has an important ship-loading facility, which makes it one of the major ports in East Africa. Although the lake has not suffered a large petroleum of chemical spills such an eventuality would have severe ramifications to the lake environment. Daily vessel operations do result in discharges and minor spills that can have local effects. Because the shipping facility is shared, a large spill could happen in any country but the impacts could potentially fall largely in another and possibly result in inter-country conflict. There are no mitigation measures yet put in place to undertake a cleaning exercise or compensate the affected should such a spill occur.

The Kenyan basin has a high potential for hydropower development, however, this potential is still underutilized and only two sites have been developed to harness hydroelectric power, one each on river Sondu/Miriu and Kuja/Migori. Waterfalls occur along most of these rivers i.e. Sondu-Miriu, Kuja, Yala and Nzoia have huge falls, thus have high potential for hydro power development.

**Biophysical characteristics of the lake**

The lake serves as an important reservoir for the region and for the larger Nile Basin. Because the lake is shallow (Fig. 2), its volume is substantially less than that of other African Great Lakes, which have much smaller surface areas. Its total volume is about 2,760 $km^3$, only 15% of the volume of Lake Tanganyika, even though the latter has less than half its surface area. In the Winam Gulf of Lake Victoria, 8.1 billion $m^3$ of water comes from rainfall over its surface and in-flowing rivers contribute 9.2 billion $m^3$. The rivers, which originate from and enter the Lake in the Kenyan catchment contribute 38% of the total river discharge entering Lake Victoria from land catchment, however River Mara, which enters the lake in Tanzania and contributes about 5% is mainly from the Kenyan catchment, therefore total contriution of Kenyan catchment is estimated at about 42% of land catchment input. Consequently activities in Kenya catchments potentially affect a substantial portion of the river discharge to the lake and especially in Winam Gulf.

The main rivers and their discharge percentages are: Nzoia - 39%, Gucha-Migori - 20%, Sondu - 14%, Yala - 13%, Nyando - 6% and Sio-4%. The remaining 4% comes from various streams such as Awach Seme, Awach Kibos, Awach Kano (clustered as North Awach) and Awach Tende and Awach Kibuon (clustered as South Awach) (LVEMP, 2002). There are also several seasonal rivers and streams originating from areas with high rainfall. Table 1 shows the river discharges and their % contribution to Lake Victoria land catchment input.

***Table 2. River discharges and their % contribution to Lake Victoria land catchment input.***

| **River** | **Discharge, $m^3s^{-1}$** | **% Kenya basin** | **% Whole basin** |
|---|---|---|---|
| Sio | 11.4 | 3.5 | 1.5 |
| Nzoia | 115.3 | 35.0 | 14.8 |
| Yala | 37.6 | 11.4 | 4.8 |
| Nyando | 18.0 | 5.5 | 2.3 |
| North Awach | 3.7 | 1.1 | 0.5 |
| Sondu-Miriu | 5.9 | 1.8 | 0.8 |
| South Awach | 42.2 | 12.8 | 5.4 |
| Kuja-Migori | 58.0 | 17.6 | 7.5 |
| Mara | 37.5 | 11.4 | 4.8 |
| Total, whole basin | 778.3 | 100 | 42.4 |

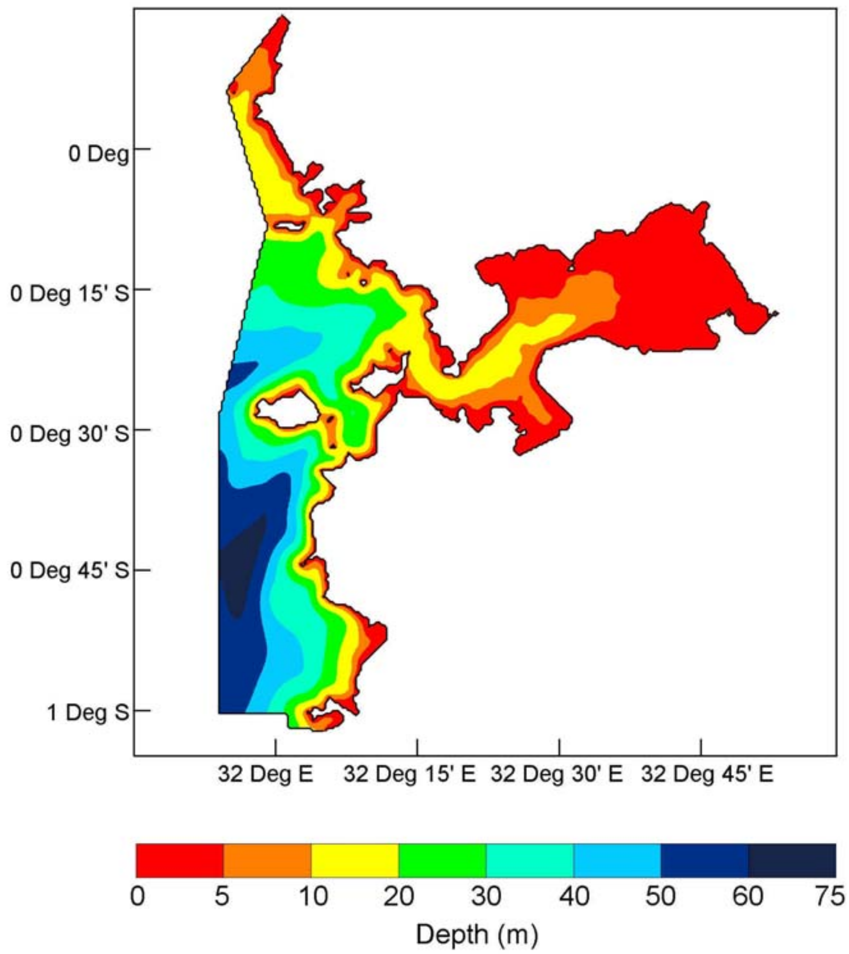



***FIG. 2. Shows the depth of the Kenyan portion of Lake Victoria***

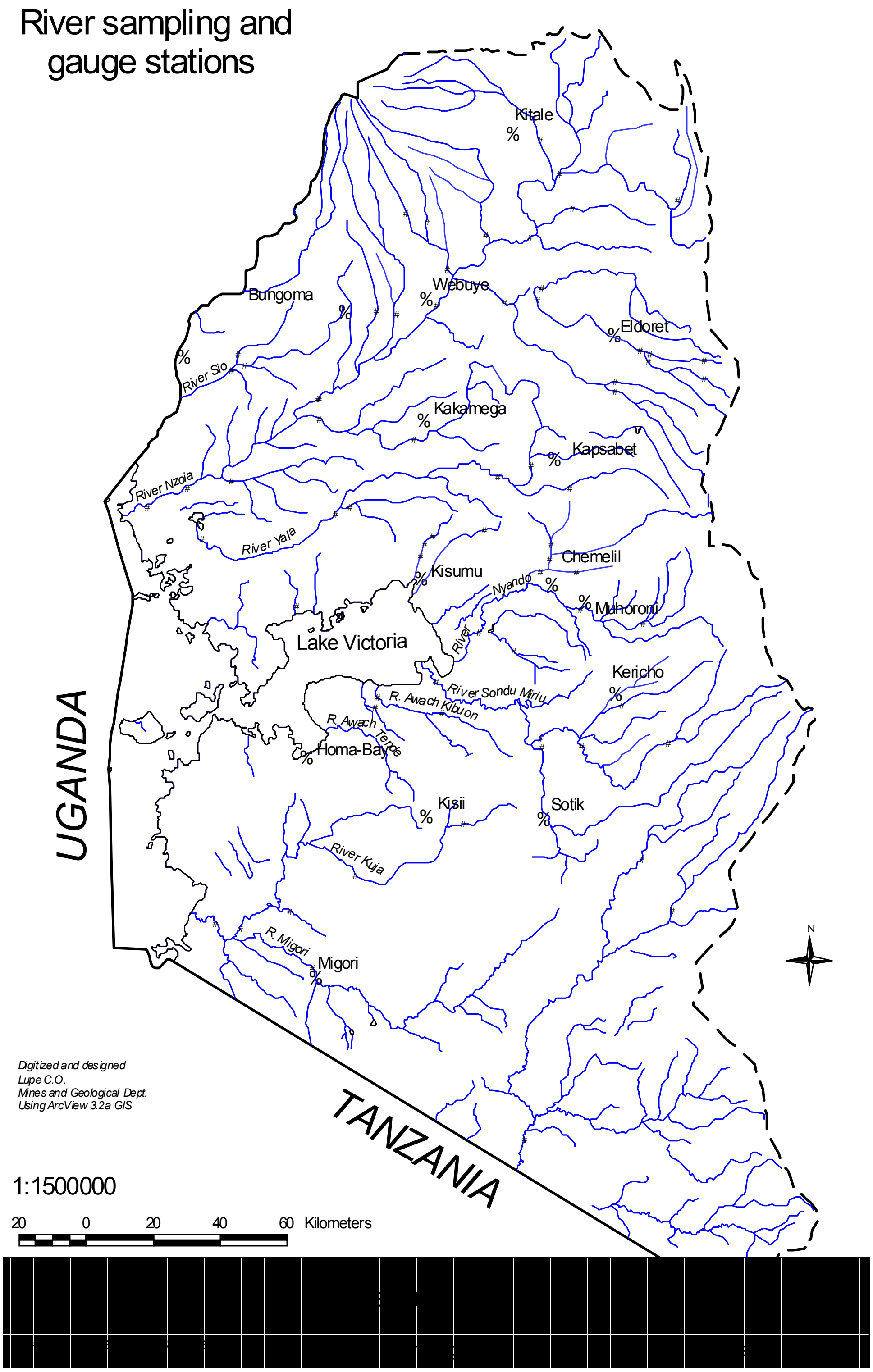



***FIG. 3. Lake Victoria basin showing the catchment and drainage system.***

The rivers generally originate from the highlands and their waters get polluted due to discharge of domestic and industrial effluents from urban centers and industries scattered within their catchments, as well as by soil erosion and agrochemicals from land use practices in the catchments. The effluent from major urban centers such as Kisumu, Eldoret, Kakamega, Kitale, Homa Bay, Muhoroni, Kisii and Migori comprise both domestic and industrial wastes. The catchment mainly has agro-based industries and therefore the pollutants are mainly organic in nature. The industries comprise of six sugar factories (Nzoia, Mumias, Western Kenya, Chemelil, Muhoroni and SONY), Pan Paper Mills in Webuye, a distillery and yeast manufacturing plant at Kisumu and Muhoroni (Kisumu Molasses Plant and ACFC) and several coffee and tea factories. Agro-chemicals, such pesticides and fertilizers also find their way into the rivers. Kisumu city and Homa Bay town are situated by the lakeshore and effluents from their waste treatment plants are discharged directly into the lake. Heavy silting of some of the rivers has resulted in the formation of extensive lakeside swamps with resultant vegetation, which renders the lakeshore areas prone to diseases like malaria, schistosomiasis, diarrhoea and other water borne diseases.

Studies on the water exchange between the Winam Gulf and the open lake have been undertaken under the water quality component. Measurements and modelling of the hydraulic conditions at the Rusinga channel has been a major objective to understand water fluxes and movements of water borned materials between the littoral and pelagic areas of the lake (Khisa, et al., this publication). The largest loss of Lake Victoria water (76%) is through evaporation from the lake surface the rest leaves the lake through the outflow into Victoria Nile at Jinja. The greatest input of water into the lake is from direct rainfall onto the lake surface (82%). Therefore only about 18% of combined rainfall and river inflow water exits the lake at the Nile. The Nile provides critical water supplies for nations beyond the basin and so there is continuous interest internationally, as well as in the basin, in the quantity and quality of water leaving Lake Victoria

**Physico-chemical characteristics**

Lake Victoria has alternating periods of stratification and vertical mixing and winds set in motion currents within the lake the periodicity of which is regulated by meteorologic conditions.

**Climate**

The Lake Victoria Basin has an equatorial climate with the temperatures modified by; the relatively high elevation of the Lake Victoria basin and its mountains e.g. Mt. Elgon. Temperatures and rainfall are lower than typical equatorial conditions and therefore the area is classified as sub-humid with temperatures ranging between 20°C to over 35°C (as indicated in Chapter 3 of this report). The rainfall ranges between 1000 mm and 1500 mm with no distinct dry season in the year. The rainfall has two major peaks with the first in March to May (long rains) and the second in October-December (short rains). The rainfall is controlled by the movement of the ITCZ (Inter Tropical

Convergence Zone). There are considerable spatial variations in rainfall in the area, mainly due to the location of the highlands and nearness to lakeshores.

The climatographs (Figs. 3 and 4) depict the conditions found at the Winam Gulf of Lake Victoria. The temperature, rainfall and wind regimes in the immediate vicinity of the Gulf provide a hot, humid tropical climate and these affect the ecology of the lake.

**Wind regimes**

The Kenyan sector of Lake Victoria is influenced by two main monsoon wind regimes and any explanation on the hydrodynamics and limnological processes operating should be based on this observation.

The wind regime is bi-modal annually with a directional variability of 68%. Two distinct wind directions were determined from the wind measurements recorded at Kadenge during 2001-2004. One mode was from SW-S-SE, which prevailed from January to March during the southeast monsoon season and from N-NE-E, which prevailed from August-September, during the northeast monsoon season. April-July and October-December were transitional periods. At Kadenge the southerly wind speeds were higher and operated for a much longer duration, when most of the mixing and upwelling took place. The contribution of the northeast winds to the mixing of the water column is relatively small. The transition periods coincided with stratification phases and the wet seasons. The study therefore suggested that the winds from a southerly direction dominated mixing and nutrient transport processes at Winam Gulf, whereas winds from the northeast were less important in the annual transport of nutrients and sediments. The major wind patterns were affected locally by a diurnal pattern of wind speeds with a land breeze that develops at night and a moderate lake breeze towards midday, reaching its maximum during the afternoon.

**Lake Level**

The study area is exposed to a mean lake level of 12 m Over Datum elevation during the wet season (April-May) and 11 m OD during the dry season (January-March). In general the mean lake level has been declining both over the long term and especially in the last few years, but has not reached the pre-1961 mean levels that occurred over the first half of the last century (Sangale et al., this report).

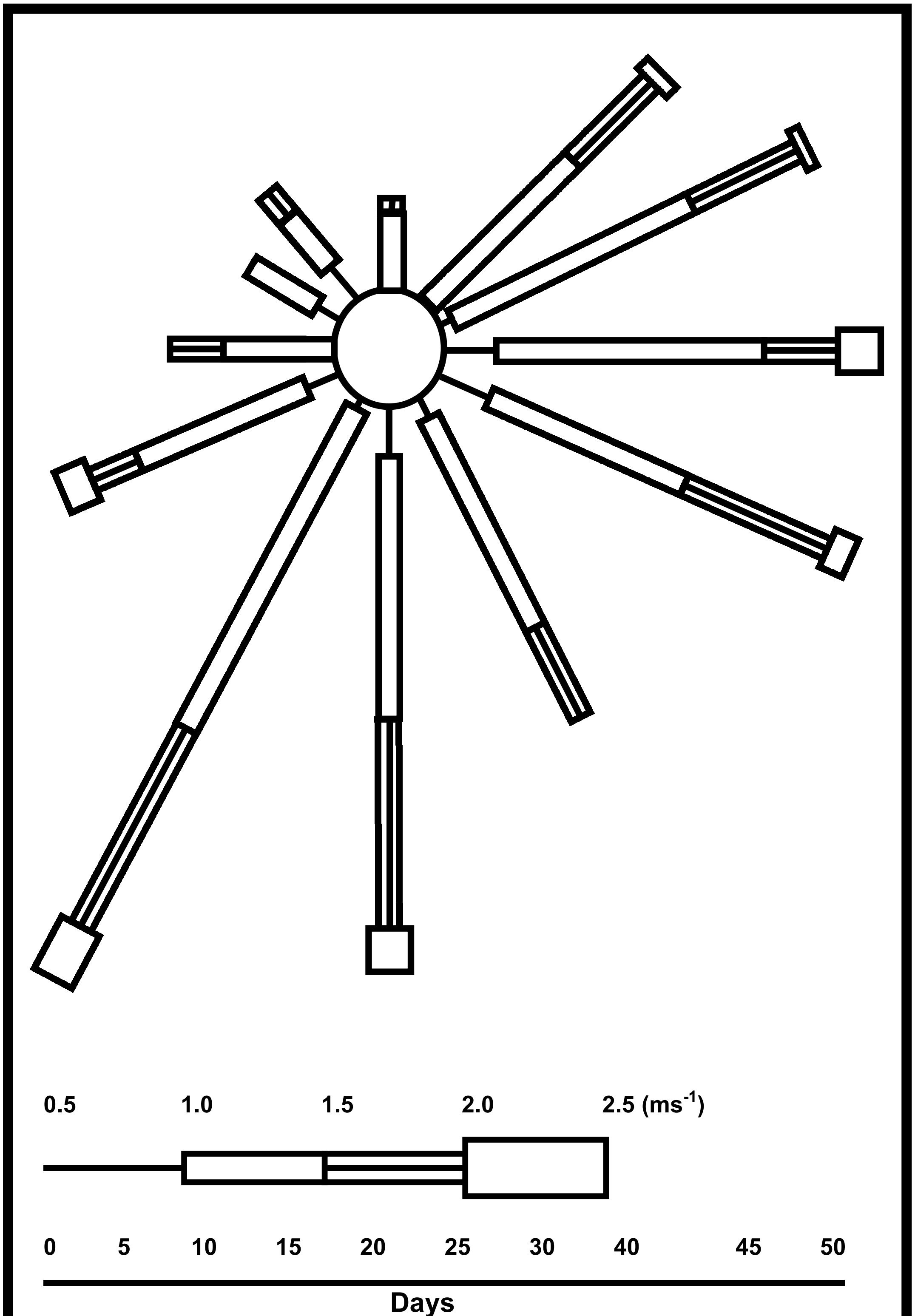
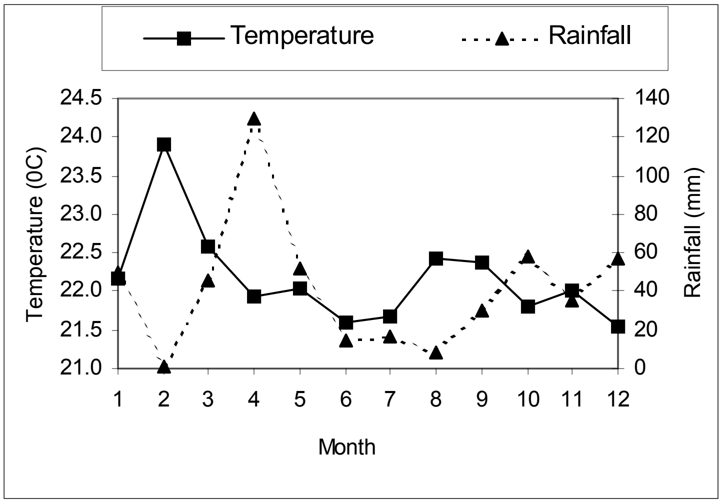



Fig. 4b. Annual wind rose recorded at Kadenge during 2003.


Temperature
Rainfall
Temperature (0C)
Rainfall (mm)
Month
24.5
24.0
23.5
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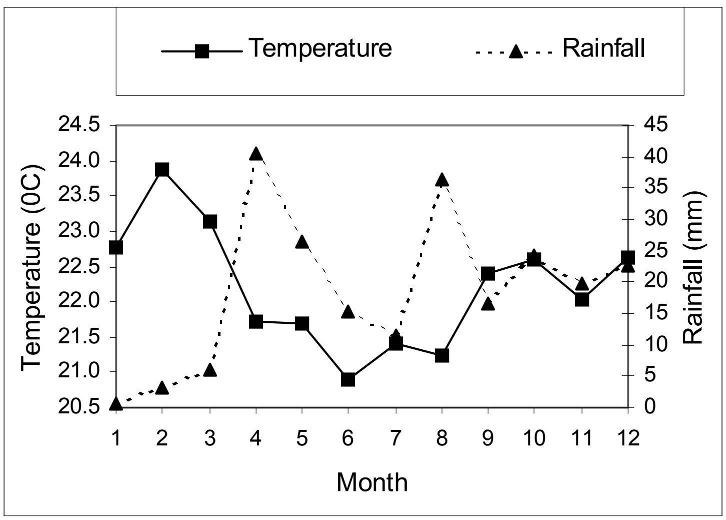
21.0
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12


Temperature
Rainfall
Temperature (0C)
Rainfall (mm)
Month
24.5
24.0
23.5
23.0
22.5
22.0
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21.0
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40
35
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25
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1 2 3 4 5 6 7 8 9 10 11 12

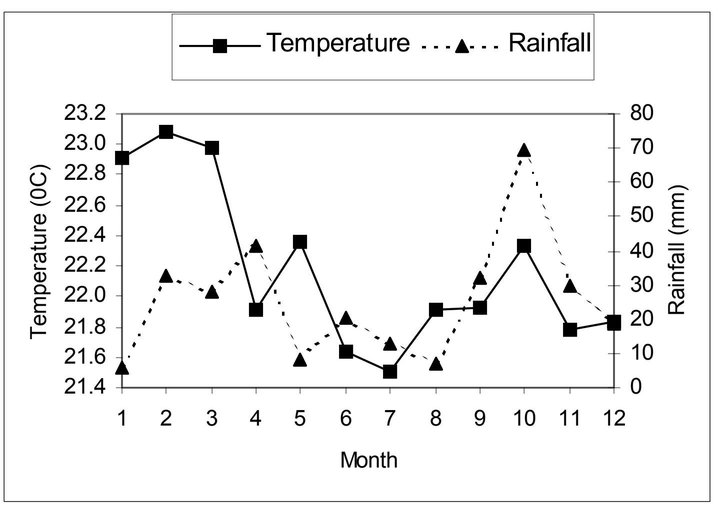
Temperature
Rainfall
Temperature (0C)
Rainfall (mm)
Month
23.2
23.0
22.8
22.6
22.4
22.2
22.0
21.8
21.6
21.4
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12

***FIG. 5. Climatographs for the Winam Gulf area. a. Mean monthly rainfall; b. Mean monthly temperature.***

## Landscape

The Kenyan catchment area within the Lake Victoria Basin has a general elevation of about 1100-1800 m above sea level. It is separated from the western highlands on its eastern side by three escarpments. Semi-circular in shape and enclosing Winam Gulf of Lake Victoria, this basin is approximately bounded on the eastern side by the 35° E longitudes and by the latitudes 1°N and 1°S, respectively.

The drainage system of the Lake Victoria Basin is mainly determined and influenced by the uplifted mountains and highlands of the Great Eastern Rift Valley running approximately north to south and forming the eastern boundary of the catchment. From the flanks of the rift valley, several rivers flow westwards to Lake Victoria. The northern drainage pattern is mainly controlled by volcanic Mount Elgon, and several streams originate from here and flow southward. The Lake Victoria Kenya Basin has diverse landforms, which can be divided into two main topographical land formations, namely the lakeshore lowland and the highland plateau: the lowest point being near Lake Victoria and the highest point being Mount Elgon. The lakeshore lowland lies between 1100-1200 m above sea level constituting areas bordering and the shores of Lake Victoria especially in the western part of the basin. The areas consist of flood areas in the plain fields of Budalangi, Nyando and Kano plains. In fact, the Kano Plains are enclosed between the Nandi Hills and the Nyabondo Plateau.

The highland plateau stands at 1219 m above sea level. The eastern highlands, which are traversed by the Rift Valley, are dominated by the Nandi Hills. The north-eastern side is occupied by Cherengani Hills while the northern highlands are the slopes of Mount Elgon, which is the source of two two rivers flowing into Lake Victoria, namely the Nzoia and Sio Rivers. The southern highlands are undulating surfaces caused by erosion of an ancient plain characterized by residual highlands of Kanyamwa escarpment along the borders of Homa Bay and Suba, Guassi Hills in Suba, Homa-Lime in Rachuonyo and the Kisii, Gucha and Nyamira highlands.

### Geology

The East African Craton occurs in west Kenya and consists of Precambrian formations, which comprise slightly metamorphosed volcanic and sedimentary deposits belonging to the Nyanzian and Kavirondian Systems (Fig. 5). The area where these rocks are exposed is structurally known as the Tanzanian Shield. Lake Victoria is perched high on the East African Craton in a tectonic sag between the two rift valleys of East Africa. The rocks of the Bukoban System constitute a platform cover on the East African Craton. In west Kenya, the rocks consist of Precambrian volcanic and sedimentary deposits of the Kisii Series. The major rock types are basalts, phonolites, andesites, dacites, conglomerates, grit, tuffs and rhyolites. The terrain is also characterized by Archean granite/greenstone formations in which gold mineralization occurs as well as Cenozoic carbonatite complexes. There are also areas of Quaternary sediments in the region and the main rock types are clays, diatomites, shales and silts some of which were deposited when Lake Victoria stood at higher elevations.

The oldest sedimentary rocks are found in western Kenya; they vary in age from Nyanzian, Kavirondian and Bukoban. Gold is mined in small quantities from the Nyanzian ironstones (Fig. 6). Fig. 6 also shows several other minerals of potential economic importance that are found in the lake basin.

The Tertiary domal uplift in East Africa including central Kenya had a strong influence on regional geological development. The uplift culminated in the formation of the East African Rifts, with the Western Rift in Uganda and the Eastern Rift in Kenya and Ethiopia. They are part of the Afro-Arabian Rift System and their formation took place mainly during Pliocene and Early Pleistocene times. The Eastern Rift divided the crust of Kenya into two large tectonic blocks. The western block has uplifted margins and a central depression in which the Lake Victoria Basin developed. Fig. 5 shows that volcanic igneous rocks are of Nyanzian, Tertiary and Quaternary ages. The Tertiary/Quaternary volcanics, which are associated with the Rift Valley, have a wide spectrum of chemical composition. Most of the building materials in the basin are tuffs, compacted volcanic ash.

Most of the lake is surrounded by Precambrian bedrock, with the exception of the Winam Gulf in the northern corner where Tertiary and Quaternary alkali volcanic and sedimentary units dominate the terrain.

The lake's origins are still the subject of scientific dispute, but it seems likely that it is much more recent than the other Great Lakes of eastern Africa; Malawi and Tanganyika are over 10 million years old. River drainage patterns and exposed lacustrine sediments to the west of Lake Victoria reveal the lake's origin as a result of uplift along the western branch of the East African Rift Valley in late Pleistocene, and backponding of rivers that previously had drained westward. Many of the rivers now flowing east into Victoria (including Kagera) once flowed west, at least in the Miocene, Pliocene, and part of the Pleistocene eras, possibly into the Nile system. A regional upthrust of the western side of the basin 400,000 years ago is thought to have reversed these rivers, and caused Lake Victoria to form by flowing eastwards, ponding and eventually overflowing in the vicinity of the modern Nile. Uplift and tilting of the basin is continuing today, resulting in a drowned morphology charaterized by highly irregular northern, eastern and southern shorelines of the lake and a continuing eastward shift in the centre and deepest part of the lake basin.

The age of 400,000 is estimated from the total thickness of lake deposits (60 m), assuming modern sedimentation rates and effects of compaction. Recent evidence suggests that it may have experienced three major dessication events in its history; the end of the most recent dessication was 14,700 years ago. Paleosol is observed throughout the lake basin, even in the deepest parts, and indicating that Lake Victoria had completely dried out during the Late Pleistocene. Table 3 gives a chronology of events in the history of Lake Victoria by the International Decade for the East African Lakes (IDEAL). The presence of three low stands over the estimated 400,000-year old lake implies that the basin may be responding to 100,000 glacial-interglacial (Milankovitch) cycles. In general East African climates were cool and dry when continental glaciers covered northern latitudes

***TABLE 3. Chronology of the Pleistocene and Holocene events in the history of Lake Victoria. (After Johnson et al. 2000).***

| Event | Age | Pleistocene terminology | EA pluvial sequence | Alpine glacial sequence |
|---|---|---|---|---|
| Origin of lake basin by backponding | 400 000 | Lower Pleistocene | Kamasian pluvial | Mindel glaciation |
| | | Middle Pleitocene | Kanjeran pluvial | Riss glaciation |
| End of most recent desiccation | 14700 | Upper Pleistocene | Gamblian pluvial | Wurm glaciation |
| Early lake evolution, rising primary production-onset of Holocene lacustrine conditions | 14700-14200 | Bolling Allerod | | |
| First brief overflow, salinity drop | 14200-13600 | | | |
| Closed basin | 13600-11200 | Younger Dryas | | |
| Beginning of permanent overflow | 11200 | | | |
| Gradual increase in water column stability | 11200-6000 | | | |
| Minimal diatom preservation, maximum stratification/stability of water column? | 9800-7500 | | | |
| Human impacts discerned in biogenic silica record | Early 1930s | | | |
| Diatoms replaced by cyanobacteria | Late 1980s | | | |

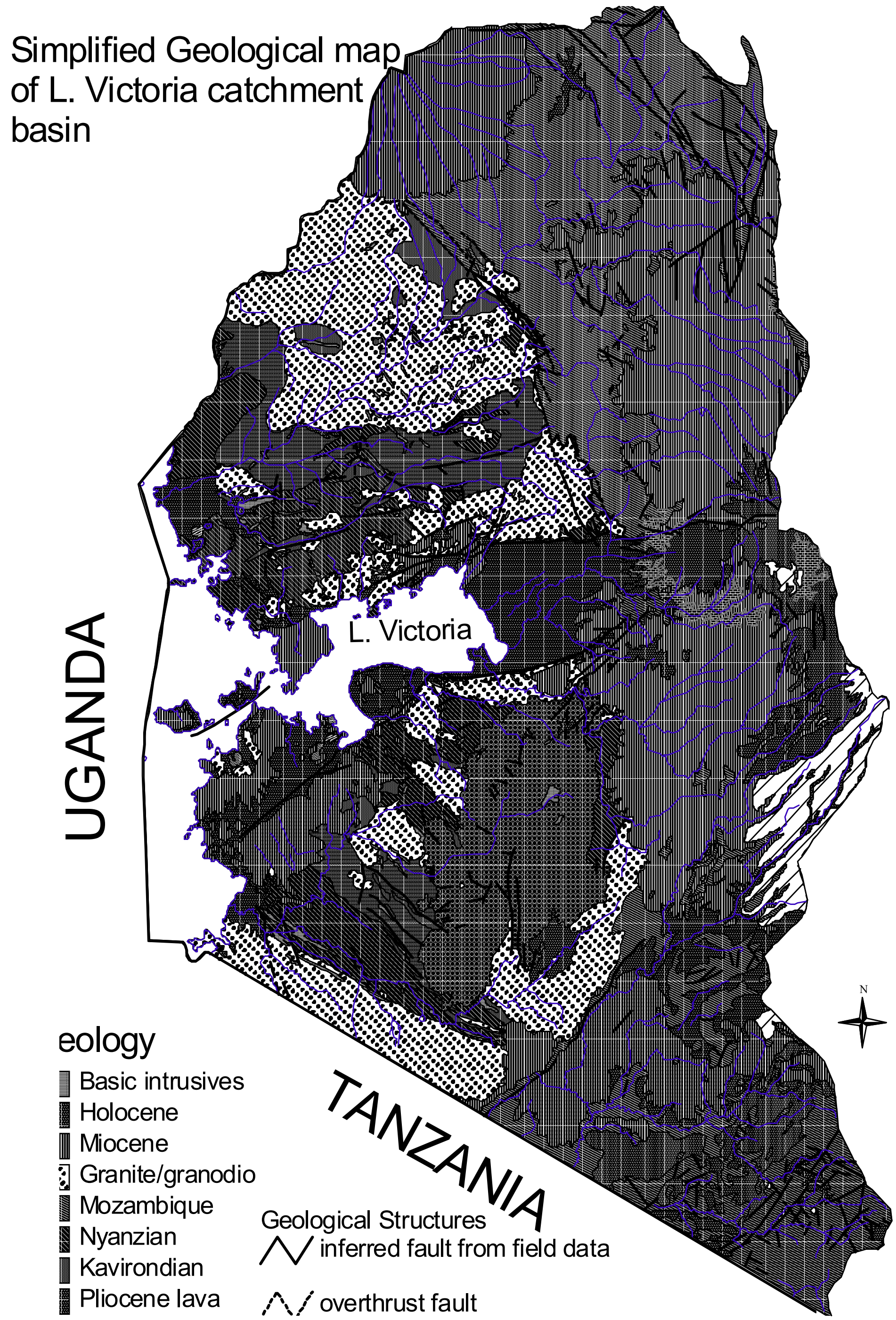


*FIG. 5. Geological map of the Lake Victoria Basin*

# Mineral occurence map of lake Basin Region, Kenyan side

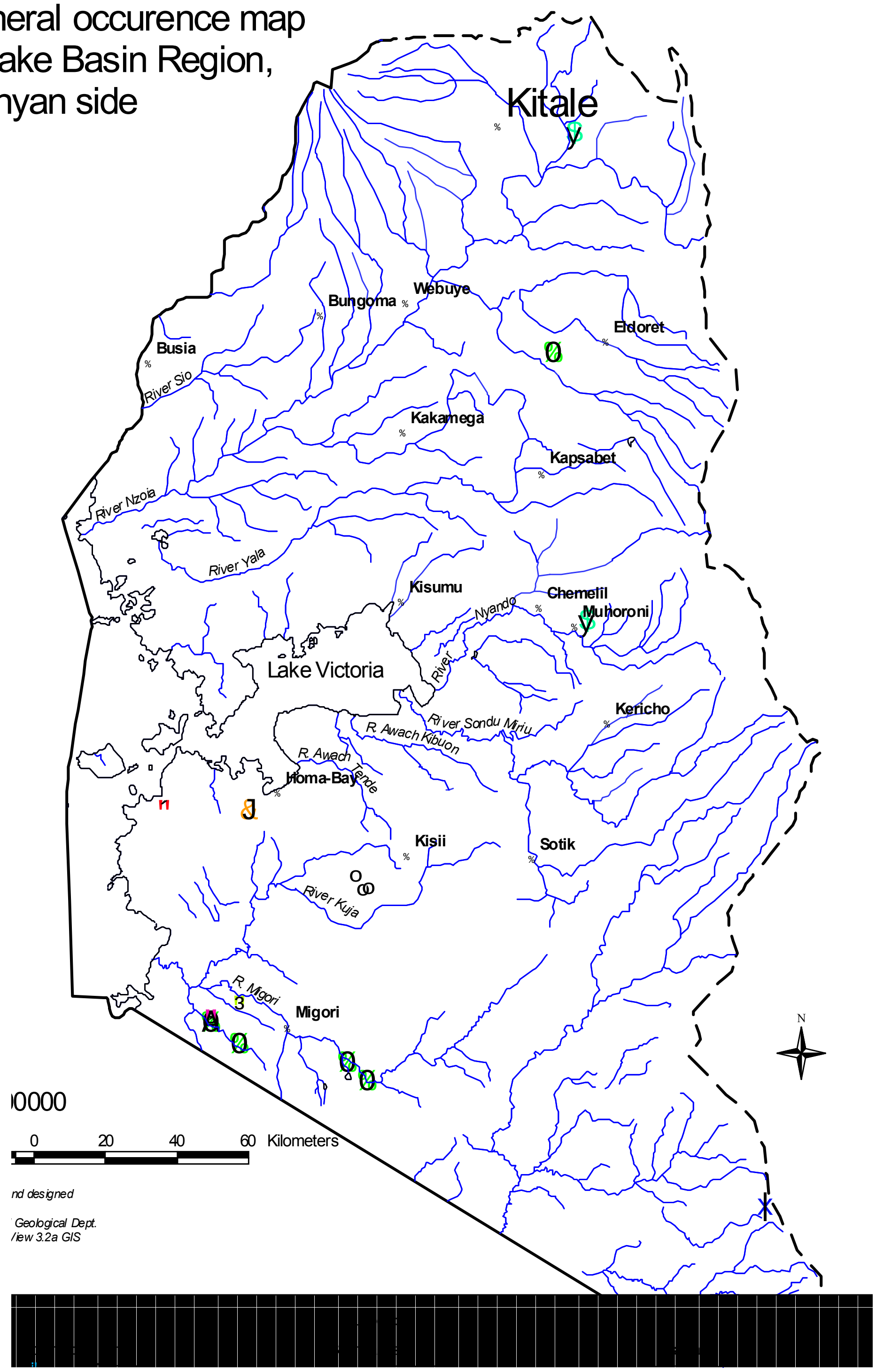

*FIG. 6. Mineral resources in the Lake Victoria Basin*

## Soils and soil types

Soil types that occur in the Lake Victoria Basin are Cambisols, Planosols, Vertisols, Regosols, Arenosols and Ferralsols (Figure 3).

In the Kano plains are found the Gleysols commonly associated with swamps, on the slightly elevated grounds and piedmont plains are Planosols and its complexes, which are of moderate fertility. On the upland are Cambisols and Luvisols of volcanic origin, which have low fertility. There are various types of soils in the sugar belt e.g. heavy black cotton soils and light soils e.g. in the Nandi escarpment.

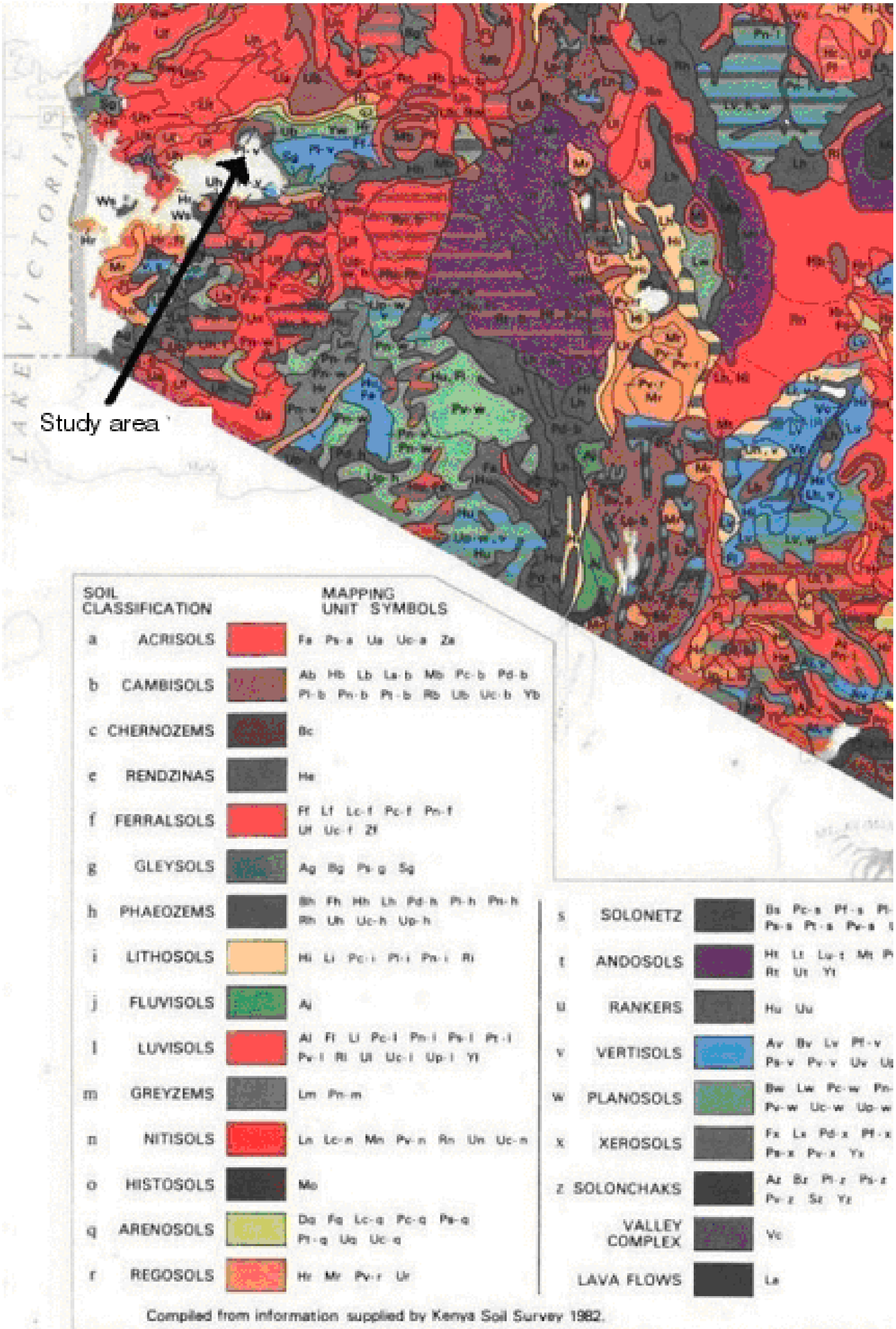
LAKE VICTORIA
Study area
SOIL CLASSIFICATION
MAPPING UNIT SYMBOLS
a ACRISOLS
b CAMBISOLS
c CHERNOZEMS
e RENDZINAS
f FERRALSOLS
g GLEYSOLS
h PHAEOZEMS
i LITHOSOLS
j FLUVISOLS
l LUVISOLS
m GREYZEMS
n NITISOLS
o HISTOSOLS
q ARENOSOLS
r REGOSOLS
s SOLONETZ
t ANDOSOLS
u RANKERS
v VERTISOLS
w PLANOSOLS
x XEROSOLS
z SOLONCHAKS
VALLEY COMPLEX
LAVA FLOWS
Compiled from information supplied by Kenya Soil Survey 1982.

**Fig. 7. Regional Soils Map of the Lake Victoria Basin**

Soil erosion continues to be a major constraint to agricultural productivity. It also causes siltation in the lake and is a major source of nutrient loading into the lake. However, there is only very limited information on the nature, magnitude and impacts of soil erosion. Gor *et al* (this report) has attempted to calculate sediment yield from each river basin on the basis of their sediment loads.

## Demography

The population size of the Lake Basin in the year 1999 census was 12 million, with inter-census growth rate of about 3% per year, one of the fastest in the world. At this rate, the population would double every 25 years, leading to growing demand for food, water, land and other natural resources. This projection is an important factor in planning for the responsible use of the Lake Basin's resource base.

## Fisheries resources

Since the 1970s total fish catches have increased by between four and five times after the introduction of exotic species such as the Nile Perch (Mbuta). However, catch per fishing effort has been dropping while effort has continued increasing, indicating that the maximum sustainable yield is below the present level of exploitation.

Furthermore, introduction of exotic species of fish has altered the food web structure of Lake Victoria, which has led to a dramatic decline in diversity of indigenous fish species. A number of original 300 species of fish are now extinct or facing depletion.

Other factors which have affected the status of lake and riverine fisheries in the Lake Victoria basin are: overfishing by use of small mesh nets and harvesting of brood stocks; destruction of fish habitats through river engineering; siltation due to deforestation, algal blooms due to nutrient enrichment, pollution, wetland conversion and development, fish pathogens and water hyacinth infestation.

## Economic development and water quality

Although Kenya controls only about 6% of the lake surface, it is estimated that Kenya's share of Lake Victoria's total fish catch is 33%. Lake Victoria contributes more than 95% of the 200,000 tonnes of fish produced in Kenya. In Kenya, fishing accounts for only 5% of the GDP, the majority of which is contributed by the Nile Perch. Between 1971 and 1981, the fishing industry accounted for an average 0.2% of the country's GDP. This marked improvement can be attributed to the export of filleted Nile perch that was introduced to the lake in 1954 and became commercially important in the early 1980s. About 15,000 tonnes of fish is sold on the international market, which generates foreign exchange in export revenue of US$ 30 million; this is substantial for a country whose current account balance of the best fiscal years is estimated to be about US$ 100 million.

Despite the relatively small contribution to the gross domestic product (GDP), the fishing industry is the lifeline for communities living around Lake Victoria, providing a significant source of livelihood and employment. It is estimated that about 1 million people are directly or indirectly supported by the sector, resulting in a regional multiplier effect as well as demand for both commercial and social services.

Construction of fish processing plants near the lake would contribute to local value addition on all fish products and realize the desired multiplier effects. Value addition would create more jobs and increase revenue for the government.

The continuing increase in socio-economic activities in the catchments has been accompanied by an even faster growth in pollution stress on the aquatic environment.

Only after a considerable time lapse, allowing for the public perception of water quality deterioration, have the necessary remedial measures been taken.

**Management**

Since Lake Victoria is shared among Kenya, Tanzania and Uganda, regional cooperation is crucial to the management of Africa's largest freshwater lake. There is therefore need for regional cooperation in controlling water hyacinth and pollution; conservation of Lake Victoria fisheries; and afforestation and soil conservation programmes to protect the catchment areas. Lake Victoria Environmental Project was a regional undertaking to provide objective baseline data on current conditions and to identify current trends that may be unsustainable and require management by the three countries.

LVEMP is a project structured to do Integrated Water Resources Management of the whole Lake Victoria Basin. The project is implemented in the three East Africa countries of Kenya, Tanzania, and Uganda. A tripartite agreement signed in August 5, 1994 set in motion a collaborative process of project preparation among the three countries and provided also for project implementation. The actual implementation of the project activities started by September 1998.

LVEMP was started as a programme for the rational and sustained utilization of the lake and its resources with the main aim of poverty alleviation, improvement of the lake basin environment and the social welfare of the riparian communities. The project was also meant to restore the lost Lake Victoria species and its damaged ecosystem and foster the development of a rich healthy ecosystem with a well representative but diverse species complex.

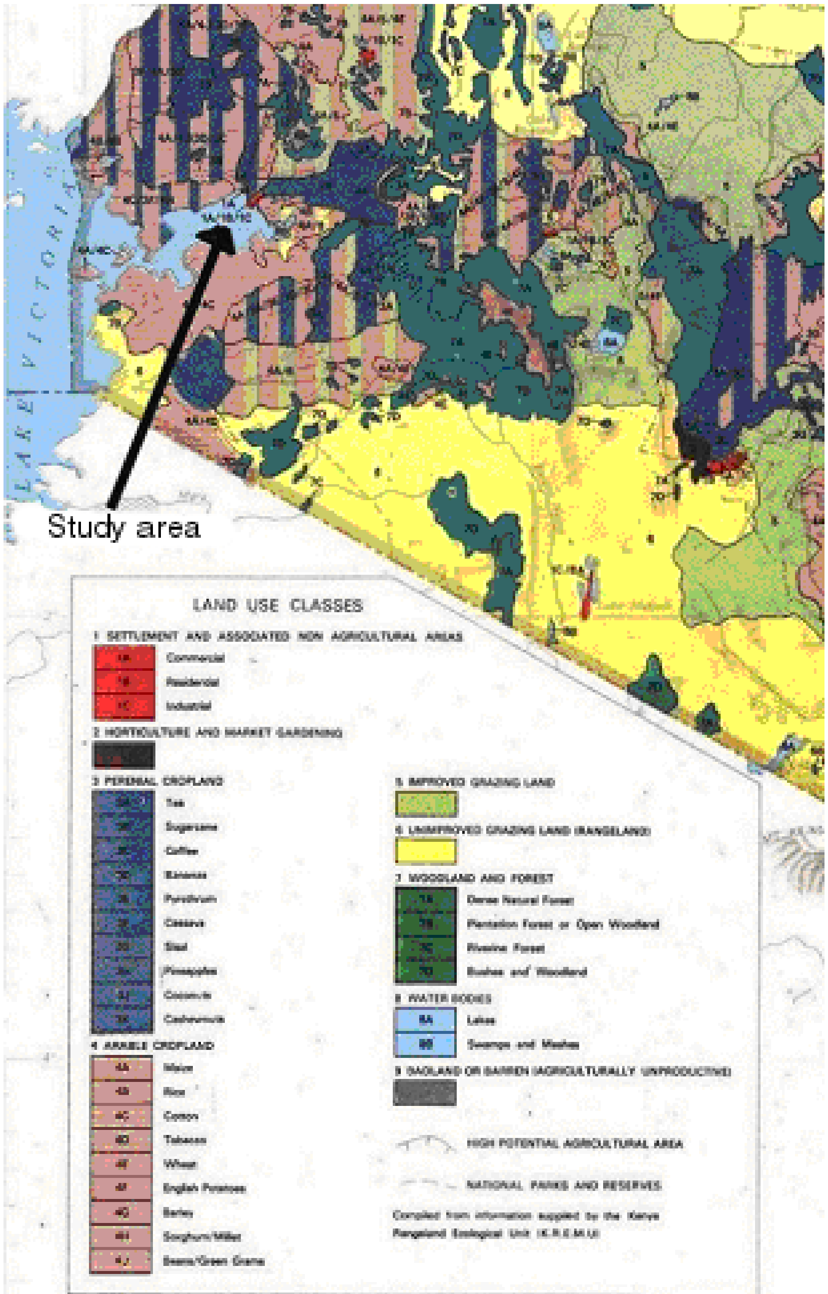


*FIG. 8. Regional Land Use Map*

**Previous studies**

Although there are many features of Lake Victoria, which are of intense interest to scientists, it is fish that has received the most attention and most studies have been on what affects fish survival. There have also been studies specific to particular areas of interest and geared to understanding just specific issues. Integrated studies of the lake have not been previously done.

The literature on limnology of the Kenyan waters of Lake Victoria is rather scanty and it is envisaged that the present data set will instigate more investigations into the ecological and eutrophication status of the Winam Gulf. In addition, this investigation will assist in the evaluation of suitable options for lake management and conservation. Several studies on the biodiversity in the lake have recently appeared. These reports describe only the fish and phytoplankton communities, but specifically, little or no detailed mention of nutrient mass balance and physical limnology. However, studies on the relationship between limnology and ecology are few.

Previous investigations on Lake Victoria focussed on Bugaia Island on the Ugandan waters of the lake. The first limnological examination was made by Talling (1965, 1966, 1969) on the seasonality of phytoplankton photosynthesis and abundance, and their relationship to thermal and oxygen regimes; he carried out a very comprehensive study of Bugaia Island for one year in 1960-61. These classic studies provide the historic benchmark against which all future charge on Lake Victoria will be assessed.

In the 1980s and 1990s the Kenya Marine and Fisheries Research Institute carried out extensive research operations and laboratory tests in the Winam Gulf of Lake Victoria (Ochumba and Kibaara, 1989; Ochumba, 1990; Ochumba, 1996; Calamari et al, 1995). Ochumba and Kibaara (1989) observed that the blue-green algal blooms in the open waters of Lake Victoria were caused by a combination of high temperature, release of nutrients from river inflows, upwelling and from sediment into the euphotic zone. The results of this investigation also showed that the blooms declined as a result of physical flushing, temperature reduction associated with rainy season and nutrient exhaustions. Ochumba (1990) noted the massive fish kills within the Winam Gulf, which occurred during violent storms. He attributed the mortality to several factors which included high levels of suspended natural in the water column (detritus and algae) which clogged the gills of fish; further, the storms transported parcels of water with both low DO and pH and high concentrations of algae.

Hecky (1993) examined changes in the lakes environmental parameters – temperature, oxygen chlorophyll, silicon, nitrogen, phytoplankton biomass. His paper indicated that environmental degradation has resulted from high human population in the catchment, biomass burning, shallow mixing depths as a result of changing regional climate, and low flushing times, and concluded that enormous effort, social transformation and investment from the international community would be required to stem the damage. Preliminary assessment of pollution levels in Winam Gulf conducted by Calamari et al. (1995), quantified urban industrial and agricultural loads, and related these to geographic and climatic condition.

Extensive measurements of water currents, temperature dissolved oxygen and winds on the Kenyan waters of the lake were done by Ochumba (1996). Hypolimnion temperatures as low as 23.5ºC observed in 1928 by Worthington (1930) in the 1950s (Fish 1957) and in 1960-61 (Talling, 1966) were not seen, suggesting a response of Lake Victoria to a possible warning trend in the climate of East Africa. Ochumba (1996) also reported that oxygen conditions have deteriorated since 1950. Hecky et al. (1994) concluded that low oxygen conditions are now more extensive and persistent than previous investigators had found.

Zooplankton dynamics in Lake Victoria was outline by Bransrator et al (1996), who suggested that the composition of cladocerans, calanoid copepods and cyclopoid capepods in the modern community were largely unchanged from historical conditions although the proportions may have changed. The results of this study also showed that recent changes in the fish community of Lake Victoria may have led to the establishment of *D. lumnoltzi* var. *monacha* in the modern zooplankton. Further, distribution of its fossils in the sediments could provide an important paleoecological marker of the distribution of fish planktivory and the timing of the fishery transformation in Lake Victoria.

In the Kenyan waters of Lake Victoria, the phytoplankton community structure have been described and related to environmental conditions (Lung'ayia et al 2000). They identified 103 species of phytoplanktons. Blue-green algae (Cyanophyceae also referred to as cyanobacteria) were the most diverse, followed by diatoms (Bacillariophyceae), green algae (Chlorophyceae) and dinoflagellates (Dinophyceae). Seasonal variations in the gulf and open lakes were observed. Chlorophyll concentrations confirmed increasing phytoplankton biomass in Lake Victoria since the 1960s.

The food web structure and contamination have been discussed by Campbell et-al. (2003a, 2003b) for the whole lake including Winam Gulf. Stable isotope data illustrated a short food web with the top predator Nile perch feeding on a restricted set of fish and macroinvertebrate species, including its own young. Campbell (2003b) determined from comparative analyses of fish, water and sediment samples that Hg bioaccumulates at a similar rate in diverse aquatic foods webs, regardless of latitude or species composition. Probably the most interesting finding from her study was that water Hg concentrations in Lake Victoria are higher than in temperate great lakes although fish concentrations were lower.

Recent ecosystem changes in Lake Victoria as reflected in sedimentary lithostratigraphic units and anthropogenic organic compounds were studied by Hecky (1993) and Lipiaton et al. (1996) for a core from station 103 in Kenya. These studies show that good preservation of natural organic matter, especially that typical of in-lake biological production, suggests that organic rich sediments have been deposited at the site for the last 200 years but that the nature of the organic matter and diatom microfossils had changed over the past 40 years indicating eutrophication was affecting the lake.

Further palaeaolimnological data are given by Verchuren et al. (2002) documenting the recent history and timing of human impact on Lake Victoria. He showed that increases in phytoplankton production developed from the 1930s onwards, which parallels human-population growth and agricultural activity in the Lake Victoria drainage basin. Verschuren et al. (2002) also found that the dominance of bloom-forming cyanobacteria since the late 1980s coincided with a relative decline in diatom growth, which can be attributed to the depletion of dissolved silica resulting from 50 years of enhance diatom growth and burial. Further, eutrophication-induced loss of deep water oxygen started in the early 1960, and may have contributed to the 1980s collapse of indigenous fish stocks by eliminating suitable habitat for certain deep water cichlids

Work by Ochumba and Kibaara (1989), Hecky (1993), Verschuren at al. (2002), Odada et al. (2004), Ikiara, (1999), Scheren et al. (2000), Wandiga and Madadi (2004) has clearly demonstrated the causes for the lake's enormous environmental changes that threaten its existence as a functioning ecosystem, and that the problems can be found and ameliorated in the catchment through improved land use practices and pollution prevention policies.

**Situation prior to LVEMP**

Before independence, issues like pollution, environmental degradation, loss of bio-diversity and environmental conservation and management were not of great concern because of the low population pressure and less human activity that could cause problems. Lake Victoria status according to the LVEMP, 1995 was that, before 1960 the lake was unpolluted, had lower levels of nutrients concentration and had balanced representation of the algae and diatom flora with less concentration of the blue green algae.

***a) Popular Concerns***

After 1960, the landscape has undergone changes with increasing intensity particularly in the recent decades due to exponentially growing populations and their activities altering the environment and the natural resource base. The problems experienced are associated with population pressure, greater urbanisation, industrialization, intensified agriculture, over grazing, deforestation, wetlands destruction, soil erosion and greater use of pesticides.

The importance of the Lake Victoria basin as a source of food, energy, and drinking and irrigation water, for shelter and transport and as a repository for human, agricultural and industrial waste cannot be overemphasized.

In the basin, increased development activities, occasioned by population pressure and associated with greater urbanisation, industrialization, intensified agriculture, over grazing, deforestation, wetlands destruction, soil erosion and greater use of agro-chemicals, cause discharge of nutrients and other wastes generated and also cause changes in the lake ecosystem. Massive blooms of algae have developed, water borne diseases increased in frequency and water hyacinth started choking important waterways and landings beaches as well as water supply intakes in the early and mid 1990's (LVEMP, 1995). The pollution problems of Lake Victoria were not confined only to areas next to the lakeshores but originated from all over the Lake Catchment.

Prior to LVEMP and since 1960 the following were reported;

- 2 fold increase in algae productivity resulting in four times increase in algae blooms
- Blue green algae (i.e. *Microcystis* and the nitrogen fixing species *Anabaena* and *Cylindrospermopsis*) were noted to be the predominant phyto-plankton.
- Chlorophyll "a" rose from a range of 1.3 – 21 mg/L to about 77.5mg/L.
- Transparency reduced 3 times
- Prolonged and pronounced thermal stratification
- Phosphates doubled in concentration
- Oxygen deficiency (anoxia), which affects up to 50% of the lake bottom for prolonged periods.

***b) Lack of routine monitoring/observation***

Isolated studies had been done but deterioration in the lake water quality had not been adequately established and quantified. There had been no established water quality criteria on biological, physical and chemical aspects for the improvement of water quality. Data collection network had been inadequate and decreasing. There had been lack of information on the levels of pollution from diffuse sources and urban surface run off e.g. residual agro-chemicals and pollutants from Urban Surface run off. Holistic ecosystem management approach was not possible based on the limited data available and the capacity of the region to provide the necessary information.

***c) Lack of capacity***

Though there was some limted trained human resource available in terms of those who were employed by different departments responsible for environmental management, who could monitor and quantify environmental degradation, there was inadequate capacity in terms of collaboration and, equipment, which could be used for field monitoring and laboratory analytical requirements. Recurrent funding for operating the existing monitoring networks were always insufficient and field installations were not maintained. Additional and modern field and laboratory equipment could not be bought and installed.

***d) Lack of conceptual models to guide understanding and information generation***

Despite attempts to develop a Lake Victoria Water Quality model, no models had been developed, calibrated or validated for the Lake to guide ecosystem management and to explore options for restoration.

**Objectives of LVEMP Water Quality Studies**

- LVEMP main objective is to strengthen, harmonise and integrate rational and sustained utilisation, management and conservation of the aquatic and natural resources of Lake Victoria taking into account regional concerns of the ecosystem and its resources and also to restore the lost lake Victoria species and its damaged ecosystem.
- The main aim is poverty alleviation through improvement of the lake basin environment to sustain the beneficial uses of the lake and to ensure sustainable socio-economic livelihoods for the riparian communities.

**The main objective of Water Quality and Ecosystem Management Component is:**

- Elucidating the nature and dynamics of the lake ecosystem by providing detailed information on characteristics of the waters of the lake
- Defining the major sources of nutrients and pollutants to the lake and improving management of Industrial and Municipal effluents and assessing the contribution of urban runoff to lake pollution in order to design effective remediation measures
- Establishing water quality monitoring network throughout the catchment to define baseline conditions, and estimating the effects of changes in land use planning on pollution loads into the lake, and developing policies and programmes to control non-point source pollution

In order to achieve these objectives, LVEMP II project, should consider the following:

1. **Build human capacity**

    - Delineate institutional responsibilities and operational terms of reference and roles in the management of the lake environment
    - Formulate an employment policy for local authorities and lake management agencies
    - Enhance awareness and participation of local communities in water resources, soil conservation and environmental management
    - Increase human, technological and financial resources necessary for efficient operation, monitoring and management of lake resources
    - Train more lake scientists and managers

2. **Establish and operationalize infrastructure**

    - Strengthen institutional capacities of the implementing agencies in lake resources and limnological data acquisition, analysis, storage and dissemination
    - Strengthen NEMA to coordinate and supervise the management and safe disposal of refuse and solid, liquid and hazardous wastes.
    - Establish a national agency to coordinate management and conservation of the Lake Victoria basin and the lake itself
    - Strengthen existing institutions or establish new ones to conduct research and environmental management of the lake

**The objectives of this national report in the following chapters are to:**

1) Define current baseline condition of Lake Victoria over LVEMP1 tenure
2) Determine historical trends in water quality and future projections
3) Identify impacts on beneficial uses
4) Recommend future actions (including LVEMP 2)

**RECOMMENDATIONS**

- Formulate an integrated water quality management plan for the Lake Victoria basin;
- Assess the full economic resources potential of Lake Victoria;
- Continue the water quality monitoring regime and insure its relevance to fisheries management and biodiversity conservation management plans;
- Identify, map, protect and study water catchment areas with the aim of instituting sustainable utilization of the resources;
- Develop plans and strategies for managing water pollution and sanitation for all urban centres in the Lake Victoria basin;
- Develop strategies for controlling and managing floods in the basin;
- Involve industries, local authorities and local communities in developing strategies to manage pollution and sanitation;
- Support cooperation with neighbouring countries in water quality studies, water hyacinth control and fisheries management;
- Put up facilities for mitigating the negative effects of pollutants reported in the present studies such as effluent treatment plants, which require rehabilitation and/or expansion;

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