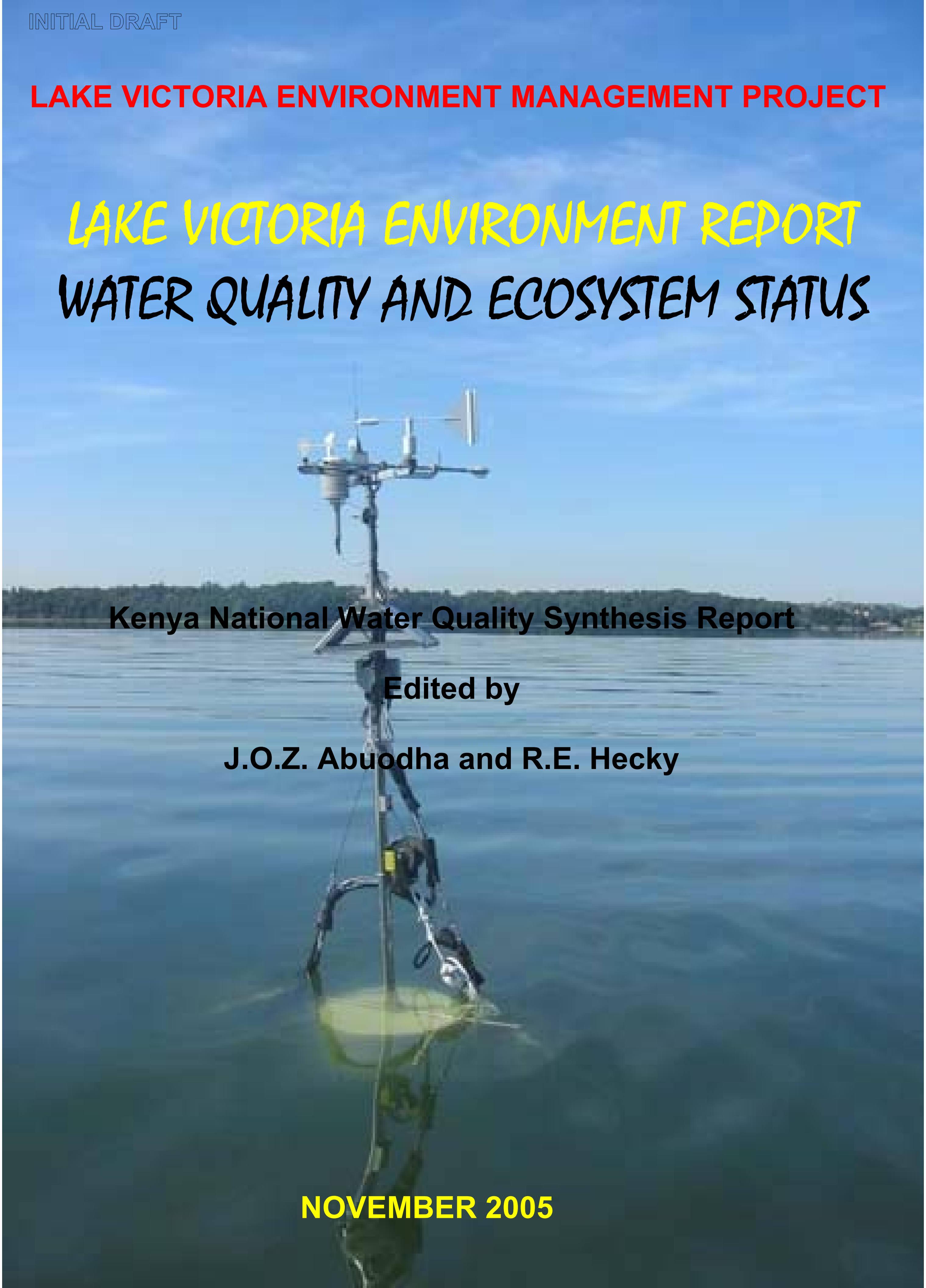

INITIAL DRAFT

LAKE VICTORIA ENVIRONMENT MANAGEMENT PROJECT

LAKE VICTORIA ENVIRONMENT REPORT
WATER QUALITY AND ECOSYSTEM STATUS

Kenya National Water Quality Synthesis Report

Edited by

J.O.Z. Abuodha and R.E. Hecky

NOVEMBER 2005

LAKE VICTORIA ENVIRONMENT MANAGEMENT PROJECT (LVEMP)

KENYA NATIONAL WATER QUALITY SYNTHESIS REPORT

Edited by

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NATIONAL WATER QUALITY SYNTHESIS REPORT, KENYA

LAKE VICTORIA ENVIRONMENT MANAGEMENT PROJECT (LVEMP)

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EXECUTIVE SUMMARY

The Winam Gulf's aquatic environment (Figure 1) represents a considerable part of the economic potential of the country, e.g. with regard to fisheries and navigation. However, the use, the management and the preservation of the aquatic ecosystem and its natural resources require an adequate knowledge of physical, chemical and biological processes and features within this environment.

Although there are many features of Lake Victoria, which are of intense interest to scientist, it is fish biology and economics that have received the most attention.

The study program had a multidisciplinary character and included the themes specified in the objectives. Methods of research within the seven interrelated themes are given in this report. Together with data from historical sources and literature collect during the LVEMP project, they provide basic knowledge about the meteorology, river regime, hydraulics, sediment transport and deposition, land use characteristics of their drainage basins (watershed), nutrient fluxes, biota associations and environmental impacts.

The Water Quality and Ecosystem Management Components of the Lake Victoria Environmental Management Project (LVEMP) in the three East African countries collaborating on LVEMP phase 1 have made considerable progress towards understanding Lake Victoria water quality and its ecosystem as well as effects of resource utilization and exploitation on the lake and its catchment. The components have been able to collect considerable amounts of data and information. In order to achieve LVEMP objectives and Water Quality and Ecosystem Management objectives, in particular, a well-coordinated analysis, synthesis and interpretation of all relevant data was required. This synthetic report documents and explains the changes that have taken place over the recent decades, and it provide an overview of the present water quality status of the lake as well as identifying past changes and continuing trends that may require remedial action. The report provides enough detailed information and spatial resolution at the regional scale to support environmental decision making in regards to possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources. To achieve the desired synthesis report, a National Consultant, Dr Joseph Abuodha and an international consultant, Prof. Robert Hecky of the University of Waterloo, Canada, were retained to guide and assist the process of preparation of this National Report as well as integration of these national reports and other studies into the required regional synthesis report. The consultants directly proceeded to visit the National Executive Secretariat and to engage the WQEM component in a working session during the Easter Weekend on 27th and 28th March 2005 as called for in the consultancy contract. An Inception Report was subsequently submitted, giving the results of that working session as well as the overall strategy and timetable for accomplishing the required national synthesis report by end of July 2005 and the regional synthesis report by the end of October 2005.

Synthesis report

- WQEM has made considerable progress towards understanding Lake Victoria water quality and its ecosystem as well as effects of resource utilization and exploitation on the lake and its catchment.
- The component has been able to collect considerable amounts of data and information.
- In order to achieve WQEM objectives, a well-coordinated analysis, synthesis and interpretation of all relevant data was required.

- This synthetic report documents and explains the changes that have taken place over the recent decades
- Provide an overview of the present water quality status of the lake
- Identifying past changes and continuing trends that may require remedial action
- The report will provide enough detailed information and spatial resolution at the regional scale to support environmental decision making in regards to possible remediation of undesirable changes that have reduced beneficial uses of Lake Victoria biological and water resources

Regional Integration and Data Sharing

- There was recognition that not all aspects of regional report can be addressed in the national report e.g. water balance and nutrient budget for Lake Victoria.
- The national reports will focus on the hydrologic and nutrient loadings to national waters and the observations at national lake monitoring stations.
- The regional report will consist of regional integration of these data into water balance and nutrient budgets
- Lake wide distribution of nutrients and physical conditions for the Lake Victoria system
- To give adequate time for the integration of these regional aspects from national databases, there was commitment to sharing physical data and nutrient data for the lake

Gaps in Spatial and Temporal Coverage

- There were problems during LVEMP with flow of funds
- There were significant gaps in the spatial and temporal coverage
- Planned cruises or sampling trips could not be completed.
- The report identified missing data as an issue
- Reduced confidence in interpretations
- We did our best to do with the data currently available.
- In the regional report identifying critical areas of uncertainty that result from incomplete data coverage
- These should be given high priority for the LVEMP II Applied Research program.

TOR for national synthesis report

- Update the Lake Victoria water balance and use it to determine current nutrient loads and balances of the lake;
- Define trends in limnology and water quality, and provide quantitative information on past, and if possible future, nutrient loading, nutrient losses and nutrient availability within the lake;
- Identify the sources of micro/macro nutrients promoting eutrophication in a spatially explicit manner that can guide remedial action and demonstrate how these inputs are affecting lake productivity;
- Summarize what is known about the presence and concentrations of contaminants in lake water and biota and, if possible, define trends in these contaminant loadings over time;
- Describe the phytoplankton communities, their composition and their effects on beneficial uses of the lake ecosystem, in particular addressing algal bloom dynamics within the lake in relation to current and past rates of primary production.

- Determine the trophic interrelationships of the lake's biological communities and especially address how eutrophication and food web alterations are affecting fisheries of Lake Victoria;
- Determine the role of lake consumers e.g. zooplankton, zoobenthos, microbes and lake flies in the ecosystem dynamics;
- Using the available information on the horizontal and vertical circulation of waters determine its effect on the spatial distribution of nutrients, algae, oxygen, contaminants and organisms in Lake Victoria;
- Integrate the WQ and Ecosystem findings with the findings of other Components of LVEMP
- Assess effects of poor water quality on the socio economic aspect of the riparian community.

OUTLINE OF THE REPORT

This report is comprised of independent but intrinsically connected chapters that are designated for publication. For this reason, some of the contents slightly overlap, especially in the introduction and location maps of the study area. In Chapter 1, all the background information necessary is brought together, including a literature review exercise of previous studies on the lake. The second chapter reviews capacity building in terms of personnel training, laboratory and field infrastructure, monitoring network and databases, and the conceptual and theoretical models operationalized; a brief on QA/QC is provided in this chapter. The next chapter (3) is concerned with updating an estimate of the total water balance for the lake (i.e. all discharges to and from the lake preferably on a daily basis) and are these water balances consistent with the recent lower levels of the lake. Analysis of river runoff from important national rivers as well as available meteorological data relevant to Lake Victoria are discusses. These results are complemented by long-term meteorological trends relative to the LVEMP period. Global and regional climate changes relevant to Lake Victoria are also discussed. The next two chapters deal with non point pollution loadings. The fourth chapter gives an inventory of wet and dry depositions on lake loadings. The total atmospheric loadings are compared to preliminary estimates by LVEMP (2002) and with Tamatamah's published values for phosphorous loading estimates for Lake Victoria. In Chapter 5, the catchment loadings to Lake Victoria from all major rivers are estimated. From the results of discharge and concentration, a method is suggested for the extrapolation of concentration data over time to generate loads. Calculation of catchment yield per unit catchment area and load estimates for each river catchment is undertaken in order to identify the primary determinants of loads and yields such as landscape characteristics and land use. The total loads are compared with preliminary estimates in LVEMP (2002) report and other published data from Lake Malawi. The measured and estimated industrial and municipal effluents loadings are the subject of Chapter 6. The relative magnitude of point sources to total lake loading and to impact on local waters is presented. Chapter 7 discusses the hydrodynamic and thermal cycles in the Winam Gulf of Lake Victoria. Stratification cycles, vertical distribution of oxygen and current measurements in both the littoral and pelagic environments are presented to improve our understanding of the exchange between the gulf and open lake. The results of lake monitoring at the pelagic, littoral, urban and river-mouth station during the LVEMP period 2001-2005 are presented in Chapter 8; this included the number, frequency and descriptive statistics of observations by parameter. Comparison was also made with historic data for the monitored stations or areas where pre-LVEMP data exist. In Chapter 9, the observed composition, areal flux rates and settling velocities are used to explain sedimentation rates and long-term sediment accumulation at the pelagic, littoral and river deltas. Chapter 10 deals with the physico-chemical and nutrient status in the lake, and tries to relate the observed changes to algal growth and other limnological interactions. Pesticides and heavy metal contamination in the lake basin is presented in Chapter 11. This chapter discusses the sources, pathways and concentration of POPs and heavy metals in several media. The issue of water quality and health is given in Chapter 12. Water borne contamination, algal toxins and water vectored diseases are related in terms of distribution and water quality parameters. Finally, environmental impacts of water quality change on beneficial uses of Lake Victoria are summarized in Chapter 13.

RECOMMENDATIONS

- Lake Victoria Basin Commision (LVBC) should play a crucial role in coordinating water research, data gathering and monitoring.
- The process of reforms at the Ministry of Water and Irrigation has substantially affected operations of the water quality component. There is need for the parent ministry to review and prioritize policy with regard to staffing for the water quality monitoring program during LVEMP 2.
- Maseno University has the geographical advantage and capacity to undertake training, research and contribute to the lake's management and development.
- Operationilization of conceptual and theoretical models is dependent on two individuals and both have been transferred to the new Lake Victoria South Water Authority where they have been given new responsibilities. The project should build capacity in model construction and development, besides training on application of purpose-buit models.
- Laboratory QA/QC procedures and calibration of field equipment should be undertaken frequently and accordance with established procedures.
- All field excursions must be properly planned and advance forethought given to safety of staff and excution of field measurements.

National Consultant: Dr J.O.Z. Abuodha

Contents

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**

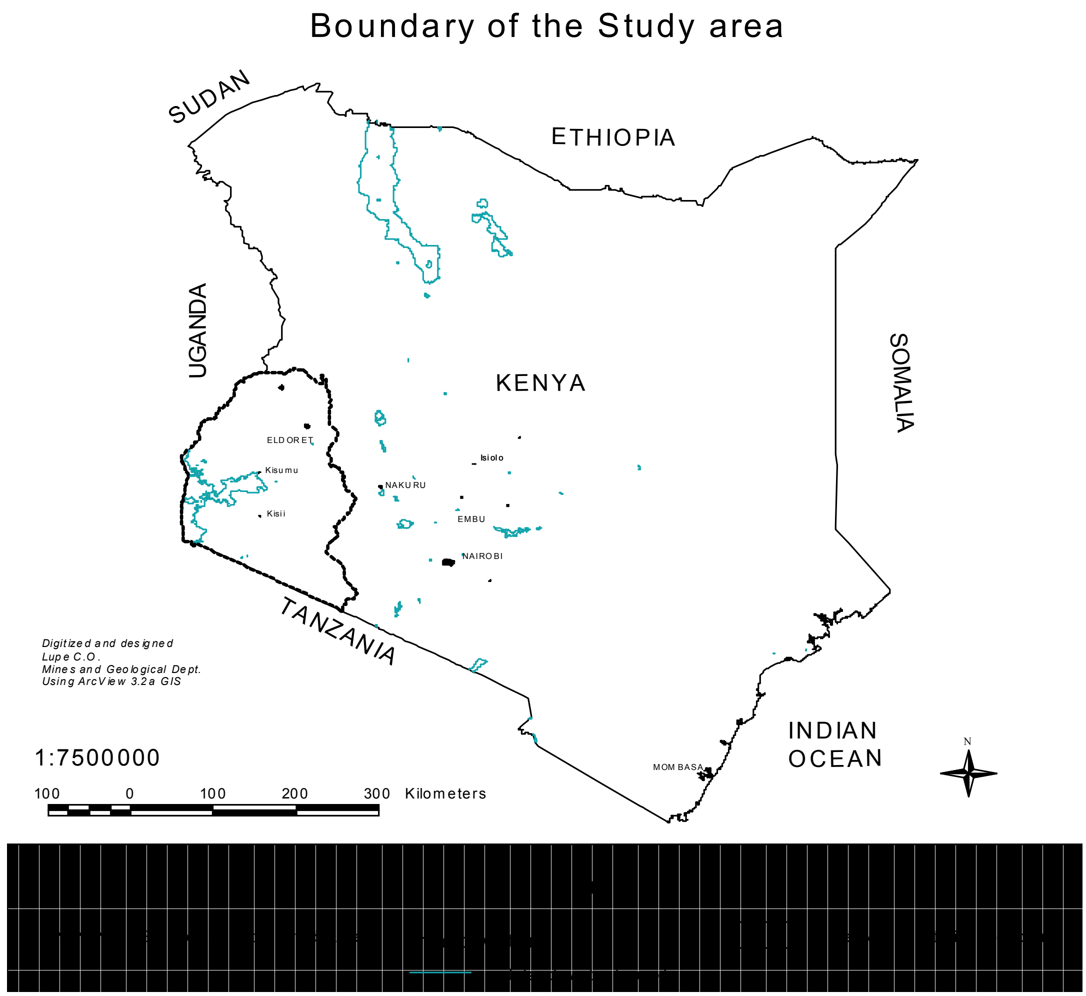


FIG. 1. Map of the study area.

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

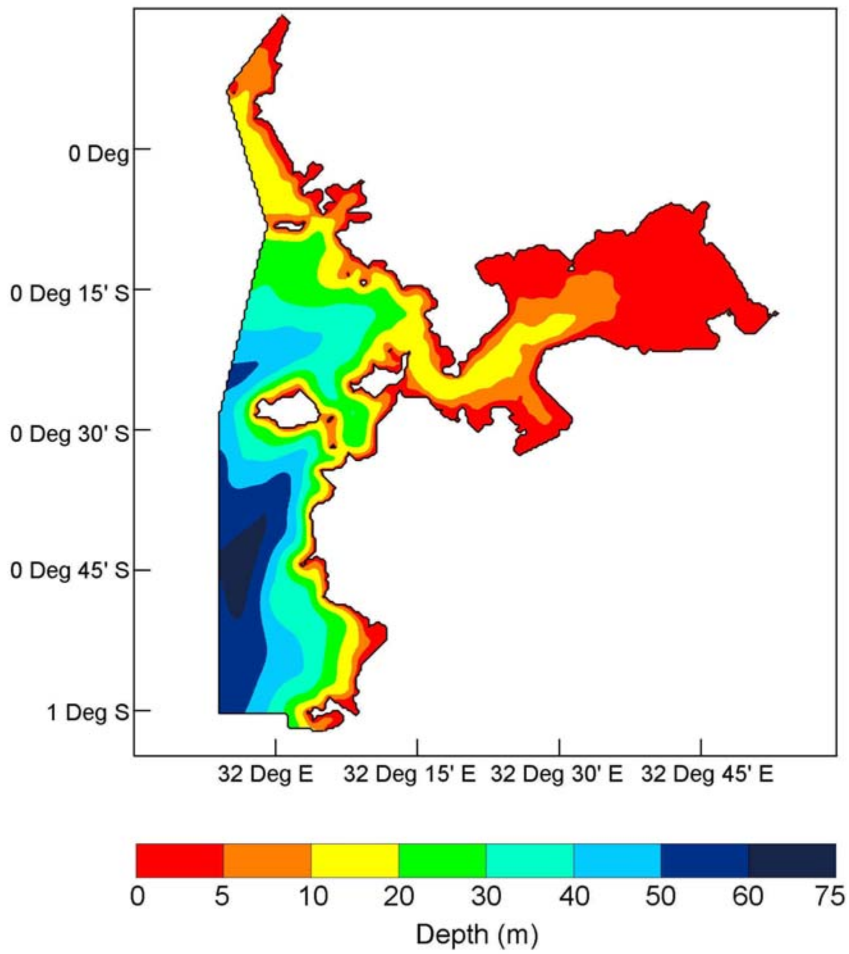


FIG. 2. Shows the depth of the Kenyan portion of Lake Victoria

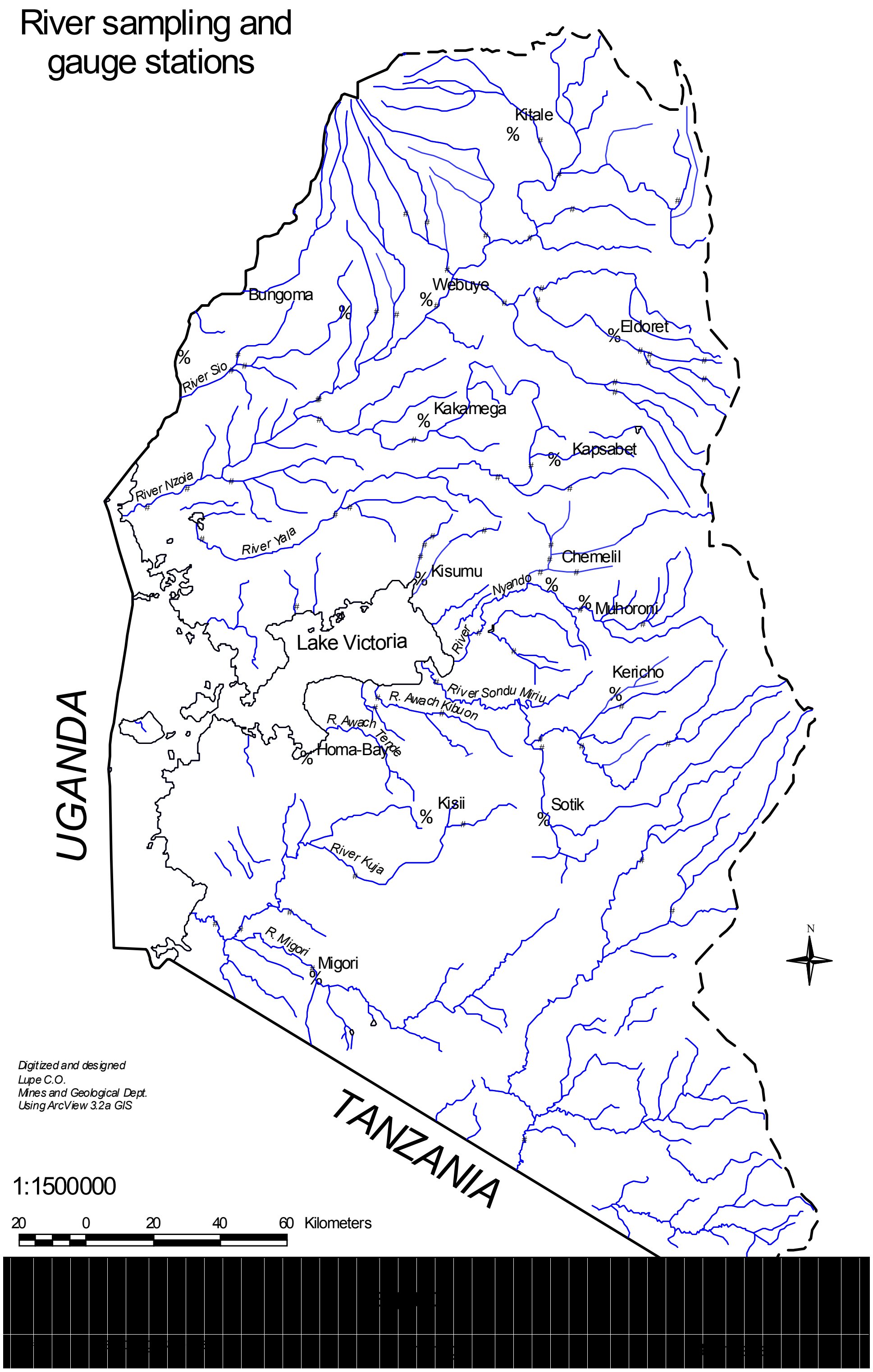


FIG. 3. Lake Victoria basin showing the catchment and drainage system.

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).

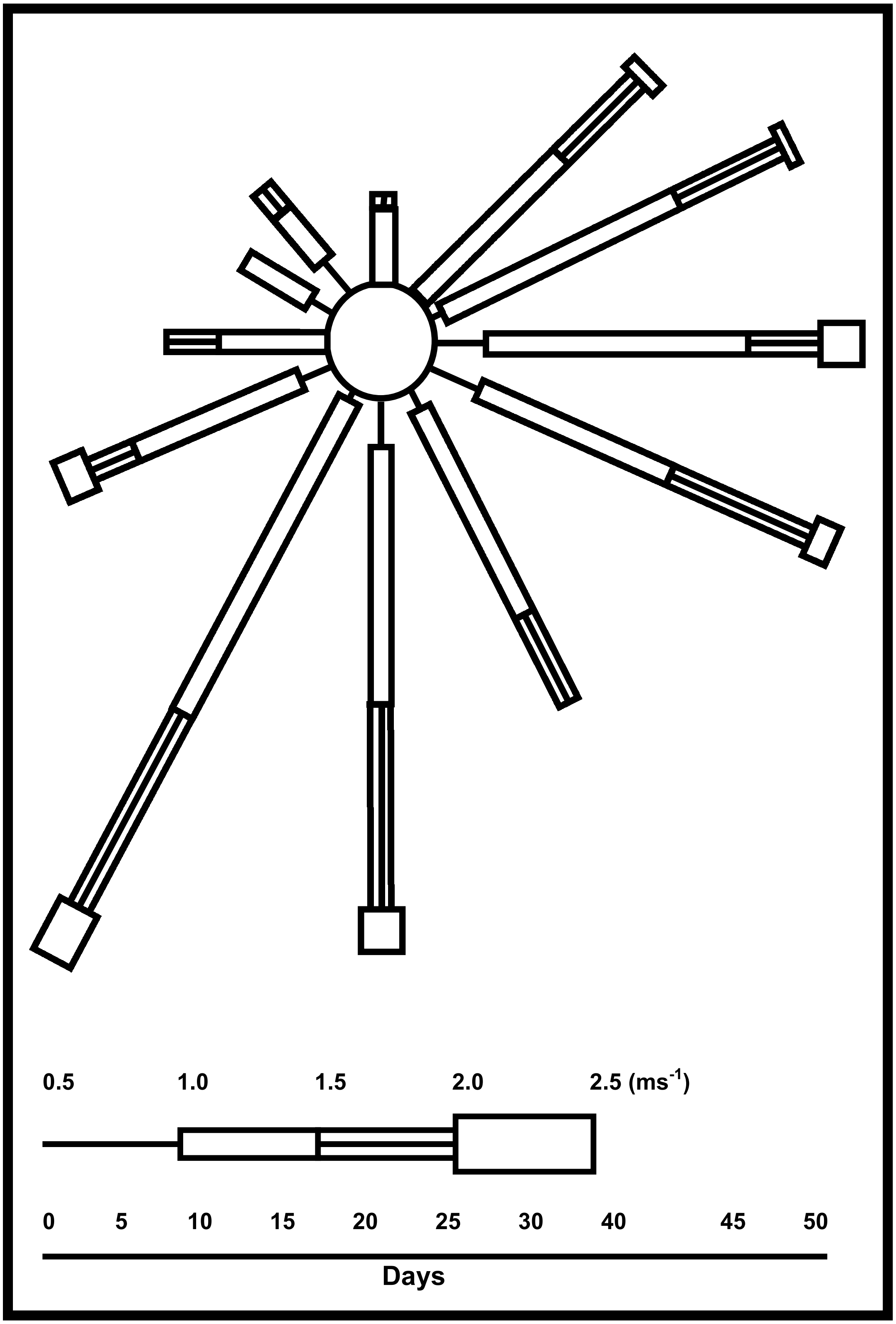
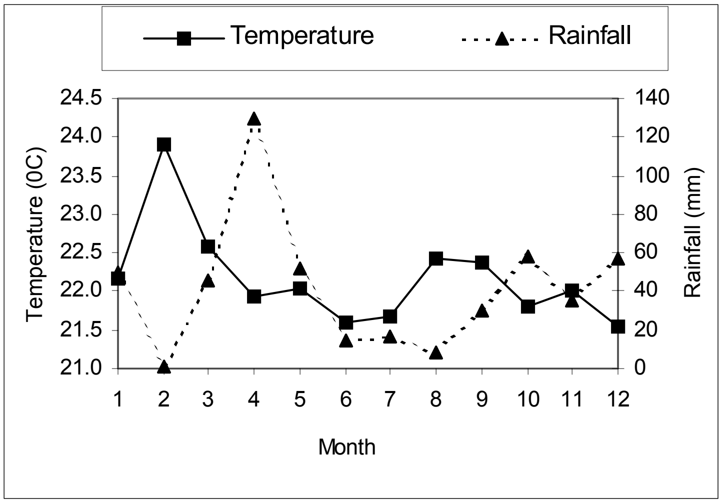


Fig. 4b. Annual wind rose recorded at Kadenge during 2003.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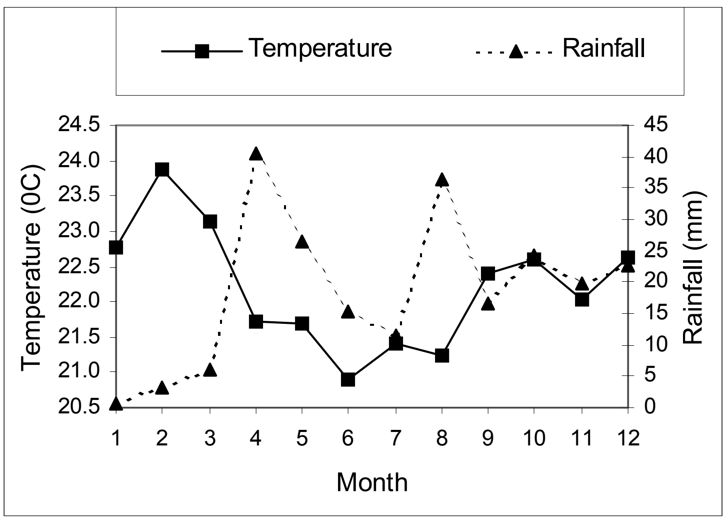
Rainfall
Temperature (0C)
Rainfall (mm)
Month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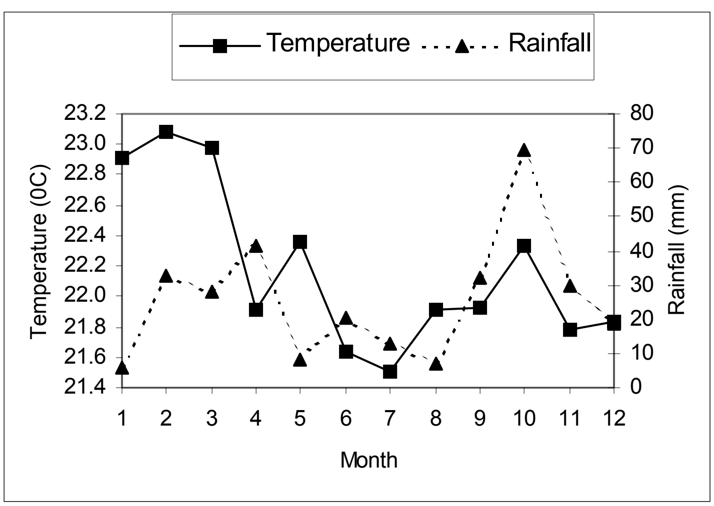

Temperature
Rainfall
Temperature (0C)
Rainfall (mm)
Month

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			

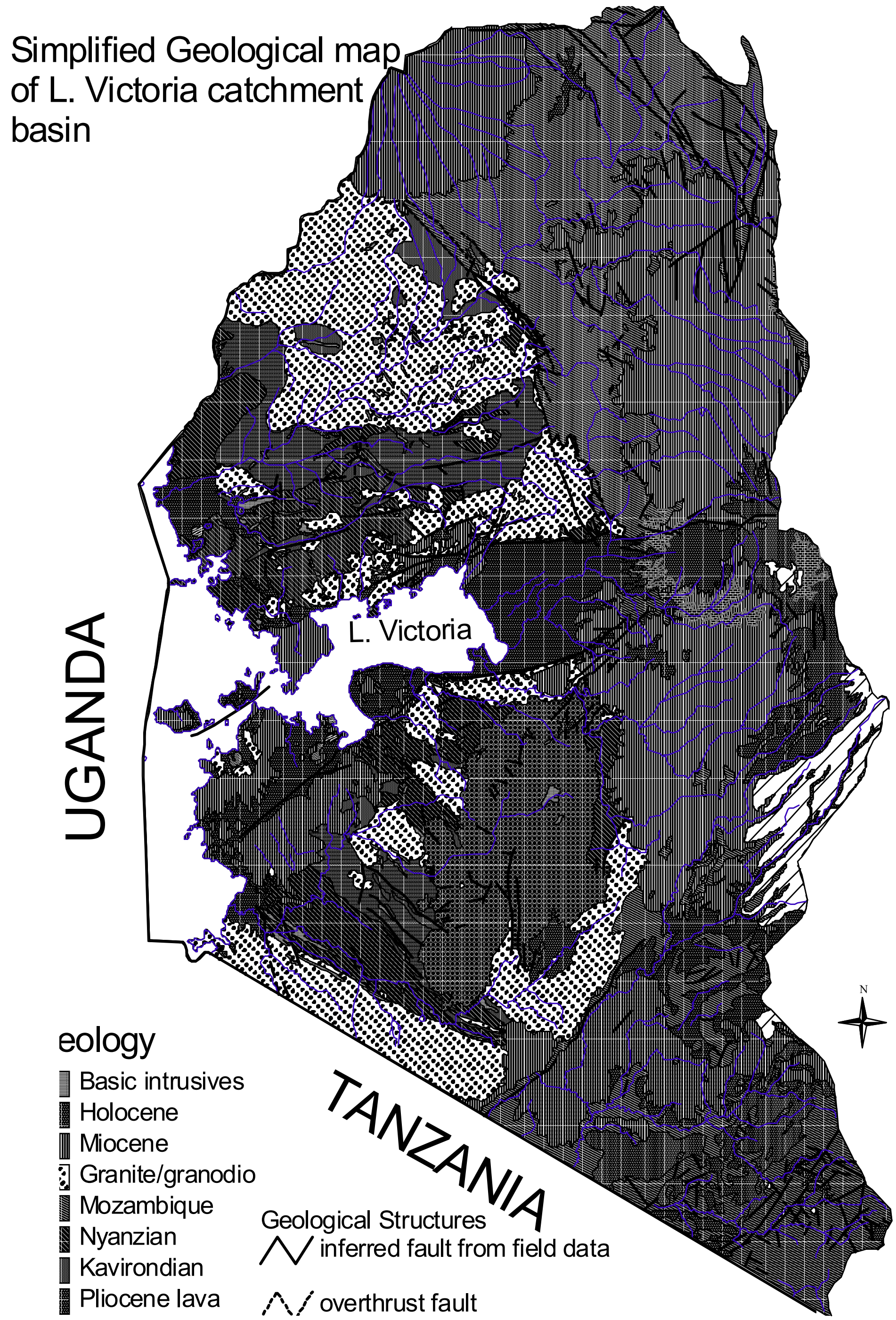


FIG. 5. Geological map of the Lake Victoria Basin

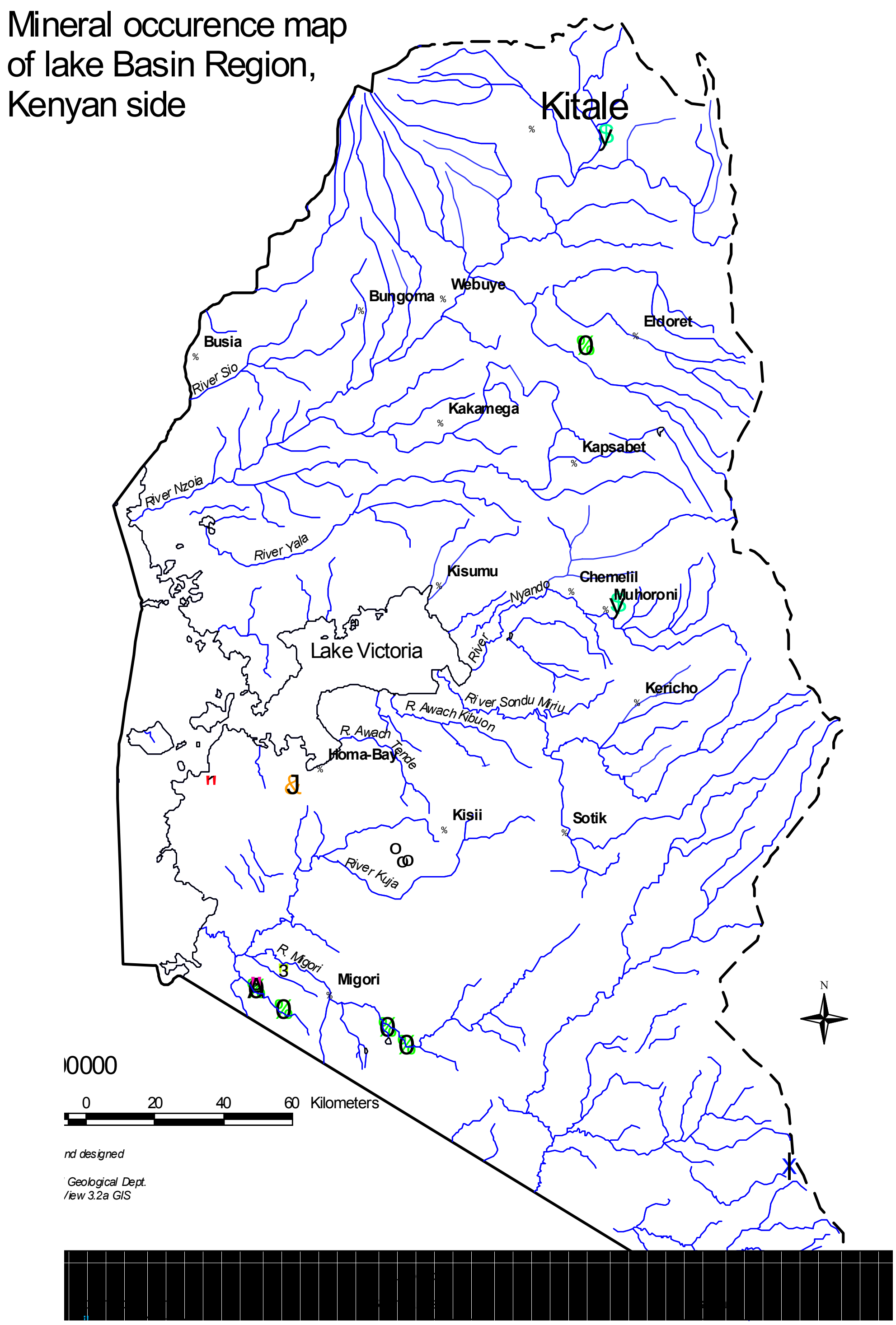
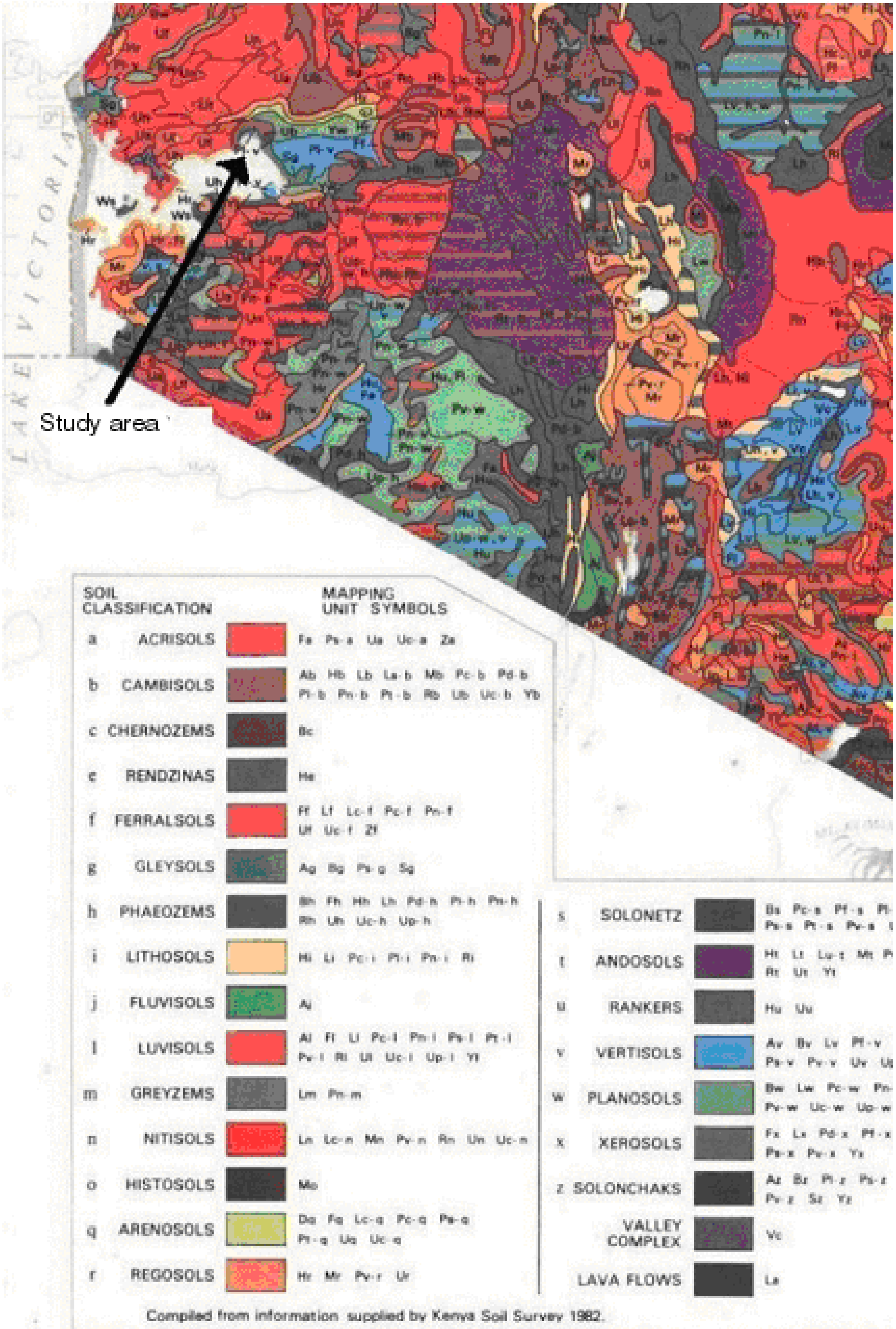

Mineral occurence map of lake Basin Region, Kenyan side
Kitale
Webuye
Bungoma
Busia
River Sio
Eldoret
Kakamega
Kapsabet
River Nzoia
River Yala
Kisumu
Nyando
Chemelil
Muhoroni
Lake Victoria
River
Kericho
River Sondu Miriu
R. Awach Kibuon
R. Awach
Tende
Homa-Bay
Kisii
Sotik
River Kuja
R. Migori
Migori
0 20 40 60 Kilometers
N

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.

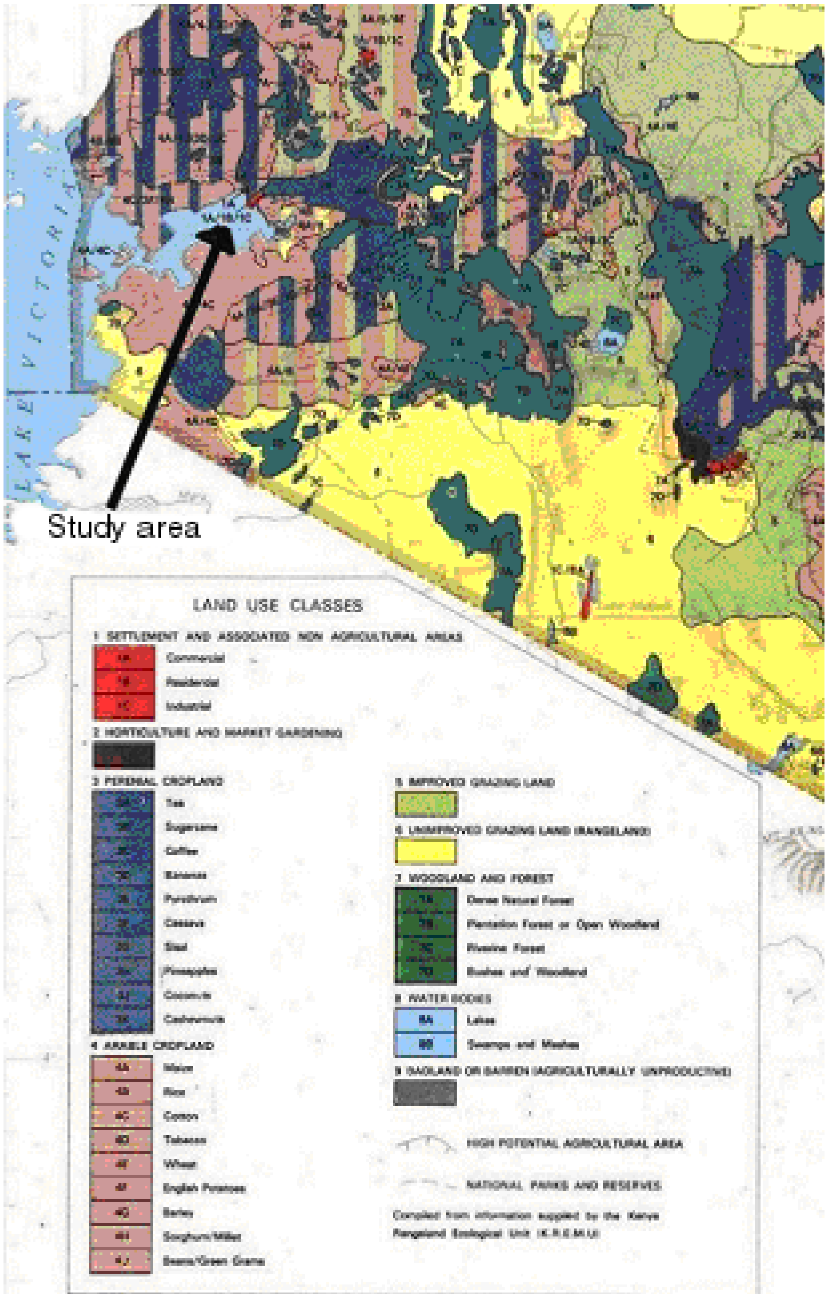


FIG. 8. Regional Land Use Map

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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CHAPTER 2

Capacity building for Lake Victoria water quality monitoring and assessment in Kenya

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Abstract

Training programs were designed to provide scientists with strengths in applied limnology, monitoring and the environment. In addition, the training provided scientists with a firm background in data analysis, interpretation and synthesis procedures, including statistics, numerical analysis, programming and conceptual modelling methods. Most hydrologists and water chemists in public and private employment were educated in a tradition that emphasized qualitative schooling, and this project therefore has managed to train a new type of scientist who can apply calculations to their research, monitoring or operational undertakings. The scientists also benefited from adequate training in computer analytical techniques, most notable in the area of model applications, graphics; including map, contour plotting, remote sensing interpretation, GIS; and interpretation of water quality data.

The scientist obtained both practical and theoretical knowledge, thus are now able to integrate and apply a number of scientific disciplines to problems of relating to the water quality monitoring of the lake and its ecosystem, in addition to environmental management and conservation of the catchment. By participating in high level courses in addition to computer training and fieldwork, the scientists have now acquired an in-depth understanding of the fundamental principles of limnology and water quality monitoring.

The scientists of this programme are now well-grounded field specialists, who apart from their high specialization in water related issues appreciate the exigencies of other related disciplines. Their specializations within an interdisciplinary/transdisciplinary framework have resulted in versatile international scholars armed with knowledge, awareness and skills to assess and solve pertinent environmental issues and problems afflicting the lake.

Apart from training, some infrastructure for water quality monitoring has been established in the lake basin. In Kisumu, laboratories based at the Ministry of Water and Irrigation at Nyalenda was rehabilited and equipped with more sophisticated equipment.

However, there is need to build and equip more laboratories in the lake region to lessen transportation and enable quicker analysis of samples. There is now a basin-wide network for data collection in the inshore and offshore areas in addition to establishment of a meteorological network. Monitoring programs have involved placement and utilization of the harmonized monitoring network. Quality control and quality assurance mechanisms is now practiced and coordinated by the component. LVEMP has put emphasis on establishment of internal and regional quality assurance mechanisms, enhancement of laboratory performances and efficiency, and data generation and management.

Although research vessels were obtained from the Kenya Marine and Fisheries Research Institute, this arrangement was not efficient since the vessels were obtained only at the discretion and convenience of the latter; it would probably be better if the component could acquire its own vessel to guarantee effective implementation of logistics.

Introduction

The training programme mounted during the project was seeking to strengthen the knowledge base of scientists, enabling them to raise awareness of important environmental management issues concerning the lake, to conduct and co-ordinate multi/trans-disciplinary research, and to disseminate information and data for sustainable use of the lake's natural resources. The knowledge gained by those specialists has enabled adequate prediction, monitoring, assessment and modelling of environmental degradation in the catchment and the lake. This will lead to effective mitigation measures in LVEMP 2 and sustainable exploitation of the lake basin resources.

But given the fact that environmental problems affecting the lake arising from land use and development efforts are well recognized and discussed publicly, and that persons were needed with knowledge and training to manage the lake in environmentally sound ways, the capacity building program aimed to produce people possessing an integrated combination of knowledge, awareness, skills, problem-solving capabilities and commitment to act as specialists, professionals, water resource managers and advocates.

The capacity building programme was meant to develop the highest level of scholarship, research capability, and creative thinking skills in the scientists' area of specialization. The world-class scientists and researchers produced through this programme will strengthen and motivate research in this field.

The capacity building for water quality monitoring and assessment had three main objectives:

- To provide training that are designed to gradually and systematically build and strengthen individuals' capacities to conduct research that contribute to the well-being of the people. This includes research into environmental management issues and problems within the lake region. Such experts will contribute towards the national goals of having a clean lake environment and managing lake's natural resources in sustainable ways.

- Produce specialists in various fields of water studies who will provide innovative ideas and solutions to our local problems based on the available resources. While providing solutions to local problems, these specialists should nevertheless be well equipped and prepared to face the world challenges such as global warming.

- The programme produced professionals equipped with knowledge, awareness, understanding, skills and concern for the environment so as to incorporate environmental considerations in all the lake basin's development strategies and plans.

People Trained

In order to achieve the project performance targets, to build professional competence of the staff to handle the planned activities and produce credible outputs, personnel capacity building was undertaken as a priority. The project trained its staff to various levels, which included undergraduate, postgraduate and short studies. Various short courses were conducted in-house, through which all officers benefited by attending courses of their professional and discipline area. For the long term training the Project sponsored officers for further training at degree levels. Through this effort, one (1) scientist has been trained to PhD level, 6 scientists to MSc level and 2 Scientists to BSc level. This was to further improve on the other trainings the personnel had undergone in their fields of expertise prior to the project. This was complemented by outreach through workshops relevant to water quality management. Details are given in the Table 1.

Laboratory and Field Infrastructure

Laboratory capacity

The component was able to construct and equip a laboratory, which enabled it to perform a number of analyses on potable water, river and lake water, wastewater and sediments. The laboratory also has a capacity to undertake microbiological examination. Where immediate capacity never existed, other competent laboratories were used for specific parameters. The component laboratory was used to analyse about 35 parameters as listed below.

Number of analyses contributing to this report volume

During the period of the project, a total of 751 samples were analysed. Since the focus was directed at eutrophication related problems, nutrient, TSS and BOD analyses were most numerous and were conducted on rain water, atmospheric dry fall, river and stream water, municipal and industrial effluents in addition to the extensive lake monitoring stations.

TABLE 1. Further/Advanced Training.

Degree Course	Research Topic	Institution	Number Trained
D. Phil Water Quality Management	The potential of a constructed wetland for treatment of pulp and paper wastewater in the tropics.	UNESCO/IHE, Delft, The Netherlands	1
M.Sc. Water Quality Management	Growth and survival of four tropical macrophytes in pulp and paper mill wastewater.	IHE, Delft, The Netherlands	1
M.Sc. Environmental Science and Technology	Ecology and demography of *Elodied* Aquatic Weeds: The effect of light and alkalinity on growth.	IHE, Delft, The Netherlands	1
M.Sc.	Assessment of the impact of closure of Mbita passage on the water quality of Winam Gulf.	IHE, Delft, The Netherlands	1
M.Sc. Water Pollution Control	Dynamics of nutrients in an evolving wetland.	Middlesex University, England, UK	1
M.Sc. Ecosystem Analysis and Governance	Remote sensing approach to biophysical studies of Winam Gulf.	University of Warwick, England, UK	1
M.Sc. Environmental Health	Fate of pesticides in Nyando basin.	Moi University, Kenya	1
B.Sc.	Chemistry	Moi University, Kenya	2

TABLE 2. Short Courses.

Course Title	Institution	No. Trained
EIA	Moi University, SES	3
Water Resources Management, Data Processing and Analysis	Institute for Meteorological Training and Research	2
GIS		1
Analysis of Water and Wastewater	Kenyatta University of Agriculture and Technology, Kenya	20
Remote Sensing, Computer Applications and GIS for Hydrology and Early Warning Systems.	Regional Centre for Mapping of Resources for Development, Nairobi, Kenya	20
Water Resources and Eutrophication Laboratory	DHI, Denmark	2
Techniques in aquatic sediment sampling, sample preparation and dating	University of Dar es Salaam, Institute of Marine Sciences, Zanzibar, Tanzania	3
Basic Computer Training	Lake Link, Kisumu, Kenya	14
Advanced Computer Training	Lake Link, Kisumu, Kenya	16
Community Organization	Consultant, Mabel Isorio	1
Environmental Audit	Kenya National Cleaner Production Centre, Nairobi	1
Quality Assurance and Laboratory Practice		3
Safe Use of Agro-chemicals	Ministry of Agriculture in collaboration with Kenya Agro-Chemical Association of Kenya	10
PRA	Egerton University, Kenya	1

TABLE 3. Parameters measured and methods of analysis.

Parameter	Method of analysis
COD	- Closed reflux method
BOD	- Winkler method
Total Organic Carbon	- Instrumental (TOC analyser)
Total Nitrogen	- Persulphate method
Nitrate	- Cadmium reduction column method
Nitrite	- Colorimetric method
Silica	- Heteropoly blue method
Ammonia	- Phenate method
Total Phosphorus	- Ascorbic acid method
Phenol	- Distillation followed by spectrophotometric method
Chlorophyll a	- Methanol acetone extraction
Alkalinity	- Titrimetric method
Total Suspended Solids	- Gravimetric method
Total Dissolved Solids	-Calculated from E. Conductivity values and gravimetric analyses
pH	- Electrometric method
Conductivity	- Conductivity meter
Dissolved Oxygen	- Electrode method
Chlorides	- Titrimetric method (Argentometric)
Sulphates	- Turbidimetric method
Potassium and sodium	- Flame photometer
Manganese	- Persulphate method
Iron	- Phenanthraline method
Calcium and magnesium	- Titrimetric
Total hardness	- Titrimetric (EDTA) method
Fluoride	- Visual comprision
Orthophosphate	- Ascorbic acid method
Turbidity	-Turbudimetric method
Sulphides	- Iodometric method
Faecal coliforms	- Multi-tube method
Total bacterial counts	- Microscopy
Total coliforms	- Microscopy
Photosynthetic activity	- Measure oxygen using Winkler method
Zooplankton and benthos	- Microscopy

Note:

- Most of the above methods are based on the Standard methods for the Examination of Water and Wastewater -19th Edition.
- Heavy metals were analysed at Mines and Geology Laboratory of the Ministry of Environment and Natural Resources since the component,s AAS was not yet installed during the period the samples were analysed.
- Pesticides were analysed at KEPHIS, Nairobi University and Moi University Laboratories, as there was a delay in acquiring a HPLC and a Gas Chromatograph (GC).

Laboratory QA/QC procedures

Staff

All technical staff working in the water quality laboratory are well trained with relevant qualifications and have gained experience over the years regarding water and wastewater analysis. However, training programmes are regularly carried out and staff encouraged in updating their professional capacities through such training courses, workshops and seminars appropriate to their needs. New employees are trained to prepare them for the duties they are to undertake. Further training is done for serving employees to acquaint them with new skills for career development purposes and quality work output. Workshop and seminars help them to share knowledge and exchange experiences

Staff who have been away for long on other assignments are retrained e.g. through use of reference materials, performance evaluation tests, etc.

Sample handling and records

The sample chain of custody was documented to ensure proper handling, to uniquely identify samples, to record conditions of samples, and permit tracing of samples through all steps from collection to analysis and display of results. Proper sample handling and documentation ensures that deterioration and damage to test and reference samples before analysis are avoided as much as possible. Good storage of samples was maintained for all items as far as practicable and samples were disposed of according to laid down procedures.

All operations and activities of the laboratory were carried out in such a way that allowed the required records to be kept. Record of testing contained sufficient information to permit repetition. All records are safely stored, held secure and in confidence to the client.

Records of the following are kept:-

- All original observations
- Calculations and derived data
- Test reports for appropriate period
- Calibration records and copies of reports
- Personnel involved in sample preparation and analysis
- Equipment used for the particular analysis
- Analytical method used for the particular analysis

Wrong observations or calculations were crossed out once with a single line NOT rubbed off completely so that they were still readable. Generally, all steps a sample passed through from the time of being received into laboratory to the time the test report was dispatched were recorded. The Project Manager who is also the Quality Control Manager for the Project keeps all records.

Facilities and Equipment

In the laboratory, equipment were housed with due concern given to environmental factors affecting their operations.

During installation of equipment the following were considered:

- Freedom from dust

- Exhaust ventilation
- Freedom from vibrations
- Adequate cooling water system supply
- Freedom from chemical contamination
- Placement (where located in the laboratory)
- High temperature variations (rooms air conditioned)
- Power consumptions
- Weight of equipment

Glassware

The following factors were observed when using glassware in the laboratory:

- Appropriate glassware with accepted calibration and tolerance were used;
- Glassware used for trace analysis was segregated from other glassware;
- All glassware were cleaned using specific washing procedures e.g. glassware used for phosphates analysis were washed using phosphate free detergent and rinsed with dilute hydrochloric acid;
- Use of scratched glassware was avoided while carrying out trace analysis.

Materials

- Deionised or distilled water was used in the laboratory where appropriate;
- Purity labeling, storage and expiry dates of all solvents, standards, chemicals and reagents were checked and confirmed before usage of a particular material.

Measurements and Calibration

Method Validation

Operational guidelines depended on the existence of a standard analytical procedure which were generally agreed to regionally to enable comparison of results. For published methods the analyst had to show that he/she could meet the requirements of the method. Essential requirements on all methods are: Precision, Accuracy, Specificity, Application/Matrix and range, Sensitivity.

Analysts establish limits of detection and limits of determination and must also be able to establish which equipment/method is appropriate for the kind of analysis to be undertaken. Standard operating procedures (SOP) for each analytical method are followed. SOP describes the methods in such detail that an experienced analyst unfamiliar with the method can obtain acceptable data.

In the process of method validation, analyses of externally supplied standards (Certified Reference Materials –CRM) were carried out. At minimum, externally supplied standards were analyzed whenever analysis of known additions did not result in acceptable recovery.

Participation in inter-laboratory performance tests is an important step in the process of method validation and was therefore practiced especially when operational constraints required that the same analyses be done in different laboratories.

Quality control involved operational techniques and activities that were used to fulfil requirement for quality. Both external and internal quality controls were implemented. External QC was done by participating in inter-laboratory comparisons.

Internal Quality Control (QC)

Internal analytical quality control was done. This encompasses the following: -

- Certification of operator competence: Analysts show competence and produce accepted single operator precision and bias.
- Recovery of known additions was used as part of a regular analytical procedure to verify the amount of interference.
- Analysis of reagent blanks was done whenever new reagents were used and as often as it was required for specific methods. This monitored purity of reagents and the overall procedural blank.
- Calibration with standards, which were internally prepared: Different dilutions of the standard were measured whenever an analysis was initiated (as many dilutions as was specified for individual methods were measured). Verification of the calibration curve was done daily by analyzing one or more standards with the linear range or as specified for individual methods.
- Analysis of duplicates was done whenever new reagents were used and as often as was required for specific methods. This monitored purity of reagents and the overall procedural blank.

Reports

Tests results were entered into a database and in case of a customer/client from outside a test certificate/report was produced. Results are reported in a test certificate accurately, clearly, unambiguously and objectively for ease of assimilation by the reader.

- Report contain parameters (variables) analysed, units of measurements and values obtained.
- Results from sub contractors are identified.
- Amendments of certificates after issue are in form of further comments
- Clients are informed in case of detection of any anomaly.
- Clients are advised that in case they need more information, they should contact he undersigned.
- The Project Manager and/or Laboratory Manager signs test reports

Quality Audits

The goal is to detect any deviations from the standard operating procedures (SOP) so that corrective action is taken.

The Laboratory Manager conducts internal audits of all activities regularly to verify that its operations continue to comply with the requirements of the quality system. The audits were planned and organized as required by schedule and were carried out by qualified personnel.

The audits were done using checklists made to document the manner in which a sample was treated from the time of reception to the final reporting of results. Performance evaluation samples were used to evaluate competence of individual analysts.

Field access and deployments-rivers and lake

The component was able to acquire 8 cars, 17 motorcycles, one boat and 5 dinghies for its catchment and in-lake monitoring activities. Through collaboration with other components, the component was able to have at its disposal, bigger research vessels from KMFRI (a LVEMP component implementing Fisheries Research activities) for the in-lake studies. These made it possible for the component to reach field stations for samples collection and *in-situ* measurements using a number of portable equipment.

The component also had a number of data gathering equipment installed at various stations in the catchmnent. These included, 3 automatic weather stations, 10 automatic hydrologic data loggers for lake and rivers levels and over 100 staff gauges and 8 rainfall stations.

Monitoring network and Databases

River monitoring-GPS positions and map

The component used a river discharge monitoring network covering the Kenyan part of Lake Victoria catchment. The catchment has 116 hydrological stations. However, for the project work 52 stations were used as shown in Fig. 1 and Table 5. The stations were all geo-referenced using GPS.

River and Lake water levels were gathered using the manually read staff gauges and the modern digital data loggers.

Lake monitoring-GPS positions and map

The water quality-monitoring network also covered the Kenyan part of Lake Victoria. The stations were geo-referenced and formed part of the wider regional network for the whole lake water quality-monitoring network. The Kenyan part had 9 stations, 6 of which were littoral (inshore) stations while 3 were pelagic (offshore) stations.

Atmospheric deposition monitoring-GPS positions and map

Although a network of 9 stations spread over various parts of the Lake Victoria basin was designed for collecting atmospheric deposition samples, only two representative stations situated at Kadenge and Kisumu due to logistical problems (Fig. 3). The other stations not sampled were DWO's Office, Bungoma, DWO's Office, Homa

Bay, Pan Paper Mills, Webuye, Kitale, Rusinga Isaland and Kisii. Samples for both dry and wet deposition were collected and analysed mainly for nutrients. TP and TN analysis were done at the Water Quality Laboratory in Kisumu.

Table 4. Principal stations used in this study.

River Basin	**Basin Area (Km^2)**	**Gauging Station**		**Catchment area U/S of station (Km^2)**	**Type of Station**	**Remarks**
		Reg. No.	***Location/name***			
SIO	1450	1AH01	MUNDIKA	1450	STAFF	
NZOIA	12,676	1EF01	RWAMBWA	12,676	STAFF AND LOGGER	
YALA	3,351	1FG01	YALA TOWN	2,388	STAFF AND LOGGER	
NYANDO	3,652	1GD03	OGILLA	2,625	STAFF AND LOGGER	
NORTH AWACH	1,985	1HA09	NYAMASARIA		STAFF	
		1HB05	AWACH SEME		STAFF	
SOUTH AWACH	3,156	1HE01	AWACH TENDE	585	STAFF	
		1HD09	AWACH KIBUON	536	STAFF	
SONDU	3,508	1JG05	SONDU MARKET	3,287	STAFF	
GUCHA-MIGORI	6,600	1KB05	WATHONGER	6,600	STAFF AND LOGGER	
LAKE VICTORIA		1HB04	KISUMU	-	STAFF AND LOGGER	

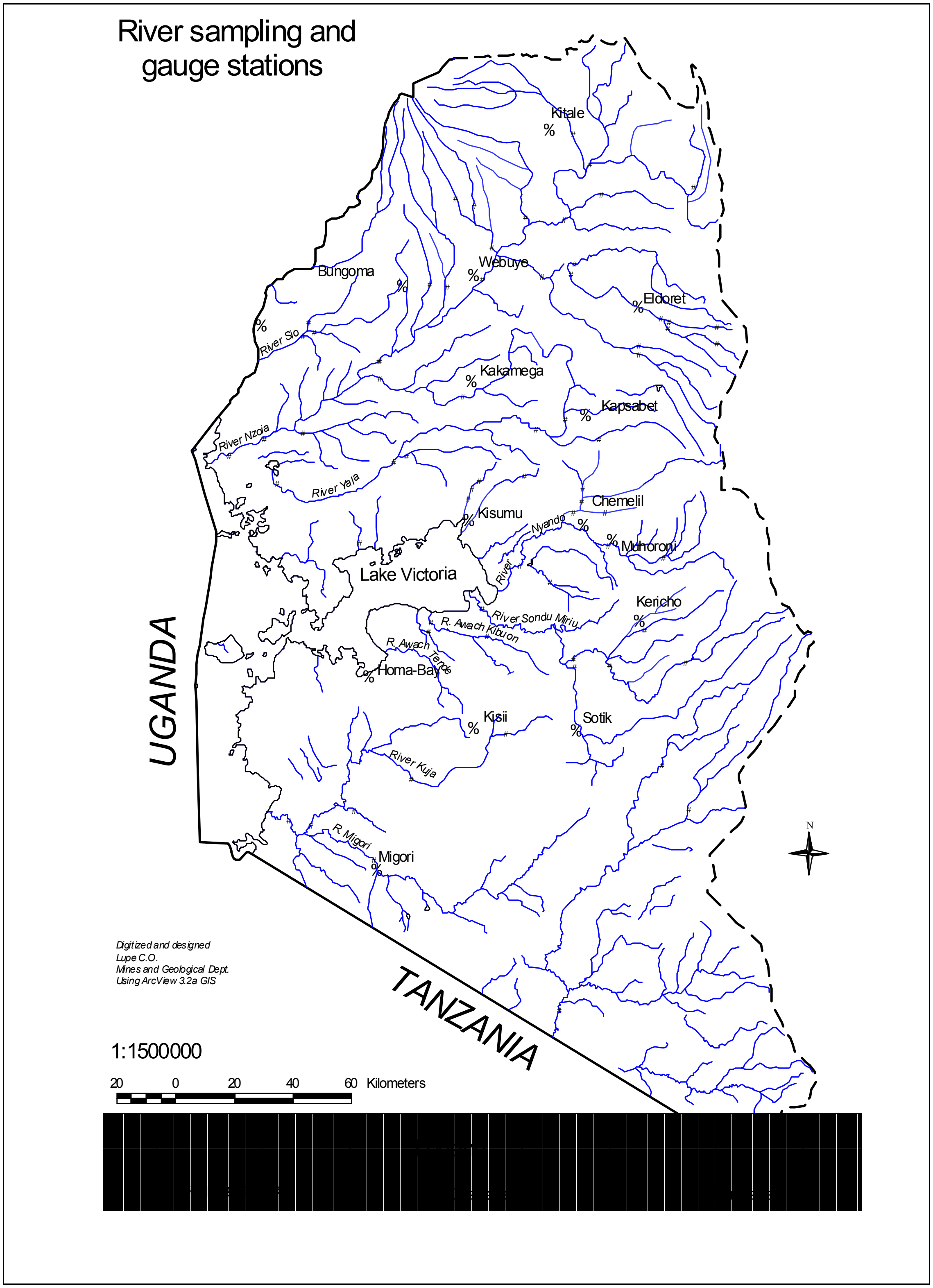

FIG. 1. River gauge stations (RGS) and sampling locations.

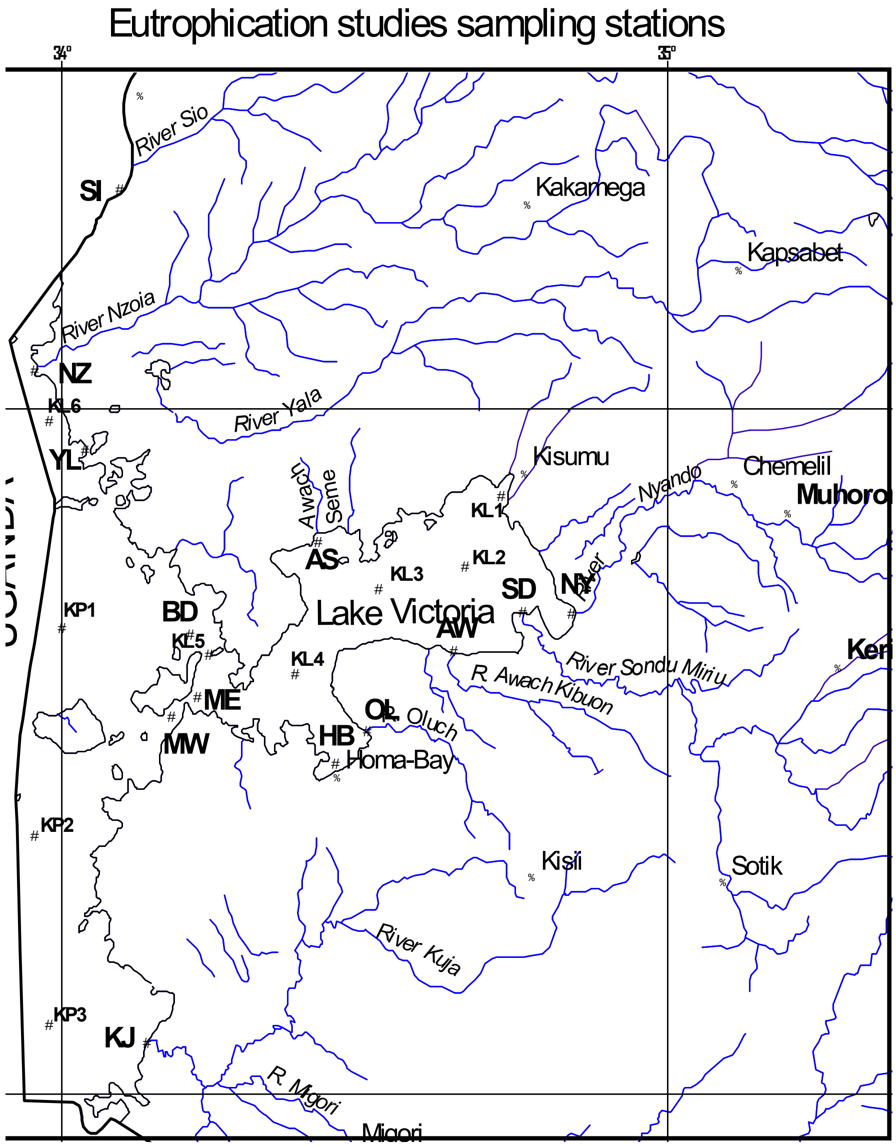

FIG. 2. In-lake and nearshore sampling stations.

Principal meteorological stations including rainfall stations-GPS and map

There are about 3 meteorological stations, 5 sub-met stations and a number of rainfall and evaporation stations within the catchment. The key stations used for these studies are SHOWN in Table 6.

The component has also installed 3 automatic weather stations at Kadenge – Yala Swamp, Bungoma District Water Office and Sosiot Gilrls High School in Kericho. The dataloggers are downloaded from time to time by the component staff.

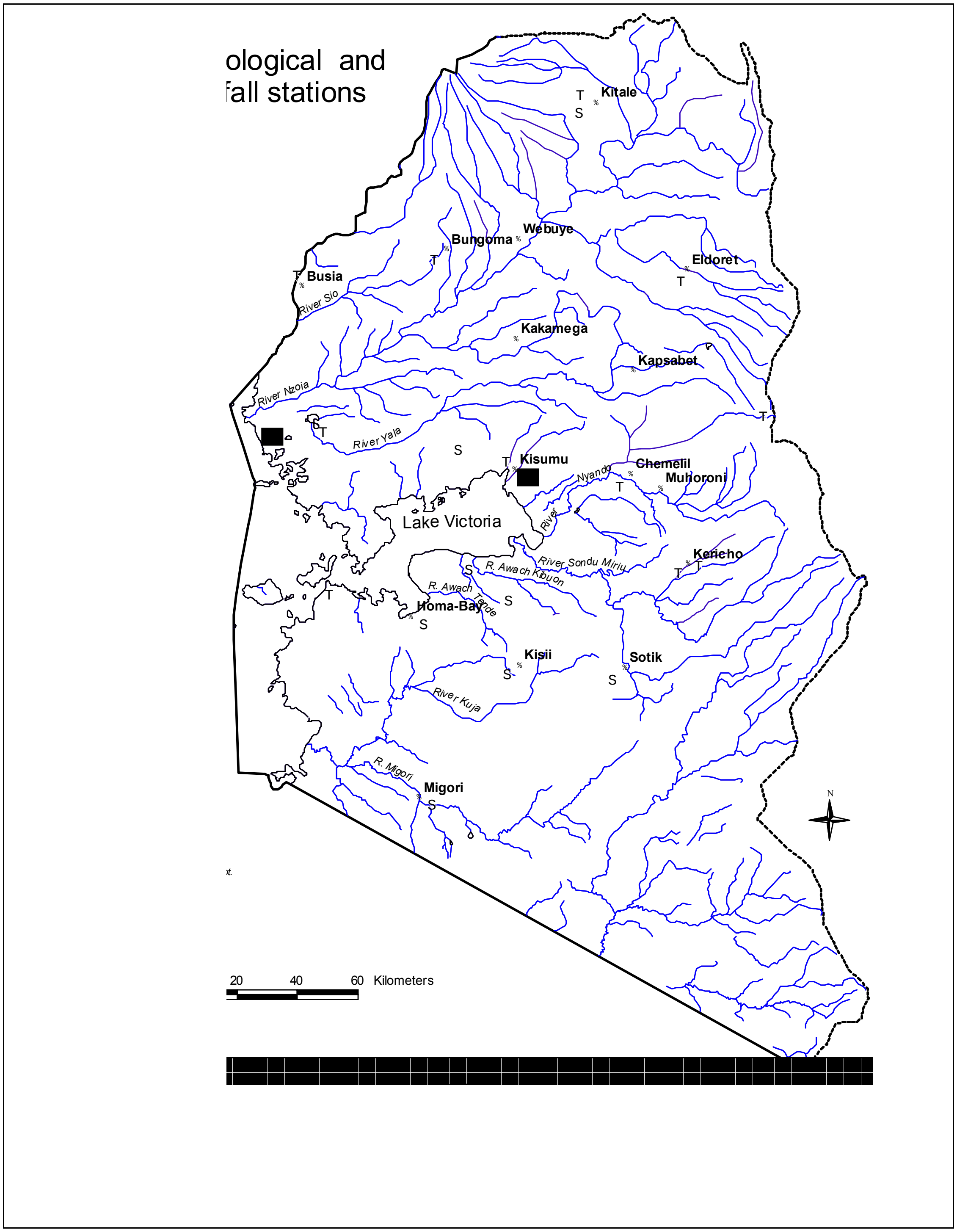

FIG. 3. Meteorological and rainfall stations; also showing atmospheric deposition measuring stations.

Table 4. River monitoring stations in the Kenyan Lake Victoria catchment showing their RGS number, GPS positions and altitudes.

RGS. No.	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
1. IAHI *	Sio	N 00 23.005	E 34 08.745	1181	Gauge Zero
2. 1AH Misc	Suo at Kusumo	N 00 27.123	E 34 20.998	1217	WL
3. 1AH Misc	Walatsi	N 00 28 40	E 34 08 30		
4. IBAI	Moiben				
5. IBB1 *	Nzoia (M/Bridge)	N 00 55.127	E 35 07.953	1811	Gauge Zero
6. IBB2	Losorua				
7. IBB3	Chepkaitit				
8. IBC1	Noigamet				
9. IBD1	Litle Nzoia				
10. IBD2 *	Nzoia (At M/Tatu)	N 00 45.622	E 35 03.756	1752	Gauge Zero
11. IBE4	Kaibei				
12. IBE5	Kwoittobos				
13. IBE6 *	Kwoittobos/Sabwani	N 00 57.763	E 35 05.384	1805	Gauge Zero
14. IBG1	Chebusani				
15. IBG7 *	Ewaso Rongai	N 00 46.309	E 34 55.617	1662	Gauge Zero
16. IBG3	Kabeyani				
17. IBG4	Kisawai				
18. IBG5	Rongai	N 00 46.309	E 34 55.617	1662	Gauge Zero
19. IBH1 *	Kamukuywa	N 00 47.045	E 34 48.198	1659	Gauge Zero
20. IBH2	Kimilili	N 00 44.680	E 34 46.446	1631	Water Level
21. ICA2 *	Sergoit	N 00 37.877	E 35 03.928	1835	Gauge Zero
22. ICB4	Sosiani				
23. ICB5 *	Sosiani	N 00 37.570	E 35 03.405	1838	Gauge Zero
24. ICB8	Endoroto				
25. ICB9	Elgerine				
26. ICC3	Olare Nyoike				
27.	Kipkarren	N 00 24.766	E 35 13.587		
28. ICEI *	Kipkarren	N 00 36.404	E 34 57.892	1661	Gauge Zero
29. IDA2 *	Nzoia (Webuye)	N 00 35.157	E 34 48.411	1479	Gauge Zero
30. IDB1/A *	Kuywa	N 00 34.377	E 34 40.831	1437	Water Level
31. IDB1	Kuywa				
32. IDB2	Bokoli				
33. IDC1	Chwele				
34. IDD1 *	Nzoia (Mumias)	N 00 22.165	E 34 28.962	1284	?
35. IDD2	Khalaba				
36. IEB2 *	Isiukhu	N 00 15.273	E 34 45.029	1479	?
37. IED1 *	Lusumu	N 00 18.383	E 34 28.761	1275	Gauge Zero
38. IEE1 *	Lower Nzoia	N 00 10.400	E 34 13.346	1195	Gauge Zero
39. IEF1 *	Nzoia (Rwambwa)	N 00 07.280	E 34 05.452	1166	Gauge Zero
40. IEG2	Wuoroya	N 00 08.937	E 34 14.606	1194	Gauge Zero
41. IFC1	Kimondi	N 00 11.782	E 35 02.983	1893	?
42. IFD2 *	Mokong	N 00 08.138	E 35 07.515	1923	Gauge Zero
43. IFE1	Yala				
44. IFE2 *	Yala (At Tindinyo)	N 00 10.875	E 34 56.238	1724	Gauge Zero
45. IFF3 *	Edzawa	N 00 18.344	E 34 34.169	1419	Gauge Zero
46. IFG1 *	Yala (Yala Mkt)	N 00 05.083	E 34 32.544	1416	Gauge Zero
47. IFG3 *	Yala (Daraja Mkt)	S 00 00.128	E 34 08.401	1162	Gauge Zero
48. 1FGMisc	YALA (D/S Power Stn)	N 00 04.000	E 34 31.000		
49. 1FGMisc	Yala Diversion	N 00 05.400	E 34 31.000		
50. IGB3 *	Ainamotua	S 00 04.536	E 35 03.358	1177	Gauge Zero
51. IGB5	Ainamotua	S 00 01.742	E 35 10.449	1438	?
52. 1GBMisc	Ainpngetuny	S 00 01.780	E 35 10.758	1338	?
53. 1GBMisc	Kapng'oriam				
54. 1GBMisc	Chemwanabei	N 00.06519	E 35.18810		

RGS. No.	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
55. 1GBMisc	King'wal	N 00.00689	E 35.18949		
56. IGB6/A	Mbogo	S 00 04.542	E 35 03.356	1200	?
57. IGB11	Ainapisiwa	S 00 01.742	E 35 10.479	1328	?
58. IGC4 *	Tugunoni	S 00 15.284	E 35 24.926	1996	Gauge Zero
59. IGC5	Masaita	S 00 28.471	E 35 32.535		
60. 1GCMisc	Kedowa	S 00 14.009	E 35 32.692	2125	?
61. 1GCMisc	Timbililwet	S 00 12.284	E 35 31.773	2035	?
62. 1GCMisc	Kipchorian/Tuyobei	S 00 11.428	E 35 30.736	2003	?
63. 1GCMisc	Cheboror/Kimoson	S 00 12.410	E 35 27.811	1934	?
64. IGD3 *	Nyando	S 00 07.544	E 35 00.003	1179	Gauge Zero
65. IGD7 *	Nyando	S 00 09.929	E 35 09.739	1265	Gauge Zero
66. IGG1 *	Namuting	S 00 12.245	E 35 20.873	1516	Gauge Zero
67. 1GGMisc	Pararget	S 00 13.183	E 35 18.348	1457	?
68. 1HAMisc	Oroba Ahero	S 00 07.400	E 34 47.500		
69. 1HAMisc	Luanda				
70. 1HAMisc	Kundos				
71. IHA1	Great Oroba				
72. IHA2	Little Oroba				
73. IHA6	Awach Nyangori	S 00 02.879	E 34 48.339	1194	Gauge Zero
74. IHAMisc	Nyamasaria	S 00 07.047	E 34 47.343	1171	WL
75. IHA14 *	Awach Kibos	S 00 02.879	E 34 48.339	1194	Gauge Zero
76. IHA16	Kibos	S 00 02.792	E 34 48.824	1192	?
77. IHB5 *	Awach Seme	S 00 05.705	E 34 28.489	1201	Gauge Zero
78. IHD1	Awach Kibuon				
79. IHD3 *	Awach Kabondo	S 00 27.100	E 34 53.058	1434	Gauge Zero
80. IHD9 *	Awach Kibuon	S 00 22.929	E 34 38.208	1172	WL
81. IHD5 *	Awach Kasipul	S 00 30.230	E 34 50.325	1519	Gauge Zero
82. IHE1 *	Awach Tende	S 00 28.087	E 34 32.968	1141	?
83. 1EHMisc	Oluch Tende	S 00 28.2	E 34 33		
84. IHE2 *	Mogusii	S 00 37.188	E 34 45.438	1526	?
85. IJAMisc *	Jamji				
86. IJA2 *	Kiptiget	S 00 06.101	E 35 15.257		
87. IJC19 *	Kimugu	S 00 28.664	E 35 10.524	1732	Gauge Zero
88. 1JC13	Sambret	S 00 24.263	E 35 18.745	1614	?
89. 1JC15	Sambret	S 00 22.100	E 35 23.347	2270	?
90. IJDMisc*	Chemosit	S 00 28.666	E 35 10.523	1734	WL
91. IJD3 *	Yurith	S 00 29.036	E 35 04.750	1651	?
92. IJF8 *	Kipsonoi	S 00 30.847	E 35 04.770	1621	Gauge Zero
93. IJG4 *	Sondu Miriu	S 00 21.267	E 34 48.330	1156	Gauge Zero
94. IJG5	Sondu	S 00 23.707	E 35 00.956	1508	Gauge Zero
95. IKA(Msc)	Riana				
96. IKA5 *	Nyakomisaro				
97. IKA9 *	Riana (At Lwala)	S 00 41.227	E 34 32.291	1341	WL
98. IKA10	Misadhi				
99. IKB1/A *	Gucha (Macalder)	S 00 58.267	E 34 15.652	1177	?
100. IKB3 *	Gucha (Rakwaro)	S 00 48.556	E 34 34.325	1359	Gauge Zero
101 IKB4	Gucha-Nyambunde	S 00 47.018	E 34 48.132	1710	Wl
102. IKB5 *	Gucha Migori	S 00 57.004	E 34 12.582	1158	Gauge Zero
103. IKB7	Gucha				
104. IKB9 *	Sare	S 00 54.274	E 34 32.103	1426	Gauge Zero
105. IKB11 *	Oyani	S 00 54.276	E 34 32.100	1426	?
106. IKB13 *	Mogunga	S 00 51.698	E 34 45.860	1701	?
107. IKC3 *	Migori	S 00 04.295	E 34 28.331	1358	Gauge Zero
108. IKC4	Migori				
109. ILA3 *	Nyangores	S 00 47.383	E 35 20.794	1906	Gauge Zero
110. ILA4 *	Mara	S 01 13.380	E 35 02.178	1601	WL
111. ILB2 *	Amala	S 00 26.247	E 35 26.247	1869	WL
112. NH/F1	Kaplelmet	N 00 05.051	E 35 11.003		
113. NH/F2	Kibegelek	N 00 05.188	E 35 09.525		
114. NH/F3	Cheptaburbur	N 00 02.473	E 35 08.176		

RGS. No.	Station Name	Latitude	Longitude	Alt. M Asl	Remarks
115. TN/F1	Tirigemet	N 00 02.314	E 35 19.809		
116. TN/F2	Chebirirkut	S 00 02.259	E 35 20.858		

*Stations which were identified as LVEMP network for continuous monitoring and assessment.

Table 5. Lake Monitoring stations- coordinates and maximum depth.

STATIONS	LOCATION	TYPE	LONGITUDE	LATITUDE	AV. MAXIMUM DEPTH (m)	NUMBER OF TIMES VISITED (n)
KP 1		Offshore	33° 59' 40'' E	00°18' 48'' S	47.0	22
KP 2		Offshore	33° 57' 3'' E	00° 36' 56'' S	56.0	22
KP 3		Offshore	34° 03' 49'' E	00° 54' 18'' S	33.0	18
KL 1	Winam Gulf	Inshore	34° 43' 14'' E	00° 07' 15'' S	3.5	22
KL 2	Winam Gulf	Inshore	34° 39' 46'' E	00° 13' 25'' S	3.0	22
KL 3	Asembo Bay	Inshore	34° 31' 11'' E	00° 15' 21'' S	5.5	22
KL 4	Winam Gulf	Inshore	34° 22' 43'' E	00°22' 48'' S	12.0	22
KL 5	Rusinga Channel	Inshore	34° 14' 17'' E	00° 20' 58'' S	23.0	22
KL 6	Off Yala River mouth	Inshore	33° 58' 23''E	00° 00' 42'' S	14.0	22

Rainfall

As a follow up of the earlier study (LVEMP 2002) most of the rainfall stations representing individual river catchments have been retained. In a few cases where some stations are either closed or abandoned, nearby stations with the required data have been adopted.

TABLE 6. Rainfall and Evaporation stations used in the study

River Basin	Station Number	Name	Rain/Evap	Reference Station for correlation
Sio	8934161 N/R 8934161 N/R	Alupe Nzoia Sugar, Bungoma Alupe Nzoia Sugar, Bungoma	R R E E	
Nzoia	N/R 8935133 8834098 8934140 N/R 8935133 8934140	Nzoia Sugar, Bungoma Eldoret Kitale Kadenge Nzoia Sugar, Bungoma Eldoret Kadenge	R R R R E E E	
Yala	8935133 8934140	Eldoret Kadenge	R R	

	9034011 8935133 8934140	Maseno Eldoret Kadenge	R E E	
Nyando	N/R 9035244 9035263 9034025 9035263 N/R	Chemelil Sugar Co. TRI Kericho Tinderet Tea Estate Kisumu Met Tinderet Tea Estate Chemelil Sugar Co	R R R E E E	
North Awach	9034025 8934140 9034011 N/R	Kisumu Met Kadenge Maseno Icipe, Rusinga	R R R R	
South Awach	N/R 9034084 9034018 9134009 9034139	Icipe, Rusinga HomaBay Gendia Muhuru Ringa, Oyugis	R R R R E	
Sondu	9035244 9035013 N/R 9035244 N/R	TRI Kericho Sotik Chemelil Sugar Co TRI Kericho Chemelil Sugar Co	R R R E E	
Gucha Migori	9134025 9134009 9034092 9134009 9034092	Migori Muhuru Kisii Muhuru Kisii	R R R E E	

At these stations, daily data is generated as an input into the Rainfall / Runoff model for generation of discharges.

Databases and current contents (categories and records held)

Data is currently stored in Excel and Access databases. Each sub-component has its database. The main information in the databases includes physico-chemical, meteorological, hydrological and biological data.

Databases and Modelling efforts

Lake Victoria Water Quality Model (LVWQMF)

During the project period, the Lake Victoria Water Quality Model (LVWQMF) which is a model framework for simulation of the physical processes and water quality in Lake Victoria was developed. The model was developed by a consortium consisting of Delft Hydraulics, HydroQual Inc. and IHE. The framework model is a preliminary or pilot model since it was based on existing data which was insufficient to support a full calibration or verification of the models. The model was intended to serve as Decision Support Tool (DST) from LVEMP for policy making formulation to have management scenarios of the lake that can be used to predict responses to possible management actions for the remediation of water quality problems in view of sustainable economic development.

Lake Victoria is a large and complex system, and it is hard to determine the effective measures for environmental management of the lake basin and to select measures that are in good balance with the (economic) needs of the people who are living at its shores. In view of this, it is clear that the formulation of common environmental policies is a demanding task. Therefore, models can effectively support the process of informing and optimizing management policies.

However, the use of models for environmental management and decision making is a relatively new science which requires trained experts and availability of input data usually on an extensive number of parameters. Modelling has its own demands for monitoring, data collection, and knowledge development. During the term of LVEMP, on-job training has been conducted using local experts on model basics including the data requirements and formats. Among the topics covered in the orientation/training were;

- the usefulness and possible uses of the modelling framework for lake basin management and decision making;
- the need to develop monitoring, data collection and research programmes adequate for modelling and which are at the same time cost-effective and sustainable;
- introduction to some basics in water quality modelling and day to day usage of the existing LVWQMF in its form.

Rainfall-discharge models

Three models, SACRAMENTO, SMAP and NAM were used to fill the gaps in the river discharge measurements. It is also used to estimate the runoff from ungauged catchments and also to assure quality of data through comparisons of model expectations with the observed data. Details of these models are shown in Chapter 3 on meteorology/hydrology. Brief descriptions of models are given below.

Sacramento Model

The Sacremento Model is used in the Lake Victoria Decision Support System (LVDSS) (Georgakakos et al, 1998). Initially it seemed logical to use the model for the all the rainfall-runoff modelling, particularly because two LVEMP staff from Kenya had been trained for 6 months in the use of the system. However, after setting it up for one catchment (Katonga), its further use was abandoned due to a number of difficulties:

- The Kenyan staff who were trained in the use of the model were not available.
- It proved to be difficult and time consuming to reformat the enormous quantities of data for use as input to the model.
- It was not user friendly.
- The NAM model is more user friendly, easier to input data, easier to calibrate, and, even although theoretically simpler, gave equally good results.

NAM Model

The NAM model originates from the Danish Technical University and was made available to the project by the Consultant. NAM is an abbreviation of the Danish name, "Nedboer-Afstroemning Model", which, translated, and simply means Rainfall-Runoff Model.

NAM is, like the Sacremento model, classified as a Conceptual Model with the following characteristics:

- Lumped (the entire catchment is considered as a single unit with uniform properties).
- The flow of water through the system is conceptualised into a number of reservoirs.
- The parameters partly reflect the physical properties of the catchment.

Although some users claim that Conceptual Models can be used to simulate changes in the catchment properties (eg deforestation) the clear recommendation is not to use them for this purpose. Deterministic, distributed models should be used for such studies. The structure of NAM is illustrated in LVEMP (2002). A Users Guide was provided with the model.

SMAP Model

The SMAP model is also a Conceptual Model, but simpler in structure than Sacremento and NAM because it has fewer reservoirs. It is best suited to use with monthly rainfall data and was therefore chosen for use on the Tanzanian catchments. The model and the Users Guide were provided by the Consultant for use in the project.

Lake hydrodynamic models

ELCOM was coupled to CAEDYM to model the hydrodynamic conditions at the Rusinga Channel. The Brief descriptions of models are given below.

The Estuary and Lake COmputer Model (ELCOM) is a three-dimensional hydrodynamics model for lakes and reservoirs, and is used to predict the variation of water temperature and salinity in space and time. The model forms the three-dimensional driver for the The Computational Aquatic Ecosystem DYnamics Model (CAEDYM). ELCOM was coupled to CAEDYM to model the hydraulic conditions at the Rusinga Channel. CAEDYM was configured to simulate the dynamics of phosphorus, nitrogen, dissolved oxygen and biochemical oxygen demand. Rate coefficients of the dominant processes were also obtained. CAEDYM contains process descriptions for primary production, secondary production, nutrient and metal cycling, and oxygen dynamics

The model solves the unsteady Reynolds-averaged Navier-Stokes equations using a semi-implicit method similar to the momentum solution in the TRIM code with addition of quadratic Euler-Lagrange discretization, scalar (e.g. temperature) transport using conservative flux-limited approach and elimination of vertical diffusion terms in the governing equations. A one-dimensional mixed-layer model from mixing energy budgets is extended to 3 dimensions for turbulence closure of vertical Reynolds stress terms, and thus the turbulent fluxes. Molecular diffusion in the vertical direction is neglected as turbulent transport and numerical diffusion are generally dominant. The free-surface evolution is governed by vertical integration of the continuity equation for incompressible flow in the water column applied to kinematic boundary condition.

The free surface elevation is governed by the vertical integration of the continuity equation for incompressible flow applied to the kinematic boundary condition. Heat transfers across the water's surface utilize standard bulk transfer models where non-penetrative components (i.e. longwave radiation, sensible and latent heat) affect only the surface layer temperature while penetrative effects of shortwave radiation are distributed vertically with Beer's law.

ELCOM computes a model time step in a staged approach consisting of:

1. introduction of surface heating/cooling in the surface layer
2. mixing of scalar concentrations and momentum using a mixed-layer model
3. introduction of wind energy as a momentum source in the wind-mixed layer
4. solution of the free-surface evolution and velocity field
5. horizontal diffusion of momentum
6. advetion od scalers, and
7. horizontal diffusion of scalers.

Recommendations

Great progress has been made in capacity building for water quality management during LVEMP 1 and the minimum requirements are in place. There are however still constraints that should be addressed in during the next stage of LVEMP. As scientific studies and monitoring activities on the lake increase, availability of ship and crew time becomes more limited. This is especially true as the current vessels are accessed from fisheries research institutions with their own mandated programs. Therefore it is recommended that a dedicated, regionally shared vessel suitably equipped to serve all aspects of the water sampling and monitoring programs be acquired. Equipment should be appropriate safety equipment including communication and positioning technology to allow continuous tracking and communication as well as adequate personal safety equipment. Additional recommendations include:

- LVWQMF was developed using example data in the early years of the project. Now that sufficient data has been generated for the lake, there is urgent need to use the actual data to calibrate and validate simulation runs.

- More water quality laboratories dedicated to Lake Victoria and its catchment are recommended for the next phase because the current laboratory based at the Ministry of Water and Irrigation is facing increasing national demand from other national programmes. The new laboratories could ease logistics of sample collection, transport and analysis.

- Performance evaluation exercises should be carried out on quarterly basis as part of the regular quality assurance and not on an ad hoc basis. Dedicated funds must be put in place to insure that QA/QC is not sacrificed to meet program sampling needs.
- There should be regular meetings of the scientists from all the sub-components to analyze the QC results and design way of improving the performance of the laboratories.
- Laboratories should be equipped with analytical instruments appropriate for detecting levels of concentrations expected in the samples/environment. This is especially true for metal and pesticide measurements that pose environmental risk to biota and humans even at very low concentrations in the water environment.
- There is need to consolidate the critical mass of scientists developed during this project and build outfit for more.
- There is need the Government of Kenya to start integrating LVEMP activities in their national programs for purposes of sustainability.
- Application of these preliminary findings into follow-up activity on Lake Victoria which has been declared as an economic growth zone.
- Acquisitions of a research vessel dedicated to monitoring water quality in Lake Victoria.

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CHAPTER 3

Meteorology and Hydrology of the Lake Victoria Basin: Kenyan Sector

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ABSTRACT. *This study reports of the results of extensive field monitoring of river flows and lake levels, rainfall and evaporation. The study's aim was to elucidate main trends and periods of meteorology and hydrology as revealed by time series of rainfall, evaporation, river discharge and lake levels and which could be used as input towards computation of nutrient and sediment load introduced into Lake Victoria.*

Hydro-metrological data for the period running 1950-2004 were analysed and form the basis for computing the pollution loadings (catchment and atmospheric) into the lake and as well as calculation of the lake water balance. Continuous rainfall and evaporation records were applied and data gaps filled were necessary. Full records of land discharges were obtained from rainfall records using the NAM model. Model performance was evaluated on the ability to simulate the total flow for catchments, rather than the peak and minimum flows, for pollution estimation.

The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

INTRODUCTION

The association between hydrology and the eutrophication of the lake is the recognition that pollution loadings from the catchment of Lake Victoria are mobilized and transported in response to the hydrological cycle. In order to determine the dynamics of river driven pollution loading, it is important to first study the hydrological and meteorological behaviour of the whole catchment area, especially so in terms of rainfall, evaporation and river discharges which are inter-related. It is because of this need that this study has been undertaken by the Lake Victoria Environmental Management Programme's Meteorology/Hydrology task whose main duty is to determine an estimate of the total discharges to and from the lake on a daily basis. In addition this data contributes to determination of the regional water balance of the lake.

The study has been carried out through extensive field monitoring of river flows and levels, rainfall and evaporation through a network of existing stations with the aim of;

- Generating continuous daily evaporation records for the period 1950 – 2004
- Calculating discharges in the rivers on the basis of rating curves and measured gauge heights.
- Performing Rainfall – Runoff Modelling to extend and fill gaps in river discharge records from 1950-2004.
- Calculating final discharges for each individual river catchment or basin.

This is a follow up of what LVEMP had done earlier in developing an initial estimate of the total water balance from 1950 to 2000. In the earlier estimate; a lot of gaps in data were noted and the NAM Rainfall-Runoff model was used to fill these. It was therefore expected that actual observed data would be collected thereafter so as to induce more reality in the analysis and hence results of the study. To a large extent, this has been achieved and where difficulties have been experienced in getting observed data, methods which had been developed during the earlier study including correlation of existing stations to nearby stations by mass curves were engaged especially in filling rainfall gaps. Much about this will be mentioned later on in this paper.

This study reports of the results of extensive field monitoring of river flows and lake levels, rainfall and evaporation. The study's aim was to elucidate main trends and periods of meteorology and hydrology as revealed by time series of rainfall, evaporation, river discharge and lake levels and which could be used as input towards computation of nutrient and sediment load introduced into Lake Victoria.

In methodology section, the manner in which the series were generated is discussed. The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

Study area

The study area is all that Kenyan catchment area in which all rivers flow into Lake Victoria. This is the area from which rivers carry water, nutrients, sediments and pollutants into the lake and covers about 42460 km^2 on the Kenyan side (Fig. 1).

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.

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.

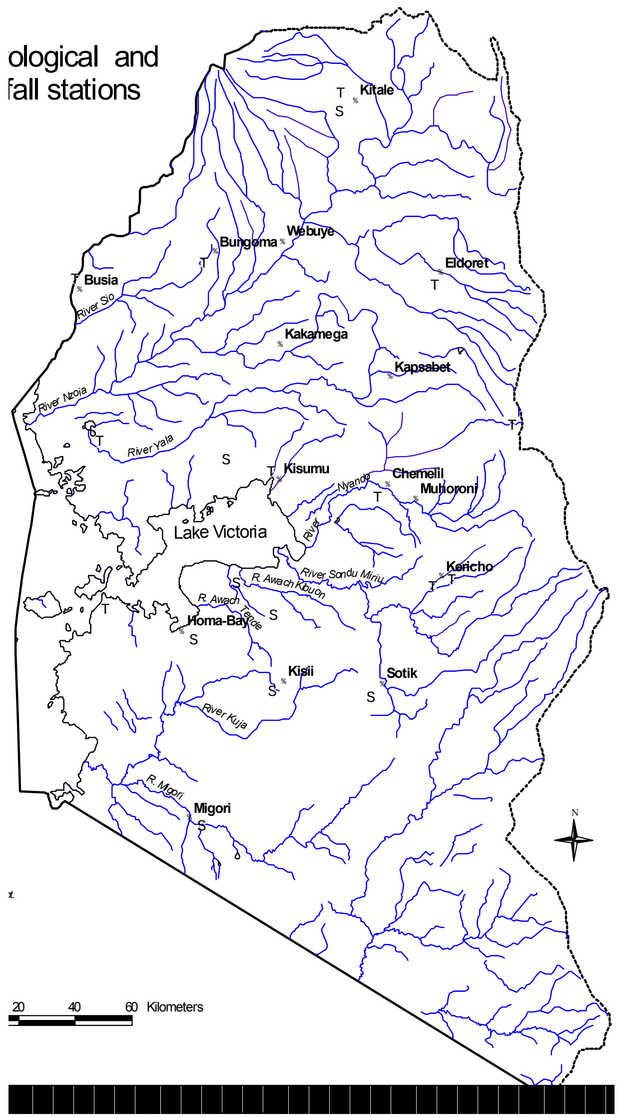


FIG. 1. Meteorological and rainfall stations.

Methods

To meet the objectives of this study, the following methods are used;

Hydrology

Between the years 2000-2005, over 950 river discharge measurements were done on 52 selected river-gauging stations all over the catchment.

Three methods were used to obtain discharges;

1. The conventional current meter 'mid-section' method was used. In this case, the river section is divided into approximately twenty (20) segments in which velocity, depth and width are measured and then the formula

   $$Q = AV$$

   is applied for the calculation of discharge.

   Where Q = Discharge in m^3s^{-1}
   A = Wetted cross-sectional area in m2
   V = Velocity in ms^{-1}
2. A modern and more convenient and safe method in deep and wide sections of rivers was the use of Rio Grande Acoustic Doppler Current Profiler (ADCP) which outputs discharge results directly.

3. The Float and Flume method, used where the above equipment was not available, is a simple manual method conducted on a reach with perceived uniform cross-section and flow.

Rainfall Runoff Modeling

River discharges were also computed from time series of rainfall and evaporation using the NAM model (Danish Technical University). This is a lumped model run on excel spreadsheets which assumes a single unit with homogenous characteristic of the flow throughout the system. The model was applied to daily values of rainfall and evaporation series (1950-2004). The manner in which the rainfall and evaporation series were generated is explained below.

Rational formula

The following rationale formula was applied to compute runoff in ungauged basins around the lake shore:

$$Q = CA(R - K)$$

Where

Q = flow in m^3/s,
C = constant coefficient,
A = catchment area in km^2,
K = lumped rainfall loss parameter which also acts as a monthly threshold value for the generation of Q and
R = autoregressive weighted monthly rainfall.

This model was particularly useful in obtaining runoff for the clustered river systems such as the North Awach catchment comprising of rivers Nyamasaria, Awach Seme, Kisian and Murguruge and the South Awach catchment comprising of rivers Awach, Tende and Awach Kibwoun.

Rating Curves

Using discharge measurement data collected at the principal stations along the major rivers within the catchment during the period 2000-2004, rating curves have been generated using a simple EXCEL Macro spreadsheet with appropriate formulas (Fig. 2).

Quality control measures include comparison with the conventional "hydata generated" curves at the Ministry of Water and Irrigation Headquarters in Nairobi and comparison with observed discharges (Fig. 3).

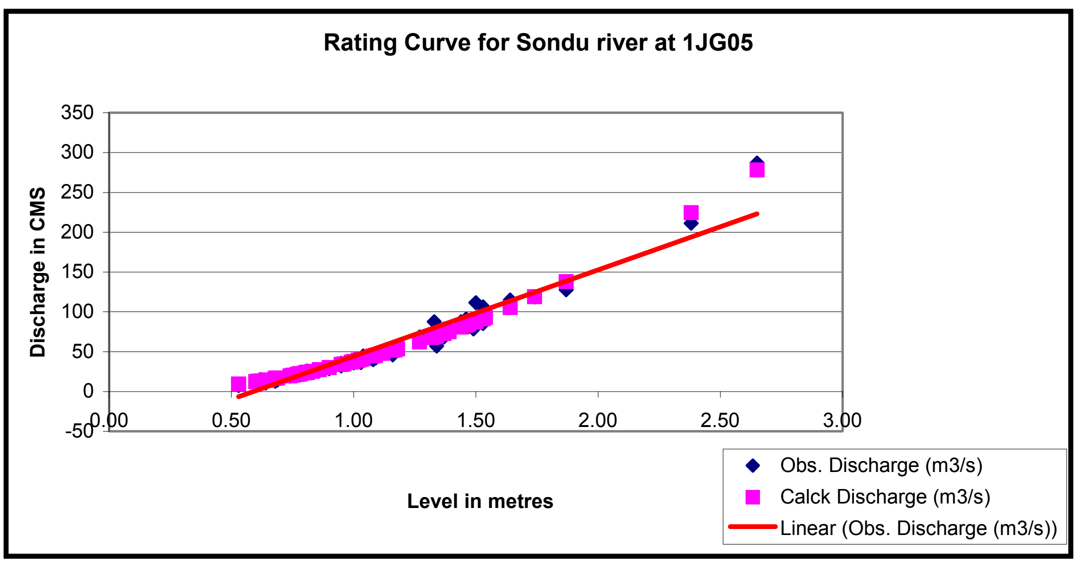


FIG. 2. Rating Curve generated for Sondu River

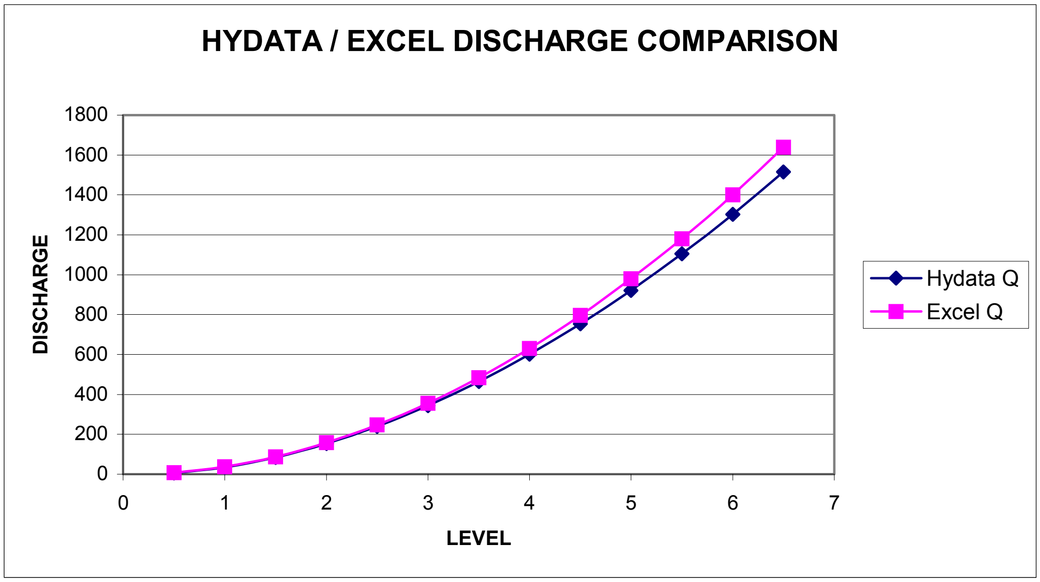


FIG. 3. Comparison of EXCEL and HYDATA generated rating curves.

River and lake water levels were gathered using the manually read staff gauges and the modern digital data loggers located at the principal stations shown in Table 1.

TABLE 1. Shows the principal stations used in this study

River Basin	Basin Area (Km^2)	Gauging Station		Catchment area U/S of station (Km^2)	Type of Station	Remarks
		Reg. No.	Location/name			
SIO	1450	1AH01	MUNDIKA	1450	STAFF	
NZOIA	12,676	1EF01	RWAMBWA	12,676	STAFF & LOGGER	
YALA	3,351	1FG01	YALA TOWN	2,388	STAFF & LOGGER	
NYANDO	3,652	1GD03	OGILLA	2,625	STAFF & LOGGER	
NORTH AWACH	1,985	1HA09	NYAMASARIA		STAFF	
		1HB05	AWACH SEME		STAFF	
SOUTH AWACH	3,156	1HE01	AWACH TENDE	585	STAFF	
		1HD09	AWACH KIBUON	536	STAFF	
SONDU	3,508	1JG05	SONDU MARKET	3,287	STAFF	
GUCHA-MIGORI	6,600	1KB05	WATHONGER	6,600	STAFF & LOGGER	
LAKE VICTORIA		1HB04	KISUMU	-	STAFF & LOGGER	

Rainfall

As a follow up of an earlier study (LVEMP 2002), most of the rainfall stations representing individual river catchments have been retained. In a few cases, where some stations have been decommissioned, nearby stations with the required data have been adopted in this analysis (Table 2).

TABLE 2. Rainfall and Evaporation stations used in the study

River Basin	Station Number	Name	Rain/Evap	Reference Station for correlation
Sio	8934161	Alupe	R	
	N/R	Nzoia Sugar, Bungoma	R	
	8934161	Alupe	E	
	N/R	Nzoia Sugar, Bungoma	E	
Nzoia	N/R	Nzoia Sugar, Bungoma	R	
	8935133	Eldoret	R	
	8834098	Kitale	R	
	8934140	Kadenge	R	
	N/R	Nzoia Sugar, Bungoma	E	
	8935133	Eldoret	E	
	8934140	Kadenge	E	
Yala	8935133	Eldoret	R	
	8934140	Kadenge	R	
	9034011	Maseno	R	
	8935133	Eldoret	E	
	8934140	Kadenge	E	
Nyando	N/R	Chemelil Sugar Co.	R	
	9035244	TRI Kericho	R	
	9035263	Tinderet Tea Estate	R	
	9034025	Kisumu Met	E	
	9035263	Tinderet Tea Estate	E	
	N/R	Chemelil Sugar Co	E	
North Awach	9034025	Kisumu Met	R	
	8934140	Kadenge	R	
	9034011	Maseno	R	
	N/R	Icipe, Rusinga	R	
South Awach	N/R	Icipe, Rusinga	R	
	9034084	HomaBay	R	
	9034018	Gendia	R	
	9134009	Muhuru	R	
	9034139	Ringa, Oyugis	E	
Sondu	9035244	TRI Kericho	R	
	9035013	Sotik	R	
	N/R	Chemelil Sugar Co	R	
	9035244	TRI Kericho	E	
	N/R	Chemelil Sugar Co	E	
Gucha Migori	9134025	Migori	R	
	9134009	Muhuru	R	
	9034092	Kisii	R	
	9134009	Muhuru	E	
	9034092	Kisii	E	

At these stations, daily data is generated as an input into the rainfall-runoff model for generation of discharges. All rainfall measurements have been subjected to quality control checks to identify erroneous data i.e. by visual examination of raw and plotted data, calculation of statistical means, maximum and minimum, comparison with data from adjacent station and calculation of accumulated mass curves. Gap filling has been done by correlation to adjacent stations for the few cases where it is necessary. This is done by taking close stations with longest data where a double mass curve is evaluated for the subject station and the reference station, a trend line fitted to the curve after which the resultant equation is applied to fill gaps in the subject station (Figs. 4-6).

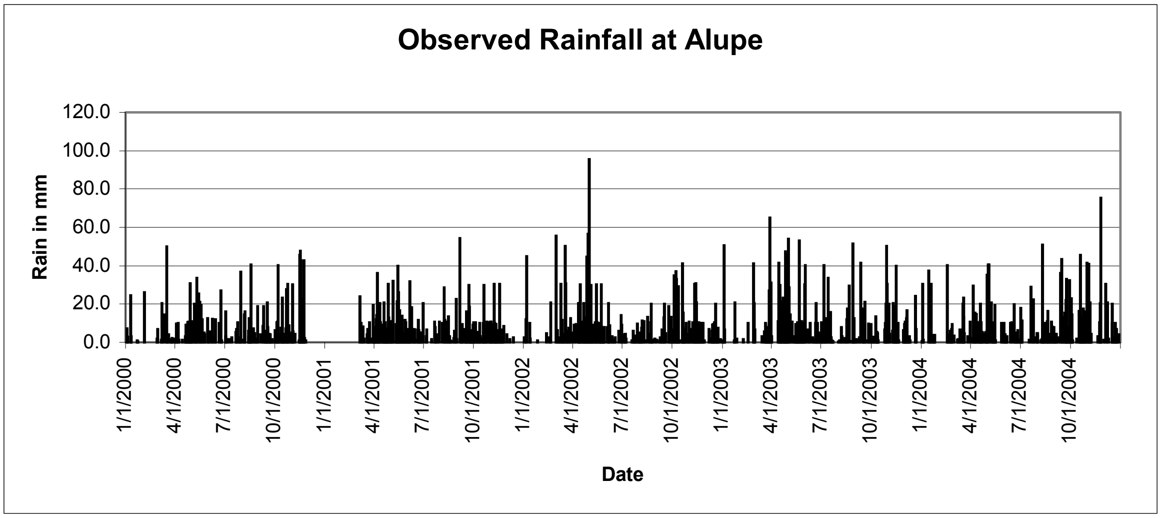


FIG. 4. Observed rainfall at Alupe from January 2000-December 2004 (with one month missing)..

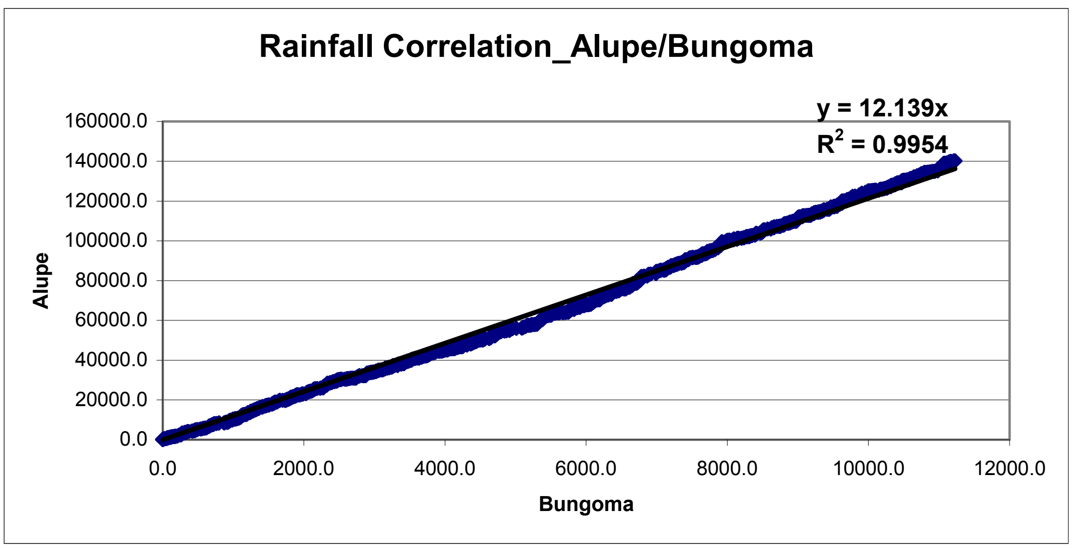


FIG. 5. Linear correlation and regression between Alupe and Bungoma rainfall.

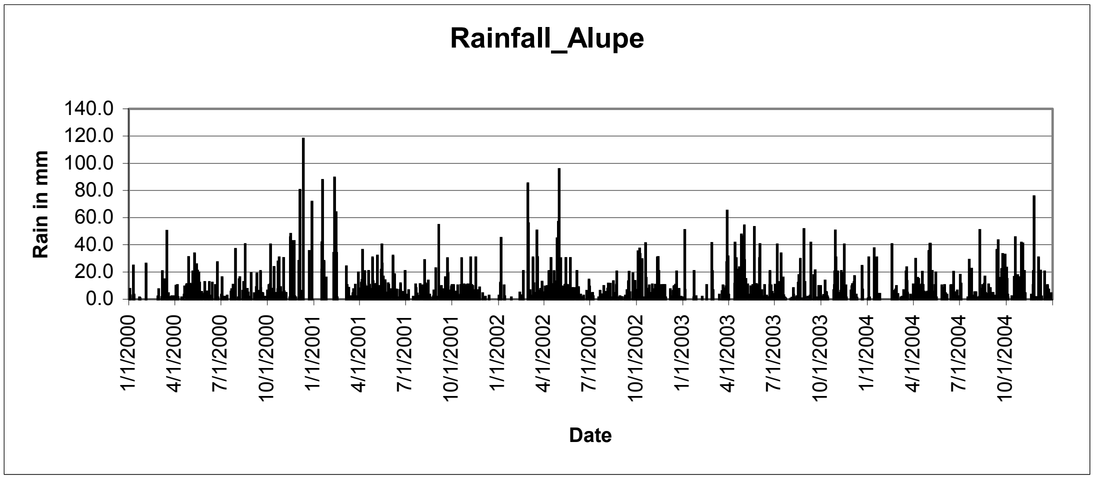


FIG. 6. Final rainfall for Alupe after filling the gap in 2001.

The earlier method of gap filling using typical wet, dry and average years (LVEMP 2000) is not applied here as the gaps are not more than a few months in a year.

From the year, 2000, the study was as much as possible based on observed data, but due to circumstances beyond our control, it was not possible in all cases. We therefore had to depend somehow on stations that are owned and run by other organizations/institutions. In a few cases, some stations that were used in the earlier study were completely abandoned or closed and this forced us to identify nearby existing and reliable stations that could be used for generation of the data. In this study therefore, we have generated daily rainfall data from 2000 to 2004, which is an extension of the earlier study done by LVEMP (2000) covering the period 1950 to 2000. Fig. 6 is an example of a rainfall series for Alupe in which gap filling has been done.

Evaporation

In general, this study has experienced difficulties in obtaining meteorological data because the weather stations that were proposed for installation have not been delivered on time.

Furthermore, observed data generation for 2000-2004 was mainly handicapped by the closure of most evaporation stations within the Lake Victoria catchments due to lack of operational funds by the various institutions that were operating them.

In principle, the method for development of continuous evaporation record is the same as that of rainfall. However, because of the fewer number of evaporation stations, correlation to adjacent stations may be irrelevant since wide distances between may cause some differences.

Some evaporation data is measured at full meteorological stations, most of which are still operational. Daily mean evaporation was therefore used to fill gaps in site records because there is no defined method of choosing evaporation values for typical wet, average and dry years. Fig. 7-8 gives evaporation series for Kitale during 2000-2004 before and after gap filling; this was done by use of average daily evaporation observed over a period of 7 years.

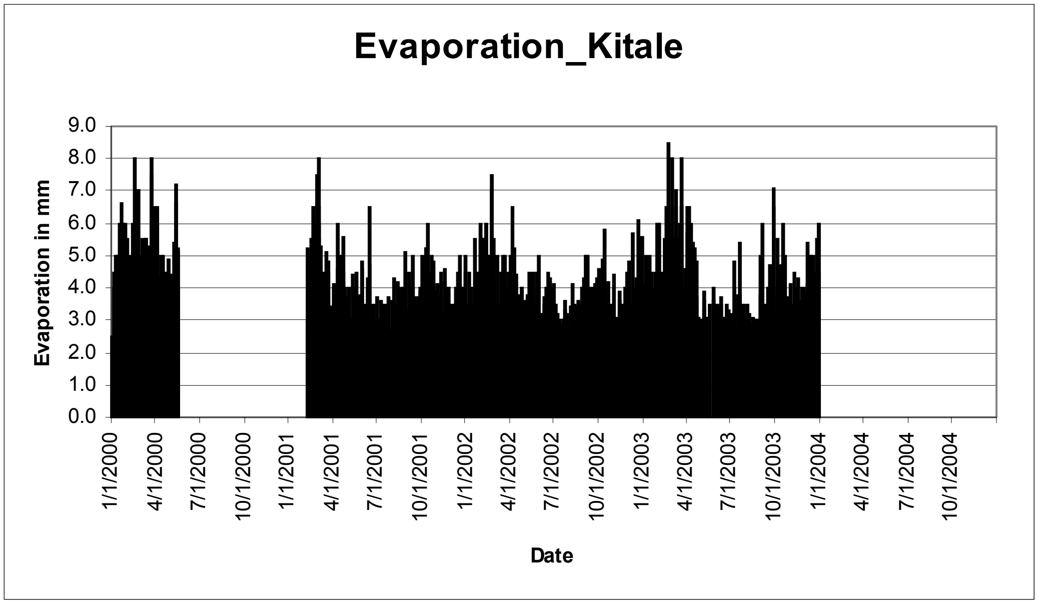


FIG. 7. Observed evaporation at Kitale with gaps.

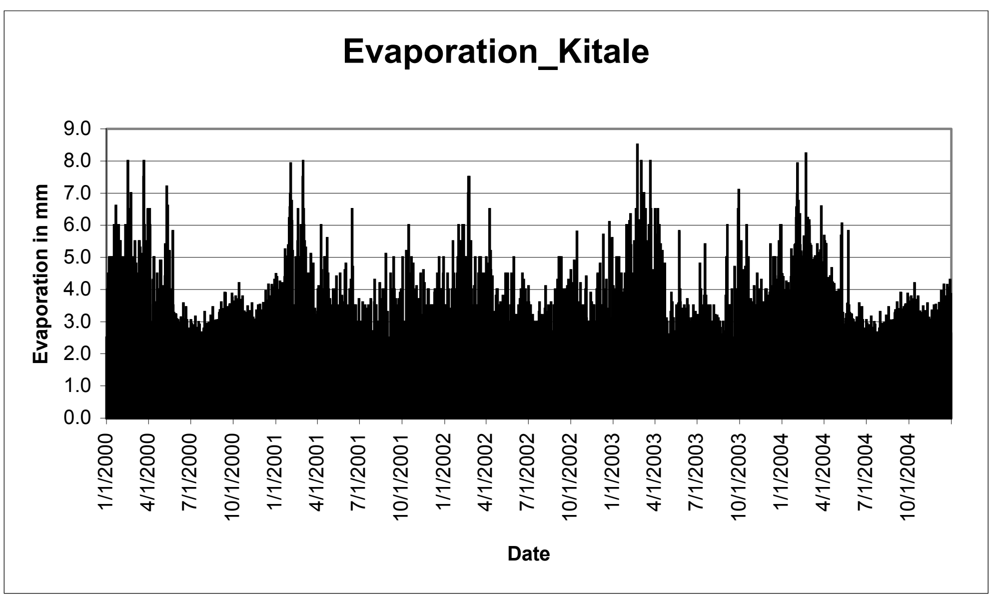


FIG. 8. Final evaporation for Kitale after gap filling by use of average daily evaporation observed over a period of 7 years.

River Discharges

Because the main interest of this study is to assess the discharge of water to the lake and to compute pollution loads, it is important to concentrate on the discharge at or near the river mouth. Rating equations have therefore been developed in a simple EXCEL MACRO using the standard formula:

$$Q = k(h - h_0)_x$$

Where,

Q = river discharge (in m^3s^{-1})
k = coefficient
h = gauge height (m)
h_0 = gauge height at zero flow (m)
x = exponent of rating curve

For quality control, a visual examination of a flow/level plot is considered sufficient to remove erroneous data. The river discharges have been computed by applying the rating equation to the daily gauge heights (see Fig. 9). Gaps in records are subsequently filled by the rainfall-runoff modeling.

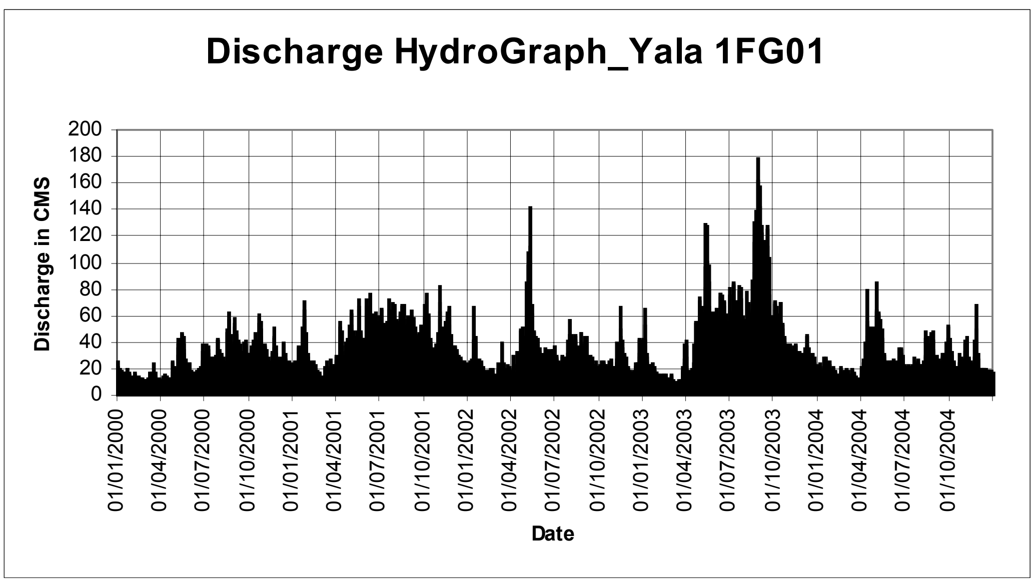


FIG. 9. Discharge hydrograph for River Yala after computation of discharges by applying the rating equation.

Rainfall Runoff Modeling

Modeling is used to fill gaps in discharge record and in this study; it has been applied in a few instances where gauge readings were not available either due to vandalism, damage or loss of gauge, lack of a reader or data logger failure. An example of discharge data gaps is shown in Fig. 10.

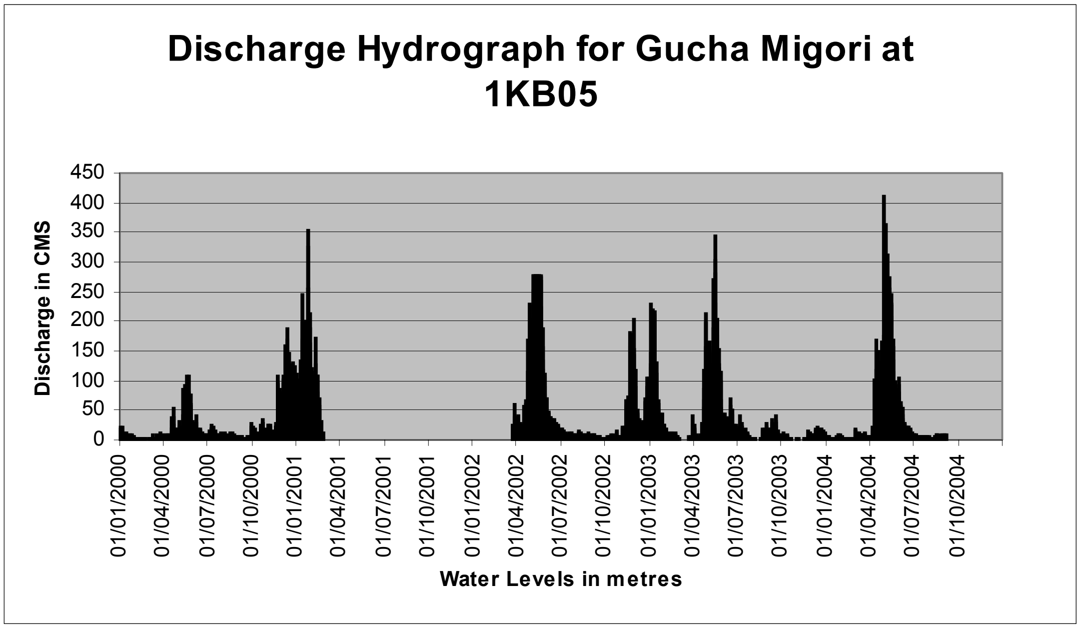


FIG. 10. Discharge hydrograph of Gucha River with gaps.

The LVEMP Water Quality and Ecosystems Component in Kenya has adopted the NAM model, (a conceptual model) which originates from the Danish Technical University. In this model, the entire catchment is lumped and assumed to be a single unit with uniform characteristics, the flow of water through the system conceptualized into a number of reservoirs and the parameters partly reflect the physical properties of the catchment.

Model calibration (see LVEMP 2000) is done by use of at least 4 years of simultaneously measured rainfall, evaporation and discharge data. The model parameters are adjusted by trial and error until the best fit is observed between modeled and observed discharges in terms of accumulated runoff from the catchment, peak flows, recession curves and low flows (Fig. 11).

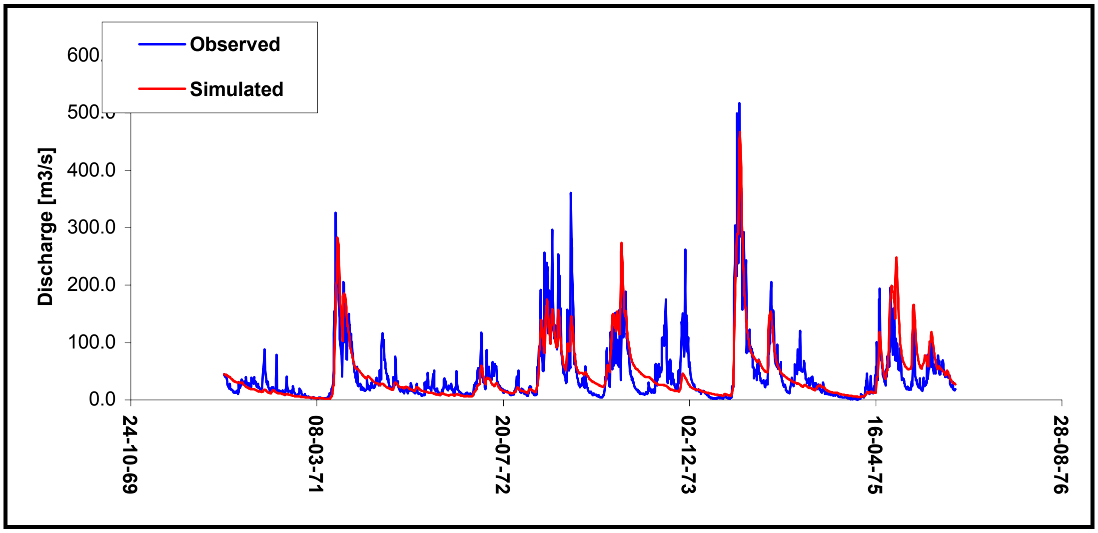


FIG. 11. Model and observed results for Gucha River from 1969-1976.

Model application is accomplished by applying the calibrated model to compute runoff at the station for the full period of 1950-2004 (Fig. 12). In this application, the final rainfall and evaporation generated for the full period is used for calculation of the water balance (Chapter 3 of Regional Report).

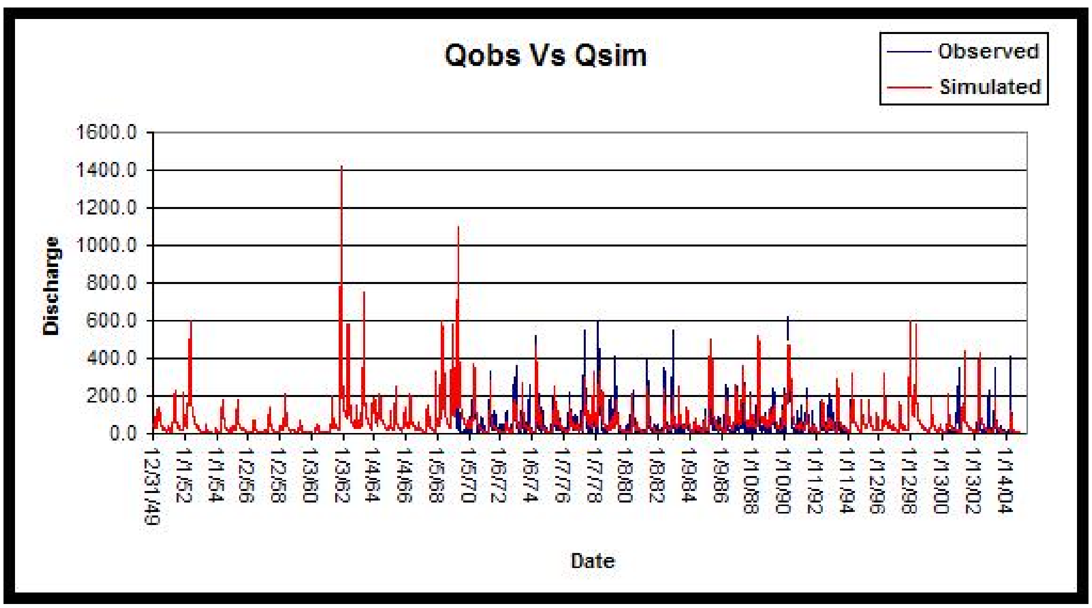


FIG. 13. Model application as accomplished by applying the calibrated model to compute runoff at a station for the full period of 1950-2004.

Some catchments and basins around the lake largely remained ungauged and have been lumped into composite basins consisting of small rivers and wetlands along the lakeshore for the purpose of estimating water inflows.

On the other hand, some of the rivers in these areas have been gauged but the data available neither sufficient nor representative of the whole basin area. In Kenya, there are two such areas namely the North Awach, which comprises of rivers Nyamasaria, Awach Seme, Kisian, Murgut, and other smaller ones and the South Awach comprising of River Awach Tende, Awach Kibwoun and other smaller ones.

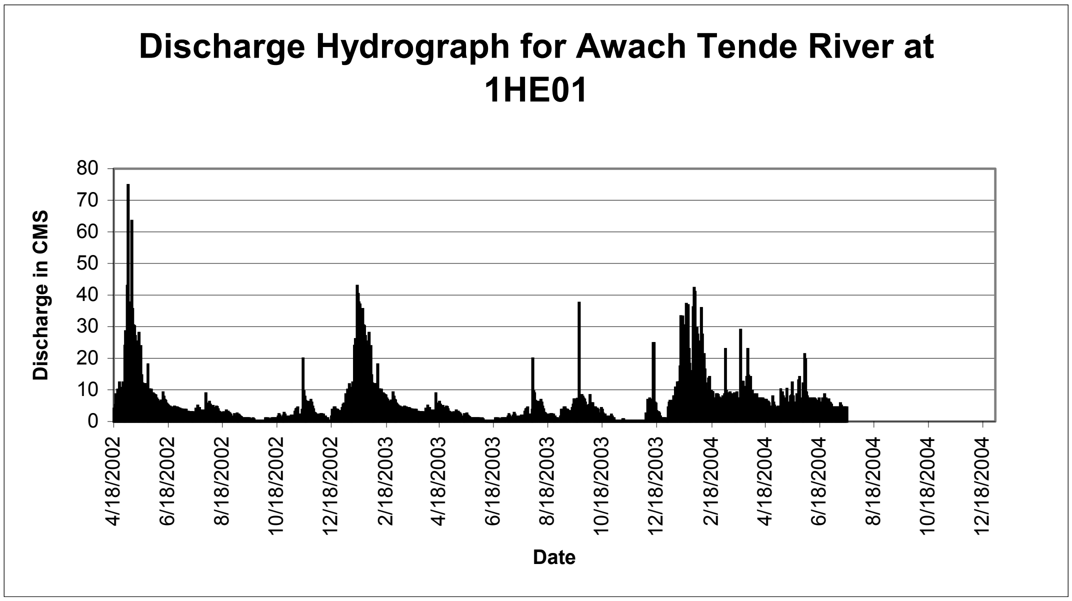


FIG. 14. Insufficiency of the data collected on one of the small rivers-Awach Tende.

In this case therefore an empirical model was applied to simulate monthly flows using parameter values from an adjacent similar catchment. The model is an application of the rational formula mentioned above.This has been tested with monthly rainfall and discharge data in Nzoia, Sondu, Kibuon and Sio River basins and a good fit was obtained.

RESULTS

Rainfall

In this case, a rainfall record for 1950-2004 at each station was generated. Fig. 15 gives an example of such a rainfall record for the Kericho station. Since a time series of rainfall data representative for a river basin is required for use in the rainfall-runoff models, it is generated as a weighted mean of the selected station in the basin. Weighting of each station is dependent on the proportional area assigned to the station and on the rainfall characteristics.

In Kenya, two prevalent zones are considered i.e. the low flat area near the lake and the high altitude area with irregular topography in upper reaches of catchments. The weighting therefore takes into account the different physiographic characteristics of these areas.

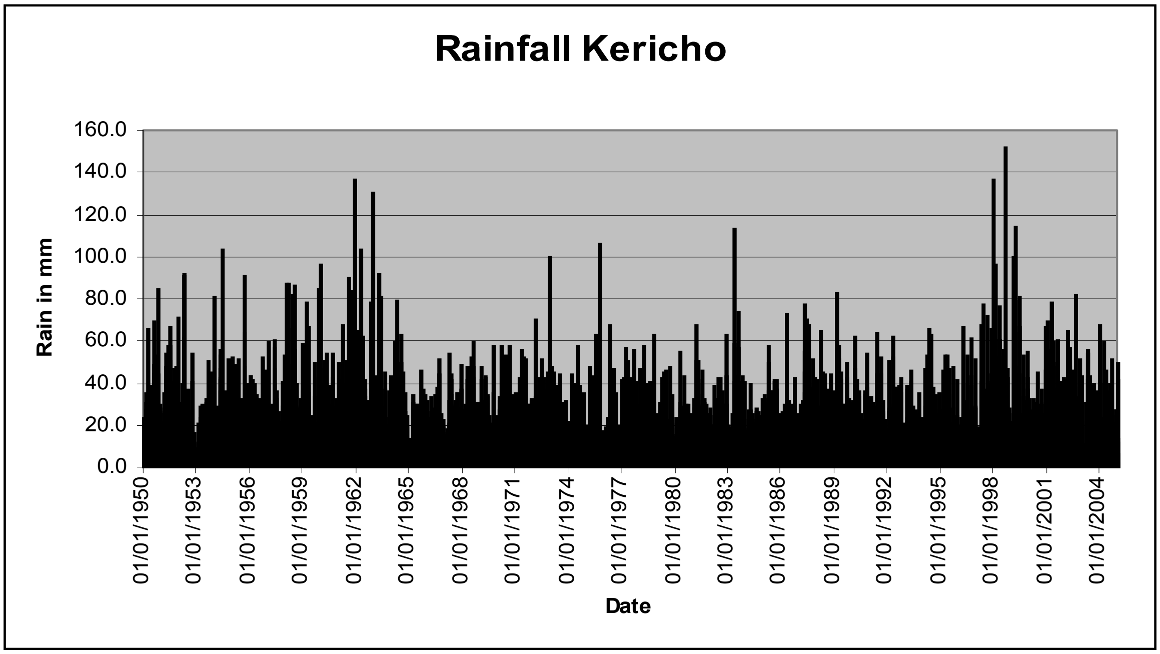


FIG. 15. Time series of rainfall data for Kericho for the period 1950-2004.

Meteorology trends in Lake Victoria basin

This study established wet and dry seasons to occur in March to May and October to November respectively (Fig. 16). Mean monthly rainfall maxima are recorded in April (213 mm) and November (345 mm). The driest months are observable during January and December. Fig. 17 shows rainfall totals over the years 1950-2004; it indicates that the driest years were 1953 (1180 mm), 1959 (1183 mm) and 1984 (1230 mm). Conversely, the wettest years were recoded in 1961 (1749 mm), 1968 (1761 mm) and 1977 (1775 mm). An autocorrelation function was produced to detect the repeat cycles of dry or wet years; however, this did not show any significant correlation at 95% confidence intervals.

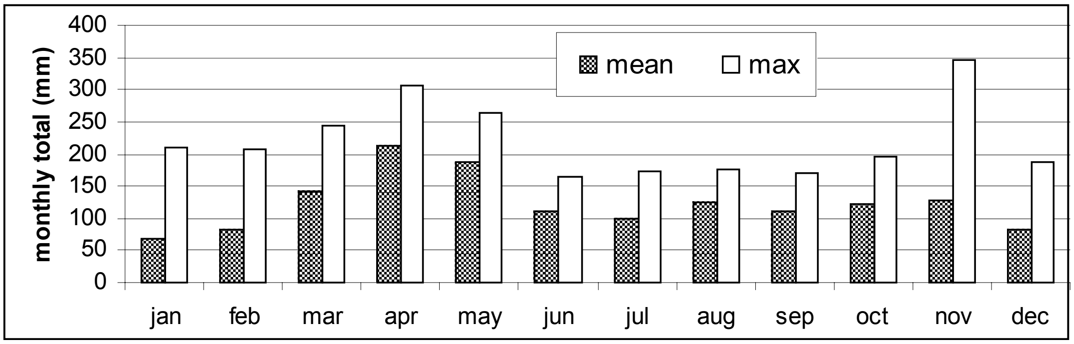


FIG. 16. Mean and maximum monthly totals of rain in Lake Victoria.

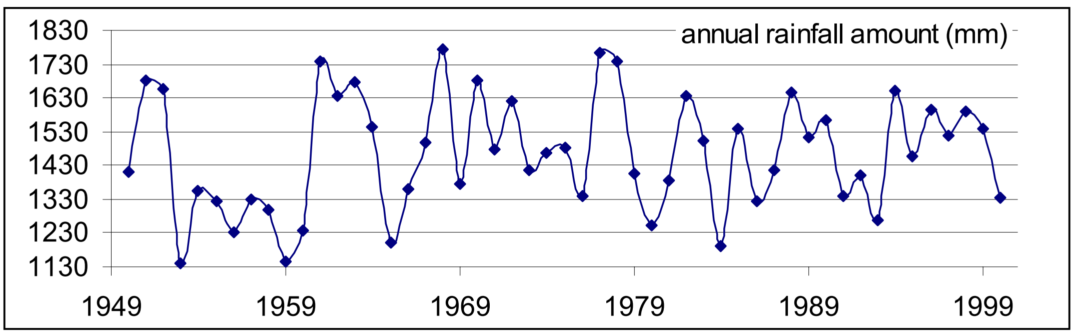


FIG. 17. Yearly total of rain in Kenya catchments of Lake Victoria.

Spatially, less rain falls near the lakeshore than upstream of the catchment (Fig. 18.). Over the years of record, it can be seen that the highest amounts have been recorded consistently in Alupe, Kisii and Kericho area. Alupe lies on the southern foothills of Mt. Elgon, while Kisii and Kericho lie on the peak of Manga hills and Mau ranges (at altitudes greater than 2000 m a.s.l) respectively.

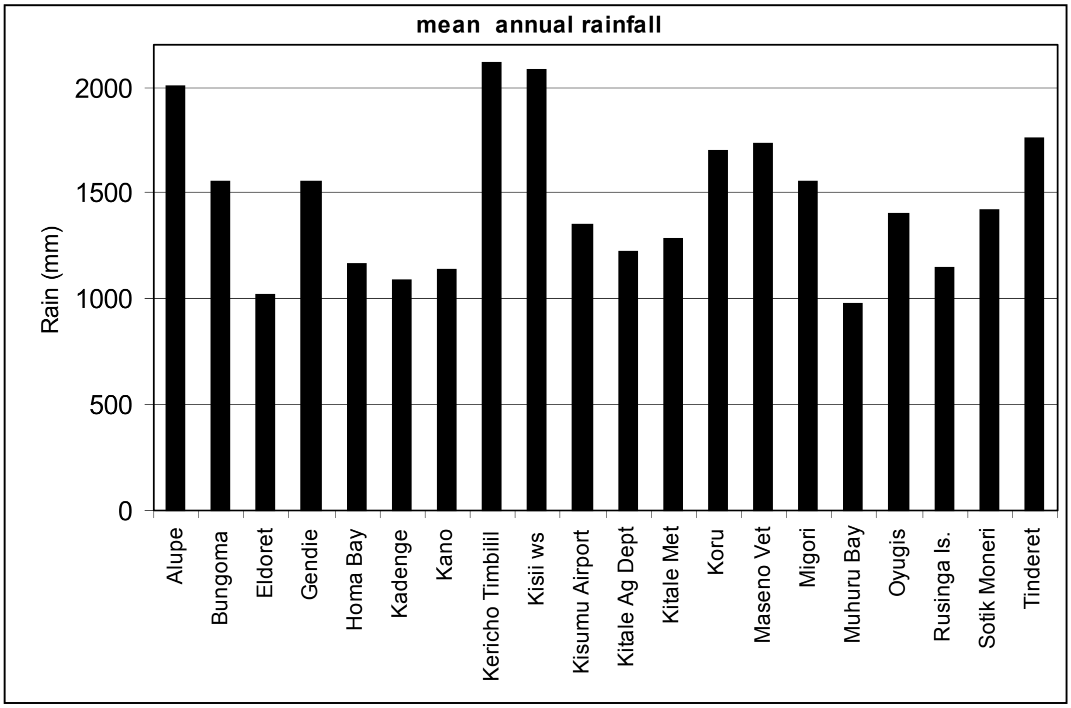


FIG. 18. Mean annual rainfall for stations in Kenyan Lake Victoria basin.

LVEMP period compared to 50-year record

By plotting on the same axis the first 60 monthly totals of each decade, the LVEMP period of record was compared to 50-year record to determine how representative it was of the longer period. Criteria for choosing the first sixty months were based on the fact that, this is the length of the period LVEMP has been collecting data. Fig. 19 and Fig. 20 shows there is no significant difference between decades in both upcountry (Kisii) and lakeshore (Kisumu) rainfall. Wet and dry months seem to occur at the same time as in every other decade. Rainfall totals for the months in the different decades do not seem different either. It was further shown that autocorrelation coefficient function for different decades have not changed significantly (Table 1 for Kisii station) which shows within decade autocorrelation coefficient as being strongest in the decade of the nineties and that of 60s which respectively gave a recurrence of 2 and 6 months period. H.M. Njuguna (pers. commun.) has found that rainfall of the 1960s and late 1970s was highest over the last half century. This is well reflected in the long term records of lake levels discussed later in this chapter.

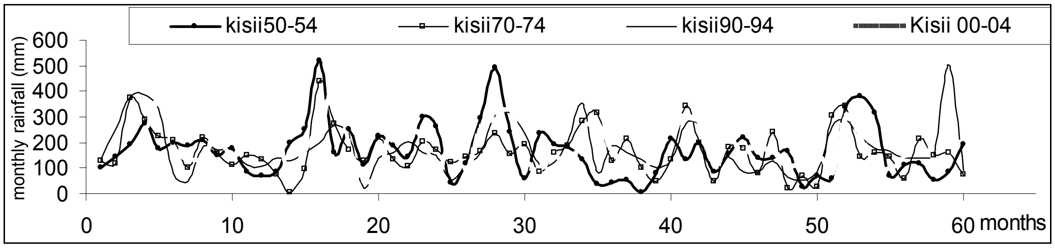


FIG. 19. Kisii station first sixty months of each decade monthly rainfall.

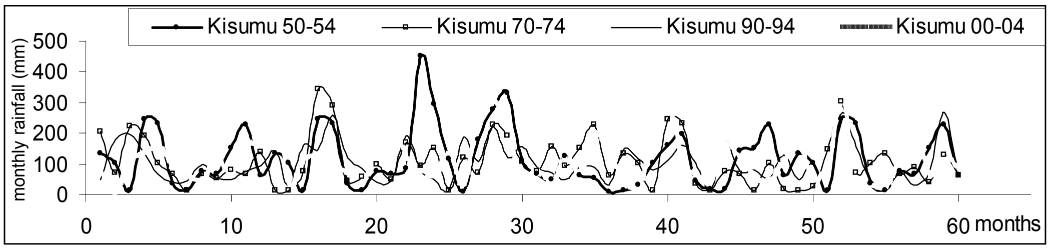


FIG. 20. Kisumu station first sixty months of each decade monthly rainfall.

Flow occurrence between decades

Total monthly flow for each decade was plotted for two rivers; Nzoia and Nyando (Figs. 21 and 22). This was done to assess whether wet and dry events occur at the same months and whether there is any significant difference in their magnitude. Nzoia depicts a regular recurrence of wet and dry seasons among the three decades though the nineties' wet season seems to have a longer duration than those of previous decades (Fig. 21). Nyando River also seems not to have had any significant difference in the frequency of wet and dry months occurrence, though the magnitude of the fifties appear smaller than the rest (Fig. 22). To assess which months among decades had close association, a cross partial correlation coefficient was computed. It can be deduced that for Nzoia River, the sixties and nineties were found to be significant after every 8, 10 and 14 months (95% confidence interval). Inter-decades analysis showed that a weak but nevertheless significant autocorrelation was present in the seventies after every 8 months, while the other two did not show any.

Nyando within decade autocorrelation was found significant after every 3 months for fifties, 4 months for sixties, none for seventies, 3 months for eighties and 8 months for nineties. Cross correlations between decades were found significant for month of fifties and sixties after every 5, 7 9 and 12 months and between eighties and fifties were strongest after every 6 months. Nineties and seventies and nineties and fifties were significant at 11 and 7 months respectively.

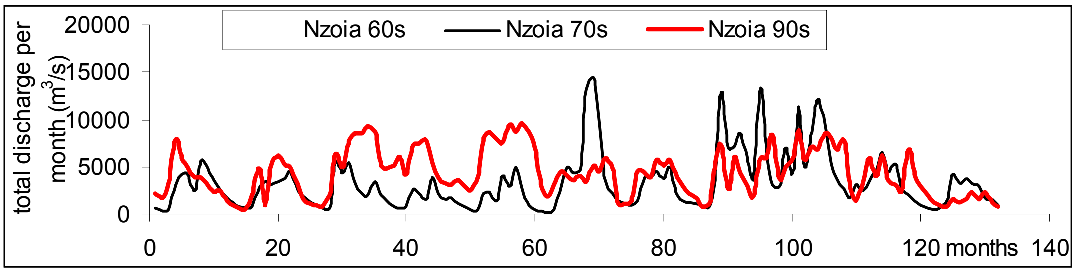


FIG. 21. Monthly Nzoia discharge compared for different decades.

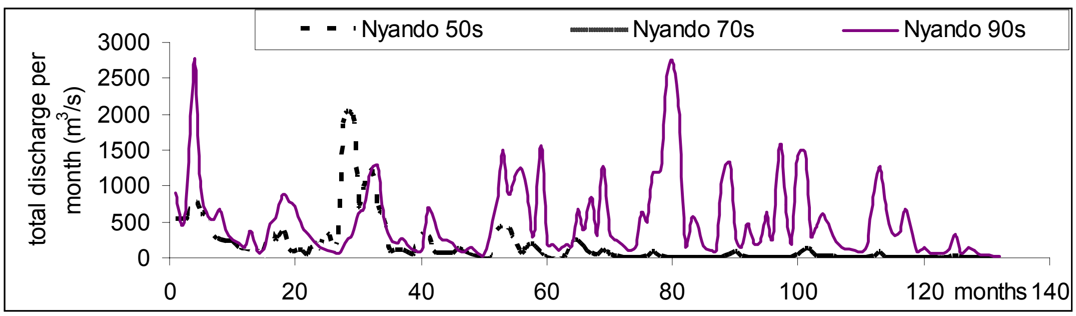


FIG. 22. Monthly Nyando discharge compared for different decades.

Lake level fluctuation

The mean lake level variability is dominated by a decreasing trend as reflected by Fig. 23, in which a high stand of 2.9 m has fallen to a low of 1.8 m (above datum); reflecting a fall of 1.1 m. Consistenct with rainfall records, water level peak is observed every May after that of peak rainfall in April, and a slight increase recurs in December. The lowest levels are measured in October and are usually about 18 cm above mean annual lake level. The months of May, June, July, January and December were found to be above mean annual lake level that has been computed as 2.45 m over the period of record. On a daily basis, highest water levels are observed at 1800 hours (6:00 p.m.) while the lowest are at 0200 and 0400 hours in the morning. Despite the seasonal rains experienced in the region, it has not been possible to restore the lake to year 1999 levels experienced after the El Nino events of 1997-1998. This means that 1997-1998 were exceptional years.

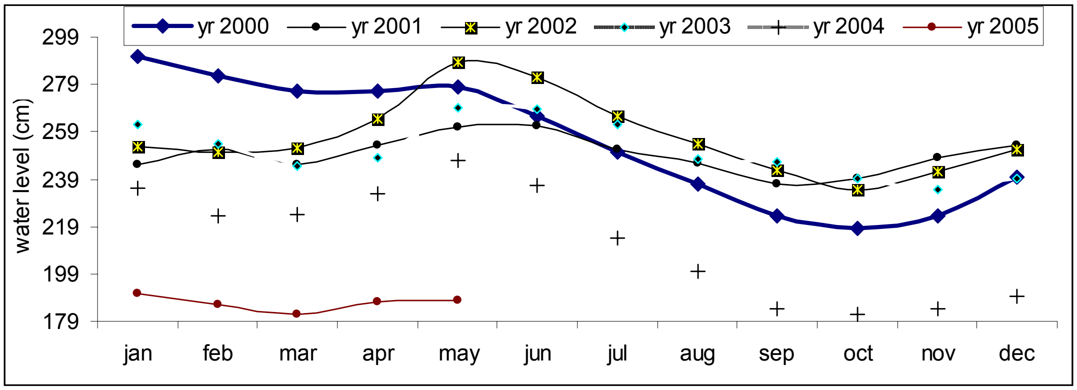


FIG. 23. Mean monthly lake level during LVEMP period.

At the level gauging site, water temperature has been on a rising trend since the year 2000 (Fig. 24). The highest rate of temperature increase occurs in the months of September and October while the rest of the months show a steady increase of 0.1 ^{o}C. The lake temperatures measured are apparently too high, probably because the level recording site is in protected and shallow water.

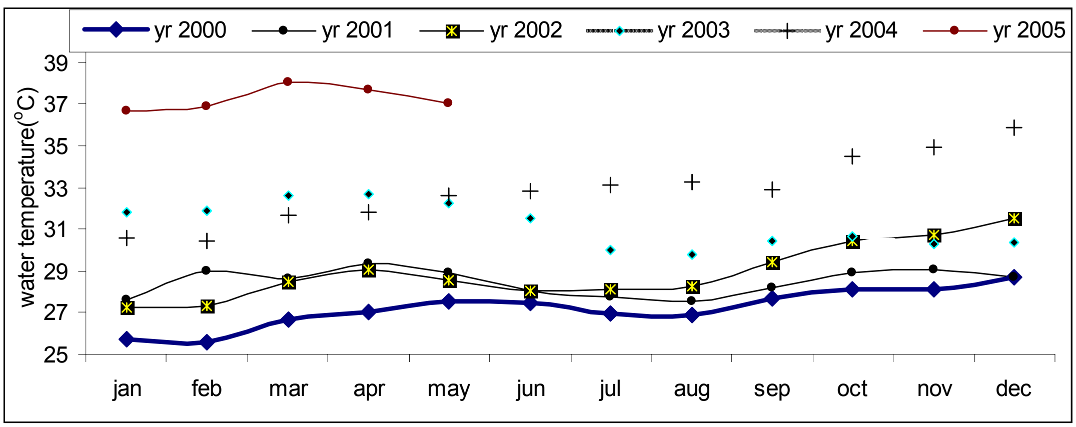
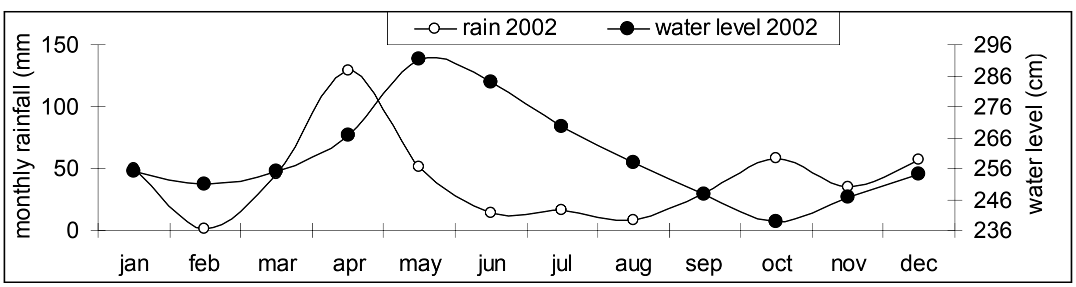


FIG. 24. Mean monthly water temperature at level gauging station.

Lake level and rainfall relationship

Reformat below

It has been acknowledged that rainfall over the lake as well as in its watershed are the fundamental causes for the accumulation of water in the lake (EAMD, 1974) and it is therefore expected that variations in the component rainfalls should be reflected in the lake level fluctuations. Peak rainfall and lake level are observed in April and May respectively. This was examined by cross-spectral analysis between the lake level and the rainfall series. Lake level lags the rain signal by a mean of 42 days emphasizing the peak occurrence of rain in April and that of the lake in May. An unusual phenomenon may have occurred b in May 2004 in which a sudden profound fall in lake level is observable in Fig?. Data of Yala swamp (where is this figure/data)show the rain signal to be dominated by a non-seasonal decaying exponential trend in which rain decreased from 1.47 to 0.695 mm per day (length of record October 2001 to December 2004). Fig ? shows the falling trend of the rain to be accompanied with reduced variability of the rain in subsequent years compared to initial years when the automatic Meteorological Station was installed. On a decadal scale, Fig current 11??? suggests a ten-year cyclic fluctuation. Others are 5.25 and 13.7 in decreased order of variance contribution. The results further show the lake level to have decreased from 2.97 in 1964 to 2.47 in 2004 a decrease of 0.5 m. EAMD (1974) observe that the highest peak was recorded in May 1964 and that level has not been recorded since the beginning of the century and monitoring records. The Lake level was lowest during May 1922 to April 1923 Compared to the 41 year record of 1923 to 1964 in which the lake experienced a rise of 2.57 m, and 2 m during 1961 to 1964 alone, the fall of 0.5 m over 40 years (1964 to 2004) is insignificant and therefore the lake is yet to resort back to previous low levels recorded prior to 1923. Kisumu's rainfall record at its airport from 1950 to year 2000shows the main component is low frequency additive season with no trend that has cyclic rain events lasting 17 years. The floods of 1997-1998 (1375 mm) were severer than those of 1961-1964 (1364 mm what are these data ? elevation change' rainfall? This section is hard to follow but important; please review for clarity) and those of 1978 -1979 (1347 mm). High frequency cyclic rain events were observed every 3.4, 8.5 and 5.1 years in that order of strength.



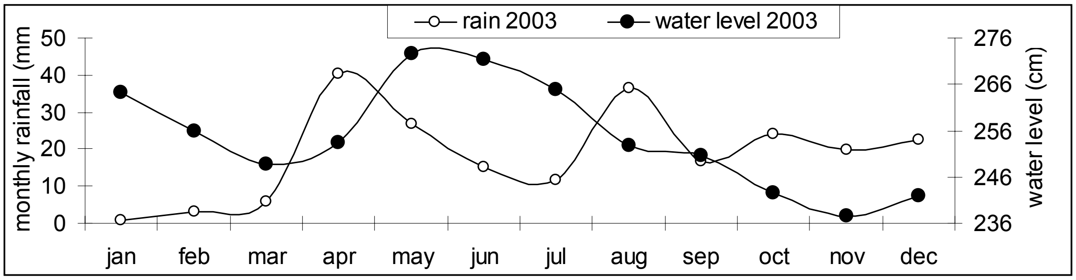


Figure ?? water level and rain signal co variation reflecting the one month lag between them

Rainfall / Run off relation

Rainfall is expected to generate run off that is reflected in the river discharge. Fig ?? shows a plot of the partial autocorrelation function of the series Kisumu rain and Nyando discharge for year 1990-1994 taken to represent this scenario. This section is very important yet it seems incomplete in presentation and is not mentioned in the Discussion below!! Is it possible to compare moden annual catchment rainfall and annual discharge (with appropriate lags if necessary) for Kenya catchments with historic data. It is often observed that land clearance for agriculture changes the rainfall-runoff relation and this in itself can cause increased sediment and pollution record. We need to examine this closely. It also can explain tendency to more severe flooding. Please comment on the stability of the rainfall-runoff relation over time or say that the data are inadequate to do such an analysis which would be unfortunate.

Rain over Lake Victoria

This represents the largest inflow of water to the lake. Just like in the earlier COWI/LVEMP study there still exists an insufficient number of rainfall stations over the lake area. With knowledge on the wind patterns, it follows that rainfall is highest along the West Coast followed by the North and lowest on the South. This has enabled estimates based on the few rainfall observation along the shore and on the islands. COWI REPORT make sure this is referenced (Pg. 69) Figure shows the rainfall stations in the lake basin used to estimate over-lake rainfall with their mean annual rainfall based on measurements above, their corresponding isohyets and divisions of the lake into a number of boxes that form the basins of estimating total rainfall over the lake. Each rainfall "box" has a reference rainfall station. Where mean rainfall is estimated on the basins of isohyetal curves respectively.

The daily rainfall in each box is calculated sing R box = R ref* MAR $_{box}$/MAR ref

Where R_{box} = Daily rainfall in the box

R_{ref} = Daily rainfall in the box

MAR_{box} = Mean annual rainfall in box

MAR_{ref} = Mean Annual rainfall at Ref. Station.

The average daily rainfall for the lake is therefore calculated as the sum of the area weighted means of the daily box rainfall (R_{box})

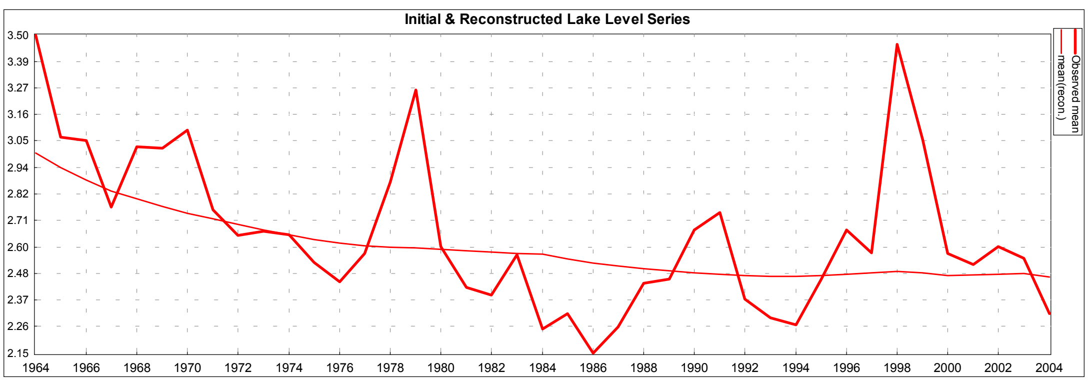
See table ??
Lake Rain = Σ (R_{box} weight)

Table:?? Shows rainfall figures for 2000-2004 in relation to the low term figures for 1950-2000

Rainfall over Lake Victoria (Kenya Side)

Box No.	Name	Wt	MAR_{box} mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean Annual Lake rain for each box
1	Muhuru	0.074				
15	ICIPE Rusinga	0.076				
16	Homa Bay	0.006				
17	Kisumu	0.01				

Table ?? shows rainfall figures for 2000-2004 in relation to the long-term figures for 1950-2000 for catchment rainfall.



Figure?. Long term lake level observed at Kisumu pier This is an important figure make sure the scales are legible

Evaporation

Evaporation data is essentially prepared and analyzed in the same way as rainfall. The only difference is that there are fewer evaporation stations with large distances between them hence it is inappropriate make correlations to extend records. Pan evaporation can vary significantly or a vary only a little on any given day. There is hardly any relationship between evaporation and the occurrence of wet and dry rainfall years. Therefore it was decided to use daily average evaporation to fill gaps in record eg the average of all records on January 1 is used to fill all gaps on January 1 evaporation figures for 2000-2004 in relation to the long term figures (1950-2000) and the boxes used for calculating average evaporation over the lake. In this table, the Muhuru Meteorological Station no longer exists. Because there is no met. station nearby, the average daily evaporation is used to fill the record.

Figure Final Evaporation For Bungoma

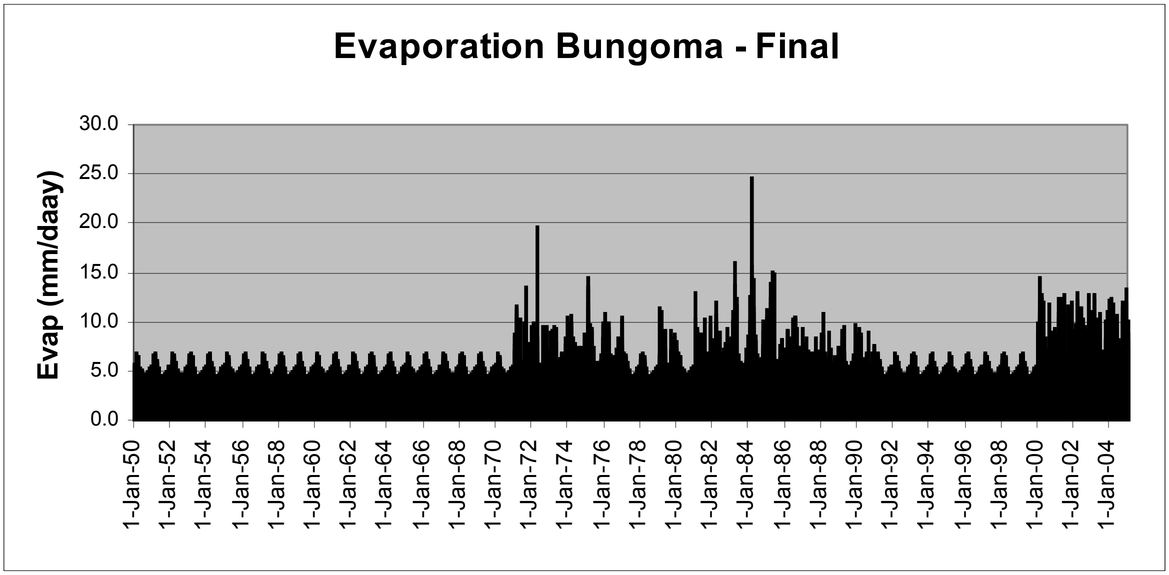


Table: Shows the evaporation boxes over Lake Victoria (Kenyan Side)

Box No.	Name	Wt	MAR $_{box}$ mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean + Lke rain for each box
1	Muhuru	0.041				
10	Rusinga (ICIPE)	0.124				
11	Kisumu	0.012				

Wind speed and direction

Wind was found to have a mean speed of 1.34 m/s and is greatest in February and March and again in September. July and November months have comparable speeds and represents lowest speeds for the series. Wind directions are represented by wind roses plotted (Fig 18) for the months of February, May and November by virtue of the other processes that occur during this time. Overall, the directions are dominated by flows from the south especially during the first six months.

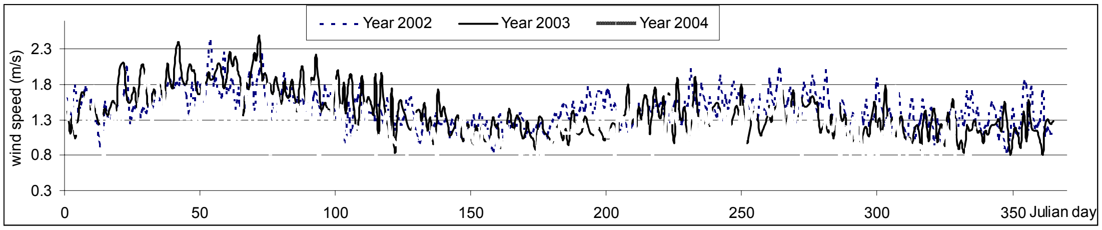
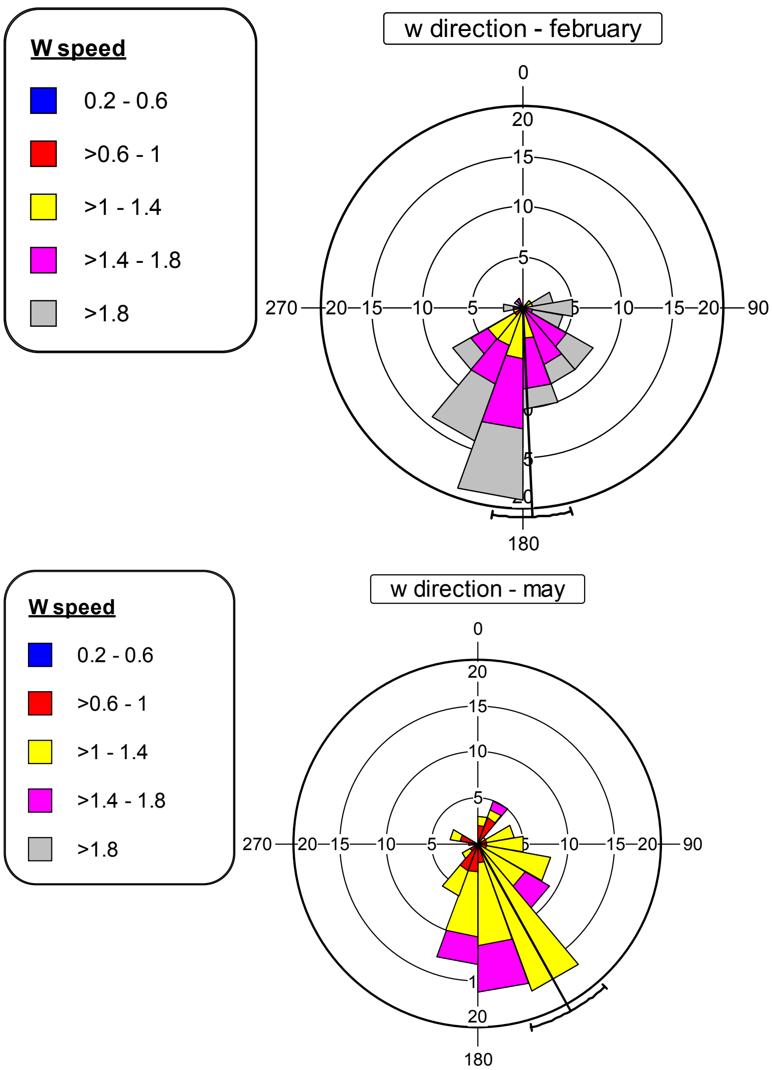
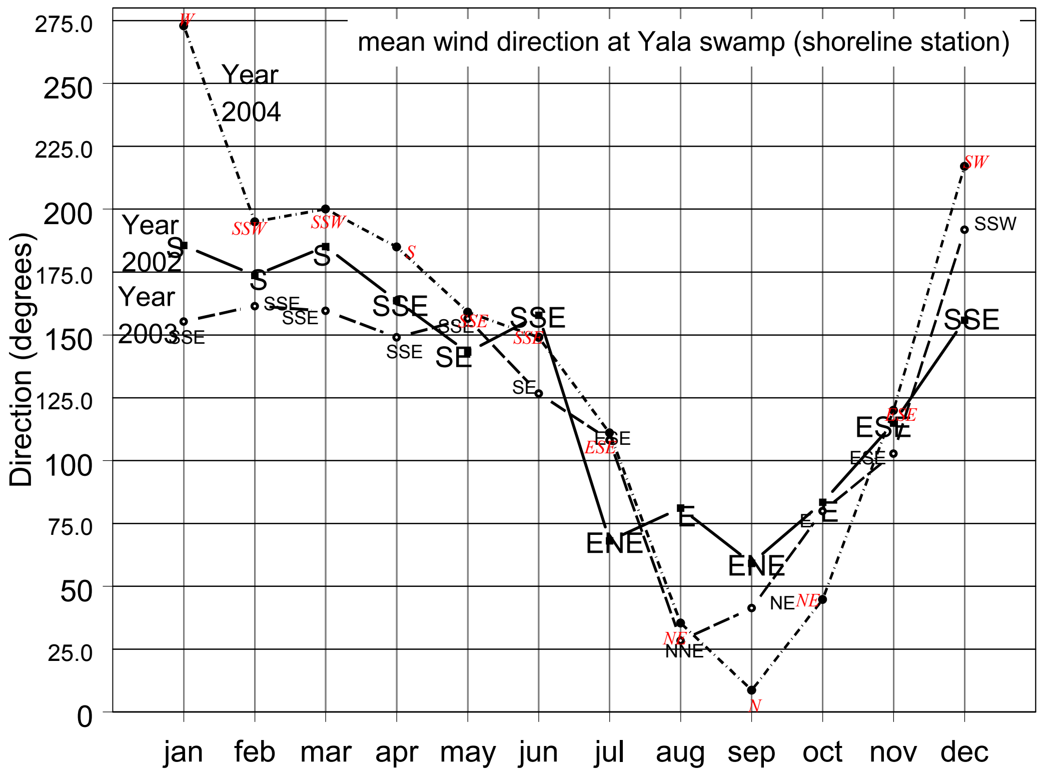


Figure ?? Mean monthly wind speed at Yala swamp



Figure??. Wind rose for the months of February and May. Constructed from 3 year wind series



Figure??. Mean wind direction measured at Yala swamp, shoreline station

Discussion

This study has presented and examined time series of river flows and lake levels, rainfall and wind as measured from the Kenyan catchment of Lake Victoria. This was done with an aim of elucidating trends and periods of meteorology and hydrology from which some plausible explanation on the variability in time of the eutrophication of Lake Victoria can be offered based on meteorology and hydrology processes.

Please comment on trends in rainfall, discharge, rainfall-runoff relationships for different basins (are they all similar or different?) You have done a lot of analysis but this discussion section is where you help the reader understand why you did all these analyses. What were you looking for; what did you find, do any trends or changes have significance to the lake. You do not want leave the reader wondering why all this was done. Discuss the data you have presented above to provide meaning to the reader.

Wind direction has been found to be south to southeasterly dominated during all the months except the period between July and November when the winds from the east. Low-level southeasterlies play an important role in the process of convection/rainfall formation by joining the over-lake convergence and by displacing the convergent center to the northwest of the lake (Nicholson and Yin, 2000).

An important finding concerning evaporation and solar radiation is the strong linear correlation coefficient during the months of April, June and July. This does not compare with the finding of Nicholson and Yin, (2000) who found evaporation to be high in the December-March season and around August, during which time the cloud cover is very low. During the three years the series used in this study was generated, evaporation was found to be high commencing November to March during which time ??? incomplete sentence

River Discharges

Gauging stations close to the mouth are chosen for this study. Table shows the list and location of gauging stations.

This whole section was presented above i.e. your methods Since the gauging stations are not placed exactly at the river mouth, the discharge is not representative of the entire basin area hence the need to calculate the discharge from the entire basin. For example is the un-gauged area represents 2% of the total basin area, then discharges are increased by a factor 1.02.

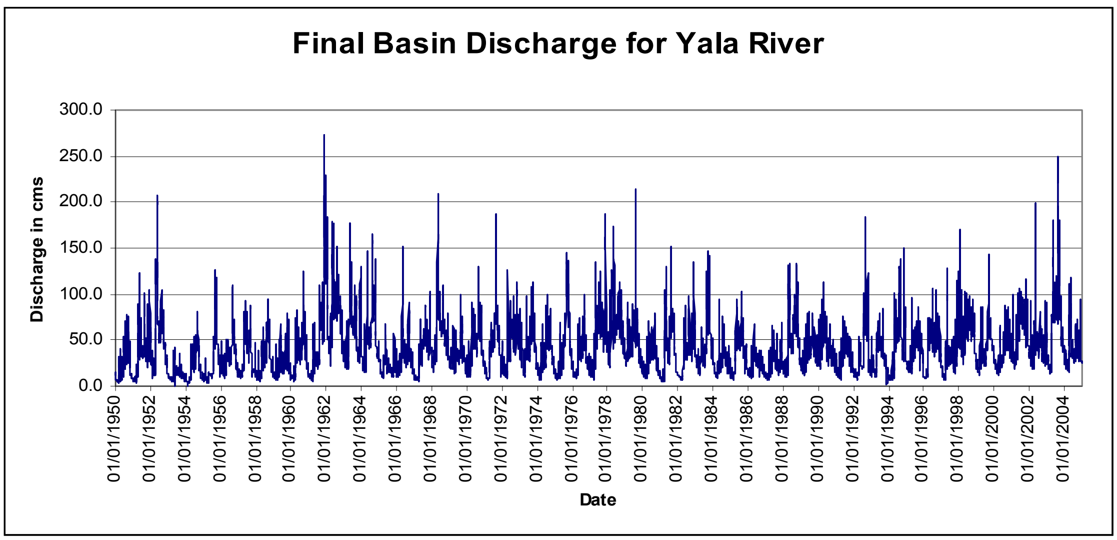


Figure ??…. Yala Basin Final Discharge increased by 1.40

Table …??…… shows the long-term average daily discharge from rivers **(M^3/s)**.

RIVER BASIN	**MEAN DAILY DISCHARGE 2000 – 2004 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2000 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2004 (M^3/s)**
SIO	9.1	11.4	11.5
NZOIA	112.5	115.3	118.7
YALA	47.8	37.6	39.3

N. AWACH	4.0	3.7	3.8
NYANDO	41.8	18.0	20.8
SONDU	41.8	42.2	43.3
S.AWACH	5.7	5.9	6.0
GUCHA MIGORI	38.8	58.0	57.9

Table ……

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sio	4.3	3.1	4.2	16.1	28.2	18.6	10.5	9.3	9.8	11.7	13.7	8.1
Nzoia	62.0	45.8	47.4	100.3	171.5	139.5	148.4	186.4	165.8	134.8	125.5	92.1
Yala	22.4	18.2	19.1	36.0	53.2	43.0	44.4	60.3	59.2	45.3	39.1	30.1
N. Awach	2.0	1.9	3.2	7.8	9.5	6.2	3.0	1.7	1.8	2.0	3.4	3.2
S. Awach	4.6	3.9	4.3	9.3	11.7	11.4	8.0	4.1	2.5	2.7	4.6	4.9
Nyando	15.1	9.3	9.9	32.8	46.8	22.8	21.3	25.9	21.1	12.7	17.4	13.3
Sondu	21.6	15.2	19.8	56.1	88.1	58.7	47.1	51.5	54.2	35.4	38.1	32.6
Gucha Migori	41.5	31.9	46.6	109.7	152.0	77.7	40.4	27.8	26.7	25.2	50.4	63.3

Figure ….shows mean monthly discharges for the Kenyan Basin ???

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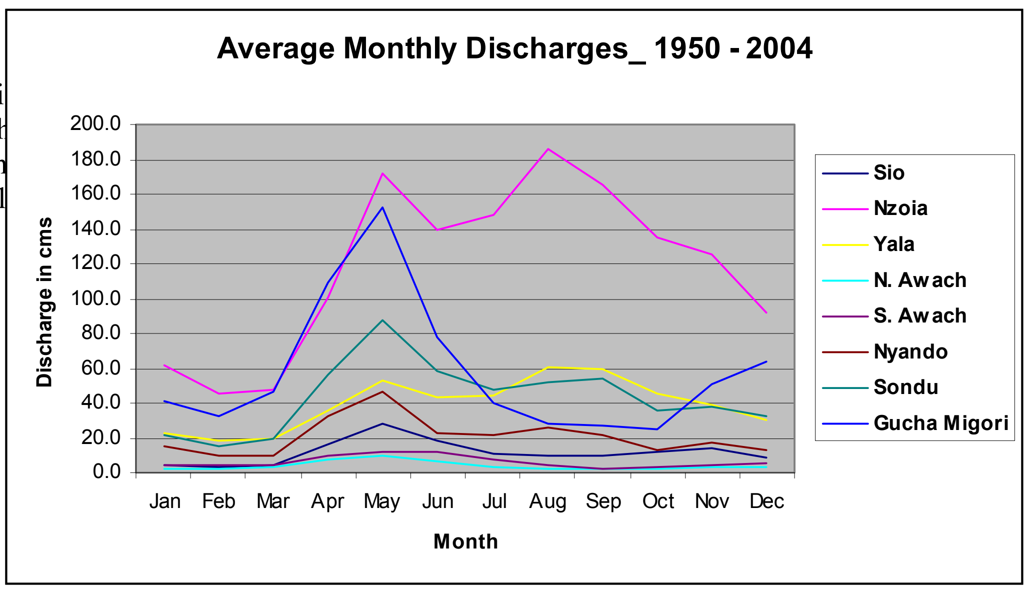
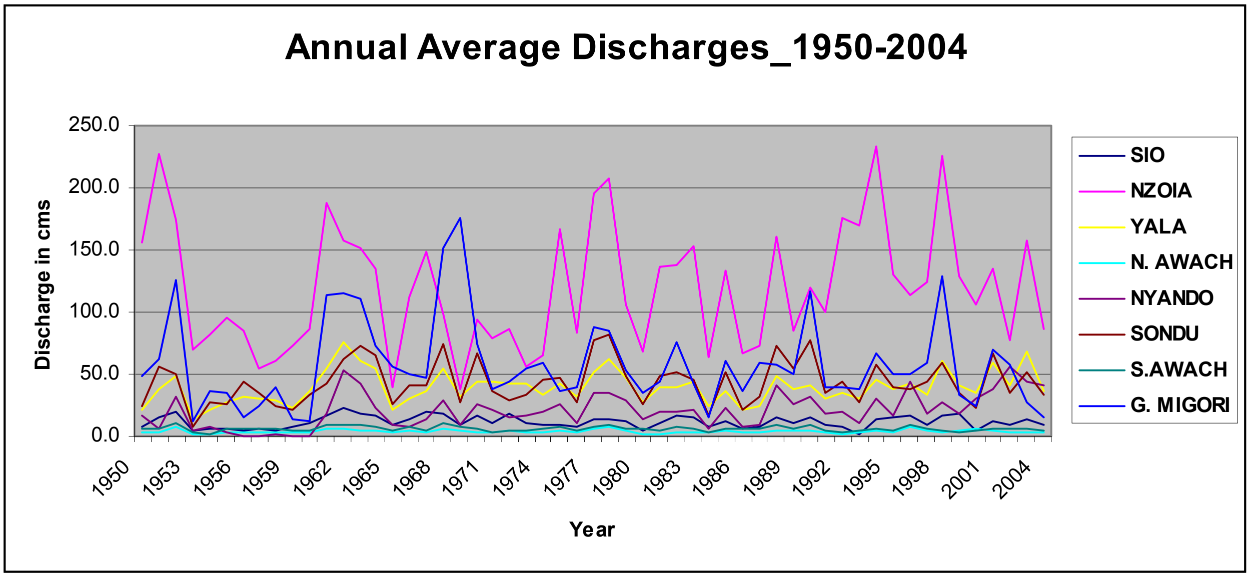


Figure …… Mean Annual Discharges ???

Also present data on runoff coefficient for each catchment i.e. discharge per unit area and discuss why they may be different in terms of the catchment characteristics. Also please comment on possibility that these runoff coefficients might have changed over time refer to Hecky et al in the special issue of the Journal of Great Lakes Research for possible discussion issues.



Conclusions and recommendations:

Conclusions (see comments above on topics to be covered in conclusion esp. concerning evidence of lack of evidence for trends in meteorology and hydrology).

- The method developed for generating discharge data is successful and quite ideal for use in such a study.
- Data gap filling techniques used have proved to be quite successful too.

    - Extension of rainfall and evaporation records by correlation to adjacent station
    - Insertion of typical evaporation data to fill gaps
    - Rainfall runoff modeling to extend discharge records.
- The time series of discharges rainfall and evaporation generated provides an important basis for water quality studies especially in assessment of pollution loads.

- The database so far generated in EXCEL spreadsheets is simple to understand and use in analytical work

- It is noteworthy and commendable that most of the currently operational meteorological stations are owned and run by agricultural based industries that have so far made a major contribution as a source of data to this study.

Recommendations:

- The institutional capacity of regional offices should be strengthened so as to continue filling data gaps with observed data and extending the studies.
- Capacity should also be increased so that more real/observed data is generated for the un-gauged catchment.
- There is need for further cooperation with private and quasi Government sector in data collection and dissemination.

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CHAPTER 3

Meteorology and Hydrology of the Lake Victoria Basin: Kenyan Sector

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ABSTRACT. *This study reports of the results of extensive field monitoring of river flows and lake levels, rainfall and evaporation. The study's aim was to elucidate main trends and periods of meteorology and hydrology as revealed by time series of rainfall, evaporation, river discharge and lake levels and which could be used as input towards computation of nutrient and sediment load introduced into Lake Victoria.*

Hydro-metrological data for the period running 1950-2004 were analysed and form the basis for computing the pollution loadings (catchment and atmospheric) into the lake and as well as calculation of the lake water balance. Continuous rainfall and evaporation records were applied and data gaps filled were necessary. Full records of land discharges were obtained from rainfall records using the NAM model. Model performance was evaluated on the ability to simulate the total flow for catchments, rather than the peak and minimum flows, for pollution estimation.

The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

INTRODUCTION

The association between hydrology and the eutrophication of the lake is the recognition that pollution loadings from the catchment of Lake Victoria are mobilized and transported in response to the hydrological cycle. In order to determine the dynamics of river driven pollution loading, it is important to first study the hydrological and meteorological behaviour of the whole catchment area, especially so in terms of rainfall, evaporation and river discharges which are inter-related. It is because of this need that this study has been undertaken by the Lake Victoria Environmental Management Programme's Meteorology/Hydrology task whose main duty is to determine an estimate of the total discharges to and from the lake on a daily basis. In addition this data contributes to determination of the regional water balance of the lake.

The study has been carried out through extensive field monitoring of river flows and levels, rainfall and evaporation through a network of existing stations with the aim of;

- Generating continuous daily evaporation records for the period 1950 – 2004
- Calculating discharges in the rivers on the basis of rating curves and measured gauge heights.
- Performing Rainfall – Runoff Modelling to extend and fill gaps in river discharge records from 1950-2004.
- Calculating final discharges for each individual river catchment or basin.

This is a follow up of what LVEMP had done earlier in developing an initial estimate of the total water balance from 1950 to 2000. In the earlier estimate; a lot of gaps in data were noted and the NAM Rainfall-Runoff model was used to fill these. It was therefore expected that actual observed data would be collected thereafter so as to induce more reality in the analysis and hence results of the study. To a large extent, this has been achieved and where difficulties have been experienced in getting observed data, methods which had been developed during the earlier study including correlation of existing stations to nearby stations by mass curves were engaged especially in filling rainfall gaps. Much about this will be mentioned later on in this paper.

This study reports of the results of extensive field monitoring of river flows and lake levels, rainfall and evaporation. The study's aim was to elucidate main trends and periods of meteorology and hydrology as revealed by time series of rainfall, evaporation, river discharge and lake levels and which could be used as input towards computation of nutrient and sediment load introduced into Lake Victoria.

In methodology section, the manner in which the series were generated is discussed. The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

Study area

The study area is all that Kenyan catchment area in which all rivers flow into Lake Victoria. This is the area from which rivers carry water, nutrients, sediments and pollutants into the lake and covers about 42460 km^2 on the Kenyan side (Fig. 1).

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.

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.

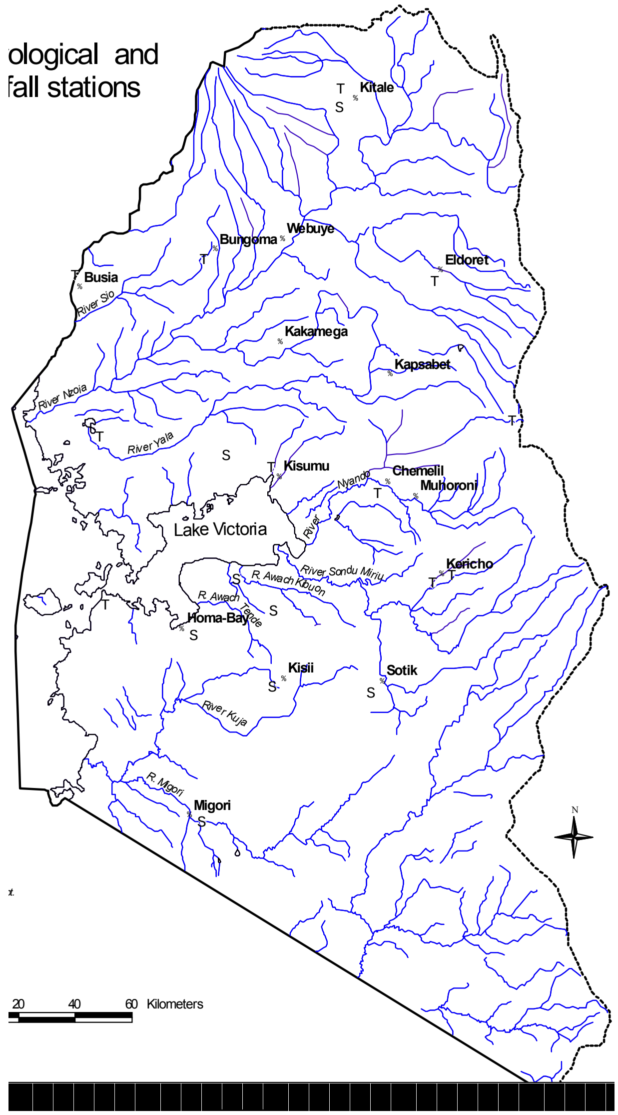


FIG. 1. Meteorological and rainfall stations.

Methods

To meet the objectives of this study, the following methods are used;

Hydrology

Between the years 2000-2005, over 950 river discharge measurements were done on 52 selected river-gauging stations all over the catchment.

Three methods were used to obtain discharges;

4. The conventional current meter 'mid-section' method was used. In this case, the river section is divided into approximately twenty (20) segments in which velocity, depth and width are measured and then the formula

   $$Q = AV$$

   is applied for the calculation of discharge.

   Where Q = Discharge in m^3s^{-1}
   A = Wetted cross-sectional area in m2
   V = Velocity in ms^{-1}
5. A modern and more convenient and safe method in deep and wide sections of rivers was the use of Rio Grande Acoustic Doppler Current Profiler (ADCP) which outputs discharge results directly.

6. The Float and Flume method, used where the above equipment was not available, is a simple manual method conducted on a reach with perceived uniform cross-section and flow.

Rainfall Runoff Modeling

River discharges were also computed from time series of rainfall and evaporation using the NAM model (Danish Technical University). This is a lumped model run on excel spreadsheets which assumes a single unit with homogenous characteristic of the flow throughout the system. The model was applied to daily values of rainfall and evaporation series (1950-2004). The manner in which the rainfall and evaporation series were generated is explained below.

Rational formula

The following rationale formula was applied to compute runoff in ungauged basins around the lake shore:

$$Q = CA(R - K)$$

Where

Q = flow in m^3/s,
C = constant coefficient,
A = catchment area in km^2,

K = lumped rainfall loss parameter which also acts as a monthly threshold value for the generation of Q and

R = autoregressive weighted monthly rainfall.

This model was particularly useful in obtaining runoff for the clustered river systems such as the North Awach catchment comprising of rivers Nyamasaria, Awach Seme, Kisian and Murguruge and the South Awach catchment comprising of rivers Awach, Tende and Awach Kibwoun.

Rating Curves

Using discharge measurement data collected at the principal stations along the major rivers within the catchment during the period 2000-2004, rating curves have been generated using a simple EXCEL Macro spreadsheet with appropriate formulas (Fig. 2).

Quality control measures include comparison with the conventional "hydata generated" curves at the Ministry of Water and Irrigation Headquarters in Nairobi and comparison with observed discharges (Fig. 3).

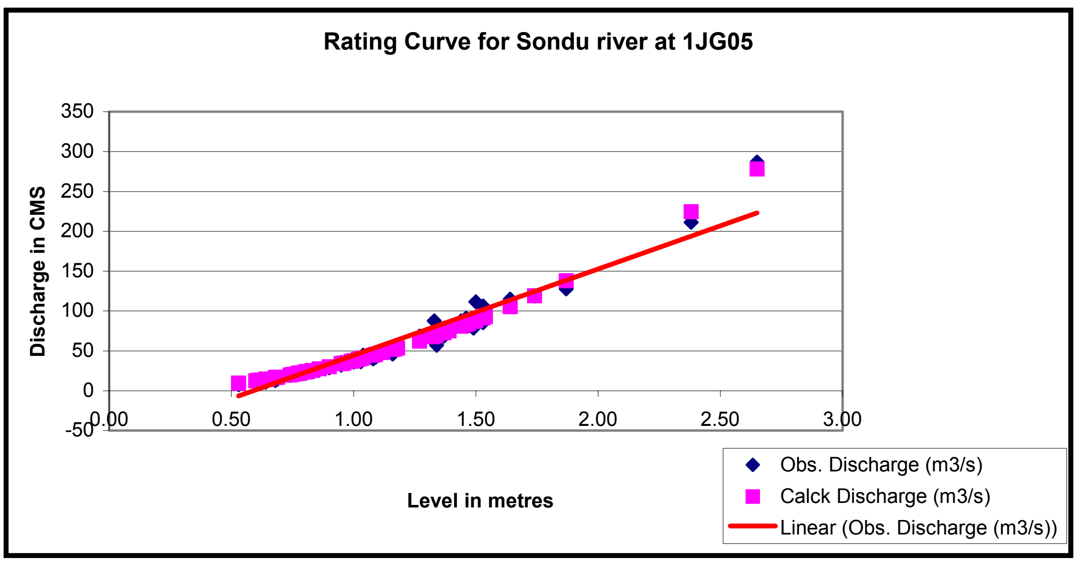


FIG. 2. Rating Curve generated for Sondu River

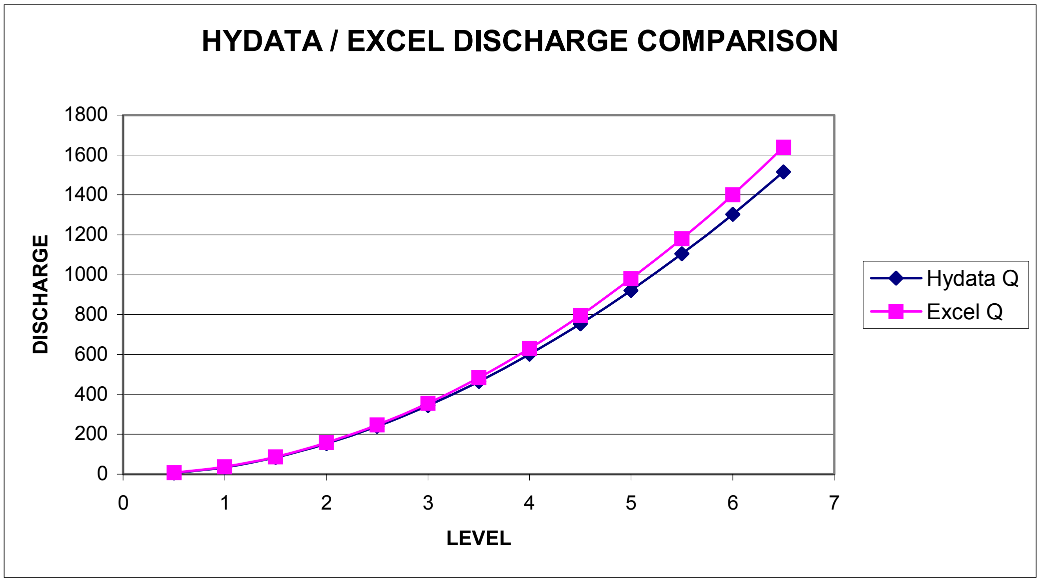


FIG. 3. Comparison of EXCEL and HYDATA generated rating curves.

River and lake water levels were gathered using the manually read staff gauges and the modern digital data loggers located at the principal stations shown in Table 1.

TABLE 1. Shows the principal stations used in this study

River Basin	Basin Area (Km^2)	Gauging Station		Catchment area U/S of station (Km^2)	Type of Station	Remarks
		Reg. No.	Location/name			
SIO	1450	1AH01	MUNDIKA	1450	STAFF	
NZOIA	12,676	1EF01	RWAMBWA	12,676	STAFF & LOGGER	
YALA	3,351	1FG01	YALA TOWN	2,388	STAFF & LOGGER	
NYANDO	3,652	1GD03	OGILLA	2,625	STAFF & LOGGER	
NORTH AWACH	1,985	1HA09	NYAMASARIA		STAFF	
		1HB05	AWACH SEME		STAFF	
SOUTH AWACH	3,156	1HE01	AWACH TENDE	585	STAFF	
		1HD09	AWACH KIBUON	536	STAFF	
SONDU	3,508	1JG05	SONDU MARKET	3,287	STAFF	
GUCHA-MIGORI	6,600	1KB05	WATHONGER	6,600	STAFF & LOGGER	
LAKE VICTORIA		1HB04	KISUMU	-	STAFF & LOGGER	

Rainfall

As a follow up of an earlier study (LVEMP 2002), most of the rainfall stations representing individual river catchments have been retained. In a few cases, where some stations have been decommissioned, nearby stations with the required data have been adopted in this analysis (Table 2).

TABLE 2. Rainfall and Evaporation stations used in the study

River Basin	Station Number	Name	Rain/Evap	Reference Station for correlation
Sio	8934161 N/R 8934161 N/R	Alupe Nzoia Sugar, Bungoma Alupe Nzoia Sugar, Bungoma	R R E E	
Nzoia	N/R 8935133 8834098 8934140 N/R 8935133 8934140	Nzoia Sugar, Bungoma Eldoret Kitale Kadenge Nzoia Sugar, Bungoma Eldoret Kadenge	R R R R E E E	
Yala	8935133 8934140 9034011 8935133 8934140	Eldoret Kadenge Maseno Eldoret Kadenge	R R R E E	
Nyando	N/R 9035244 9035263 9034025 9035263 N/R	Chemelil Sugar Co. TRI Kericho Tinderet Tea Estate Kisumu Met Tinderet Tea Estate Chemelil Sugar Co	R R R E E E	
North Awach	9034025 8934140 9034011 N/R	Kisumu Met Kadenge Maseno Icipe, Rusinga	R R R R	
South Awach	N/R 9034084 9034018 9134009 9034139	Icipe, Rusinga HomaBay Gendia Muhuru Ringa, Oyugis	R R R R E	
Sondu	9035244 9035013 N/R 9035244 N/R	TRI Kericho Sotik Chemelil Sugar Co TRI Kericho Chemelil Sugar Co	R R R E E	
Gucha Migori	9134025 9134009 9034092 9134009 9034092	Migori Muhuru Kisii Muhuru Kisii	R R R E E	

At these stations, daily data is generated as an input into the rainfall-runoff model for generation of discharges. All rainfall measurements have been subjected to quality control checks to identify erroneous data i.e. by visual examination of raw and plotted data, calculation of statistical means, maximum and minimum, comparison with data from adjacent station and calculation of accumulated mass curves. Gap filling has been done by correlation to adjacent stations for the few cases where it is necessary. This is done by taking close stations with longest data where a double mass curve is evaluated for the subject station and the reference station, a trend line fitted to the curve after which the resultant equation is applied to fill gaps in the subject station (Figs. 4-6).

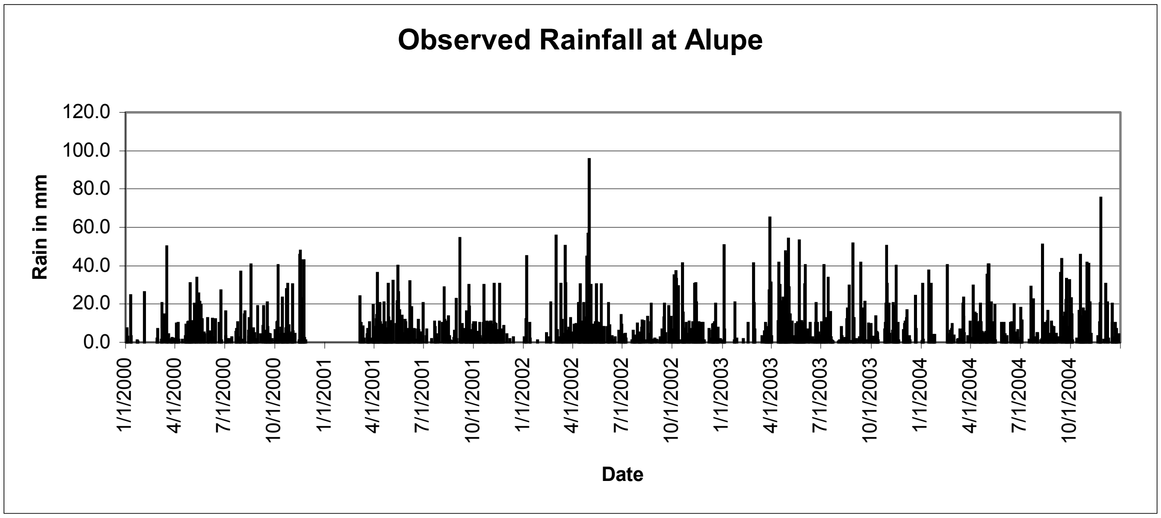


FIG. 4. Observed rainfall at Alupe from January 2000-December 2004 (with one month missing)..

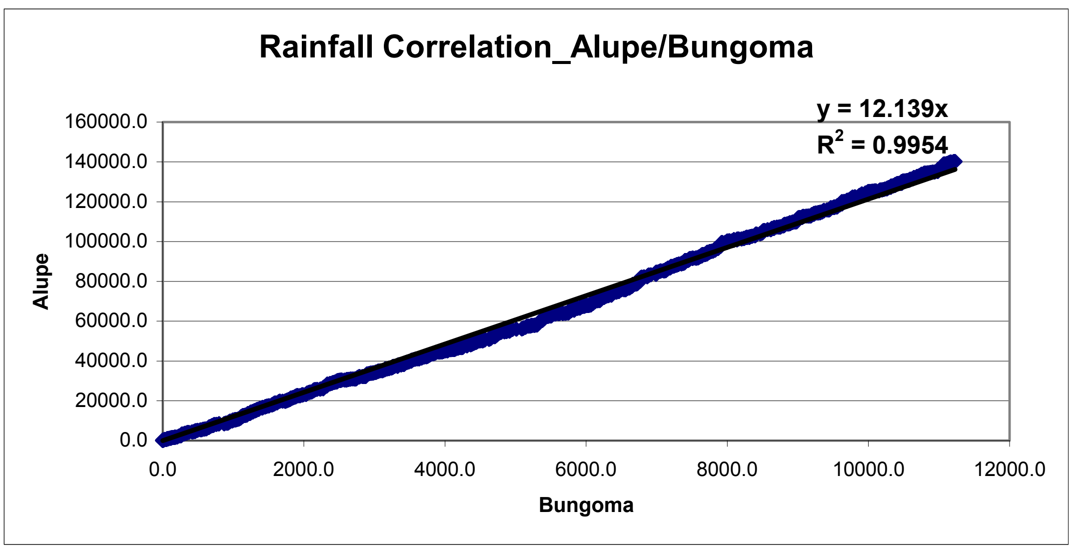


FIG. 5. Linear correlation and regression between Alupe and Bungoma rainfall.

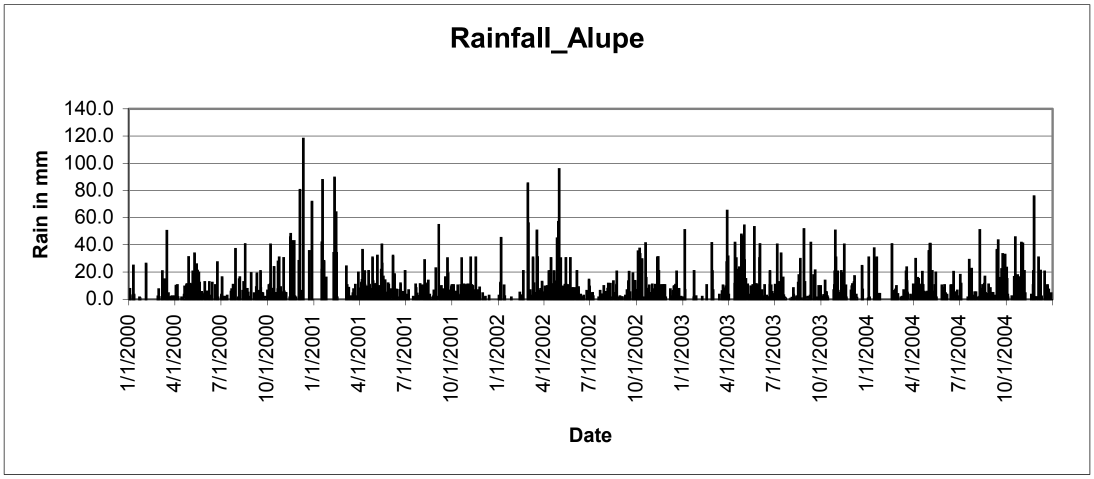


FIG. 6. Final rainfall for Alupe after filling the gap in 2001.

The earlier method of gap filling using typical wet, dry and average years (LVEMP 2000) is not applied here as the gaps are not more than a few months in a year.

From the year, 2000, the study was as much as possible based on observed data, but due to circumstances beyond our control, it was not possible in all cases. We therefore had to depend somehow on stations that are owned and run by other organizations/institutions. In a few cases, some stations that were used in the earlier study were completely abandoned or closed and this forced us to identify nearby existing and reliable stations that could be used for generation of the data. In this study therefore, we have generated daily rainfall data from 2000 to 2004, which is an extension of the earlier study done by LVEMP (2000) covering the period 1950 to 2000. Fig. 6 is an example of a rainfall series for Alupe in which gap filling has been done.

Evaporation

In general, this study has experienced difficulties in obtaining meteorological data because the weather stations that were proposed for installation have not been delivered on time.

Furthermore, observed data generation for 2000-2004 was mainly handicapped by the closure of most evaporation stations within the Lake Victoria catchments due to lack of operational funds by the various institutions that were operating them.

In principle, the method for development of continuous evaporation record is the same as that of rainfall. However, because of the fewer number of evaporation stations, correlation to adjacent stations may be irrelevant since wide distances between may cause some differences.

Some evaporation data is measured at full meteorological stations, most of which are still operational. Daily mean evaporation was therefore used to fill gaps in site records because there is no defined method of choosing evaporation values for typical wet, average and dry years. Fig. 7-8 gives evaporation series for Kitale during 2000-2004 before and after gap filling; this was done by use of average daily evaporation observed over a period of 7 years.

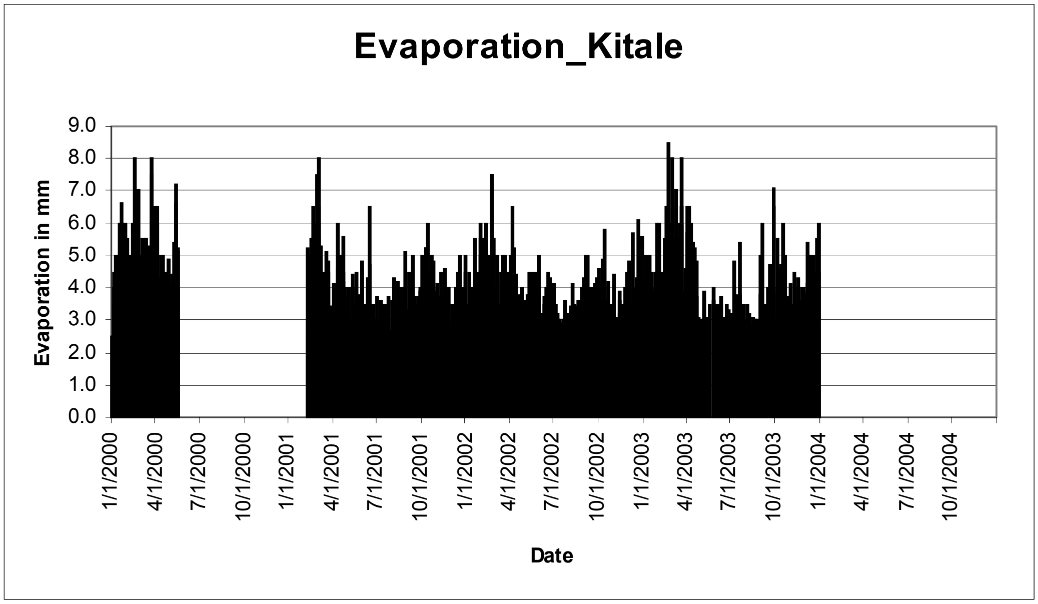


FIG. 7. Observed evaporation at Kitale with gaps.

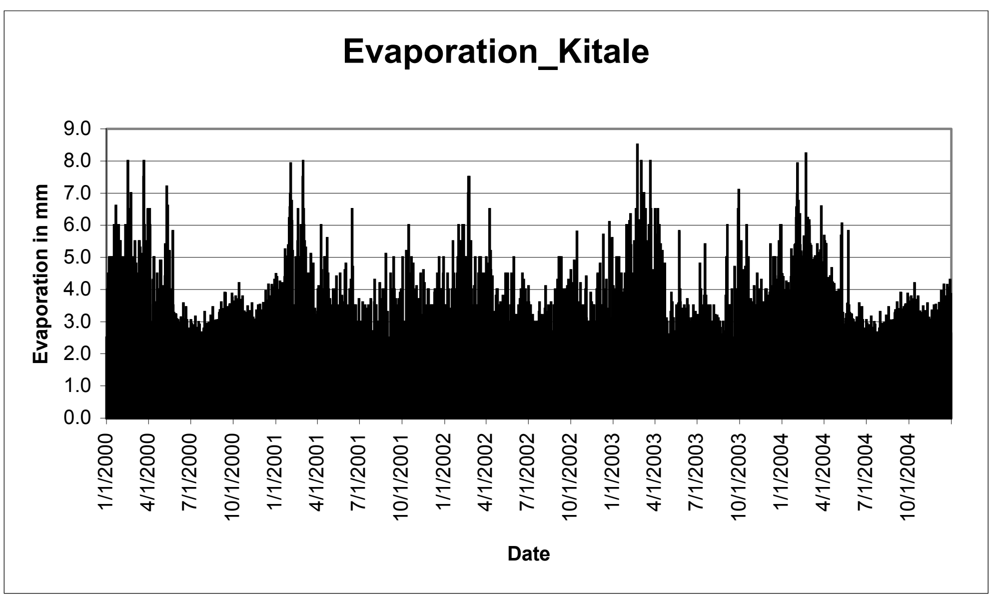


FIG. 8. Final evaporation for Kitale after gap filling by use of average daily evaporation observed over a period of 7 years.

River Discharges

Because the main interest of this study is to assess the discharge of water to the lake and to compute pollution loads, it is important to concentrate on the discharge at or near the river mouth. Rating equations have therefore been developed in a simple EXCEL MACRO using the standard formula:

$$Q = k(h - h_0)_x$$

Where,

Q = river discharge (in m^3s^{-1})
k = coefficient
h = gauge height (m)
h_0 = gauge height at zero flow (m)
x = exponent of rating curve

For quality control, a visual examination of a flow/level plot is considered sufficient to remove erroneous data. The river discharges have been computed by applying the rating equation to the daily gauge heights (see Fig. 9). Gaps in records are subsequently filled by the rainfall-runoff modeling.

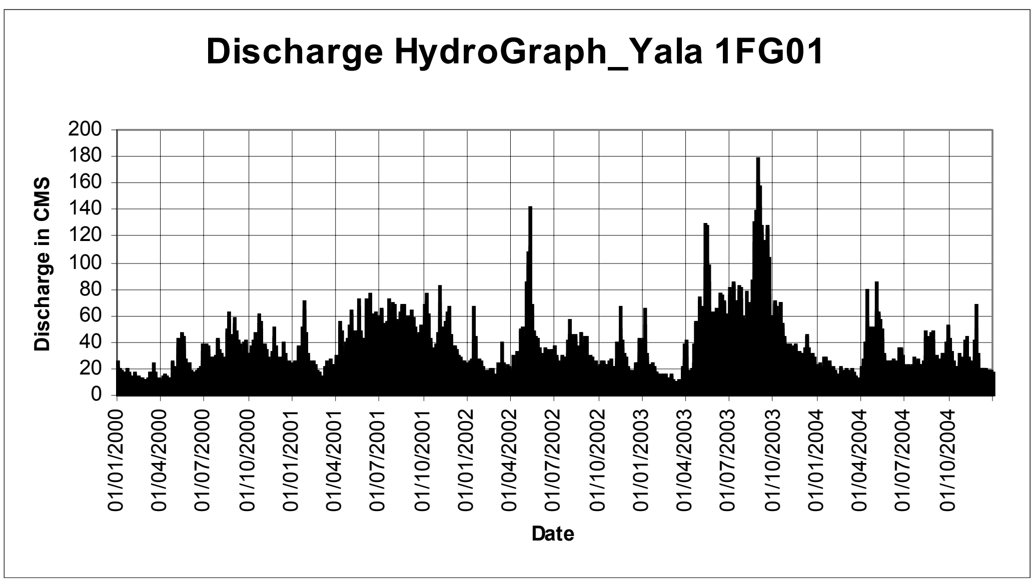


FIG. 9. Discharge hydrograph for River Yala after computation of discharges by applying the rating equation.

Rainfall Runoff Modeling

Modeling is used to fill gaps in discharge record and in this study; it has been applied in a few instances where gauge readings were not available either due to vandalism, damage or loss of gauge, lack of a reader or data logger failure. An example of discharge data gaps is shown in Fig. 10.

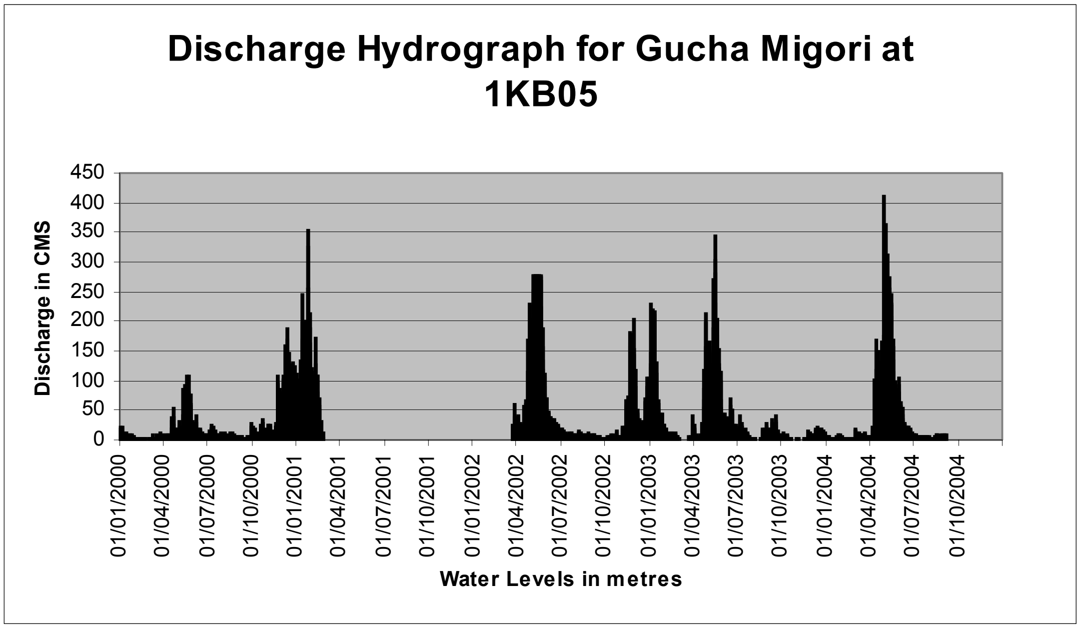


FIG. 10. Discharge hydrograph of Gucha River with gaps.

The LVEMP Water Quality and Ecosystems Component in Kenya has adopted the NAM model, (a conceptual model) which originates from the Danish Technical University. In this model, the entire catchment is lumped and assumed to be a single unit with uniform characteristics, the flow of water through the system conceptualized into a number of reservoirs and the parameters partly reflect the physical properties of the catchment.

Model calibration (see LVEMP 2000) is done by use of at least 4 years of simultaneously measured rainfall, evaporation and discharge data. The model parameters are adjusted by trial and error until the best fit is observed between modeled and observed discharges in terms of accumulated runoff from the catchment, peak flows, recession curves and low flows (Fig. 11).

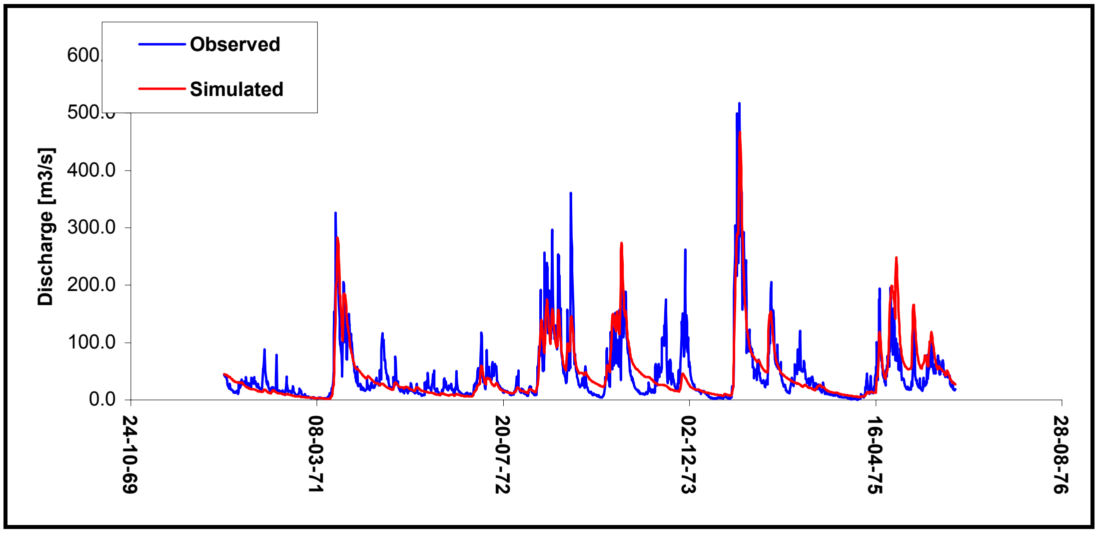


FIG. 11. Model and observed results for Gucha River from 1969-1976.

Model application is accomplished by applying the calibrated model to compute runoff at the station for the full period of 1950-2004 (Fig. 12). In this application, the final rainfall and evaporation generated for the full period is used for calculation of the water balance (Chapter 3 of Regional Report).

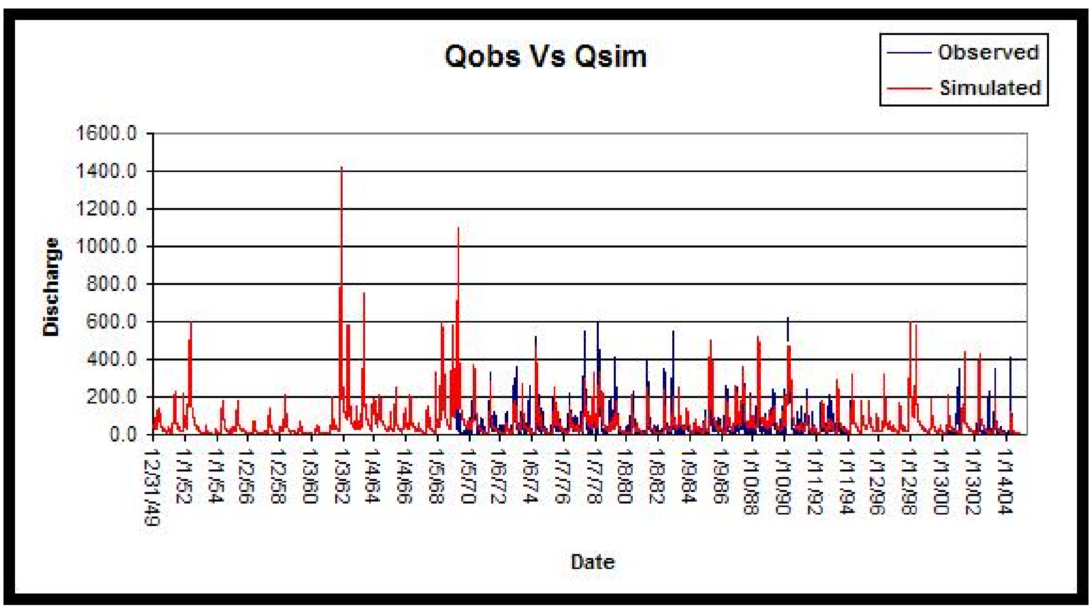


FIG. 13. Model application as accomplished by applying the calibrated model to compute runoff at a station for the full period of 1950-2004.

Some catchments and basins around the lake largely remained ungauged and have been lumped into composite basins consisting of small rivers and wetlands along the lakeshore for the purpose of estimating water inflows.

On the other hand, some of the rivers in these areas have been gauged but the data available neither sufficient nor representative of the whole basin area. In Kenya, there are two such areas namely the North Awach, which comprises of rivers Nyamasaria, Awach Seme, Kisian, Murgut, and other smaller ones and the South Awach comprising of River Awach Tende, Awach Kibwoun and other smaller ones.

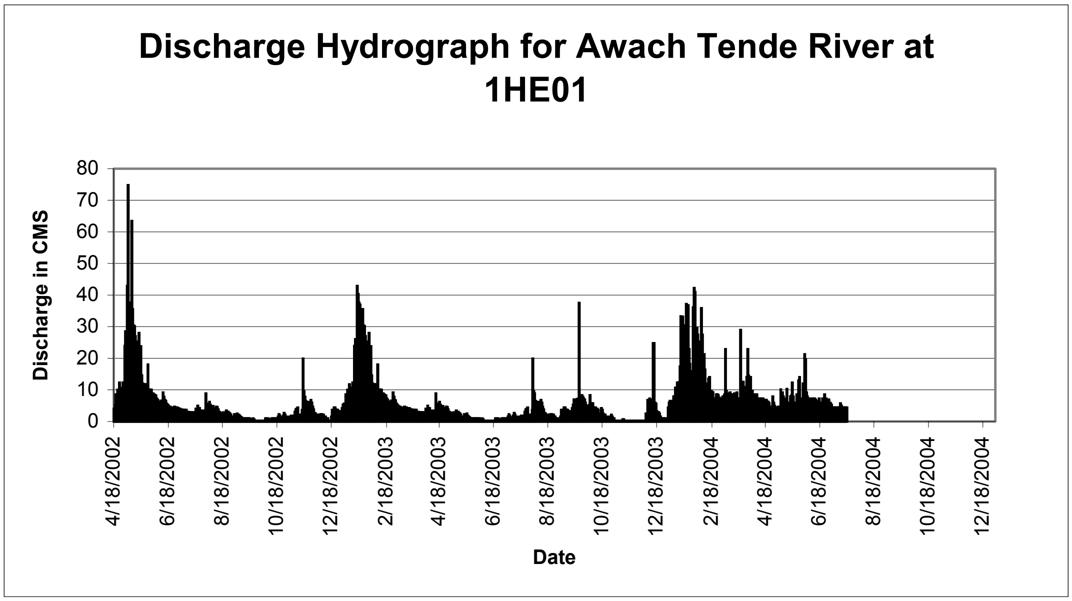


FIG. 14. Insufficiency of the data collected on one of the small rivers-Awach Tende.

In this case therefore an empirical model was applied to simulate monthly flows using parameter values from an adjacent similar catchment. The model is an application of the rational formula mentioned above.This has been tested with monthly rainfall and discharge data in Nzoia, Sondu, Kibuon and Sio River basins and a good fit was obtained.

RESULTS

Rainfall

In this case, a rainfall record for 1950-2004 at each station was generated. Fig. 15 gives an example of such a rainfall record for the Kericho station. Since a time series of rainfall data representative for a river basin is required for use in the rainfall-runoff models, it is generated as a weighted mean of the selected station in the basin. Weighting of each station is dependent on the proportional area assigned to the station and on the rainfall characteristics.

In Kenya, two prevalent zones are considered i.e. the low flat area near the lake and the high altitude area with irregular topography in upper reaches of catchments. The weighting therefore takes into account the different physiographic characteristics of these areas.

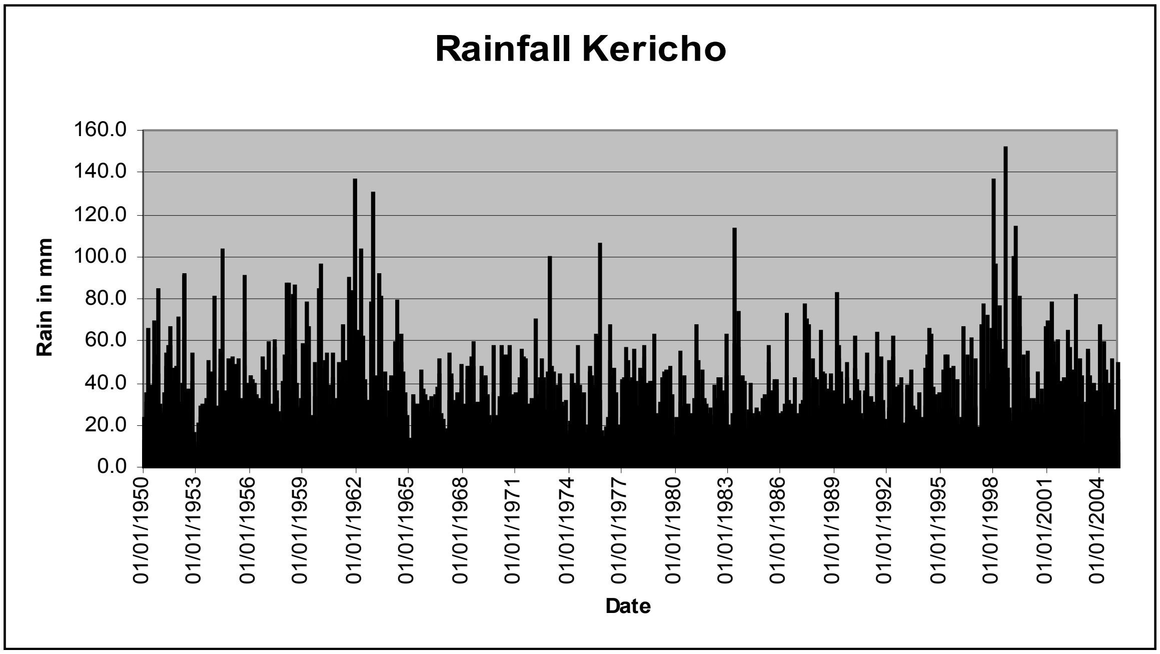


FIG. 15. Time series of rainfall data for Kericho for the period 1950-2004.

Meteorology trends in Lake Victoria basin

This study established wet and dry seasons to occur in March to May and October to November respectively (Fig. 16). Mean monthly rainfall maxima are recorded in April (213 mm) and November (345 mm). The driest months are observable during January and December. Fig. 17 shows rainfall totals over the years 1950-2004; it indicates that the driest years were 1953 (1180 mm), 1959 (1183 mm) and 1984 (1230 mm). Conversely, the wettest years were recoded in 1961 (1749 mm), 1968 (1761 mm) and 1977 (1775 mm). An autocorrelation function was produced to detect the repeat cycles of dry or wet years; however, this did not show any significant correlation at 95% confidence intervals.

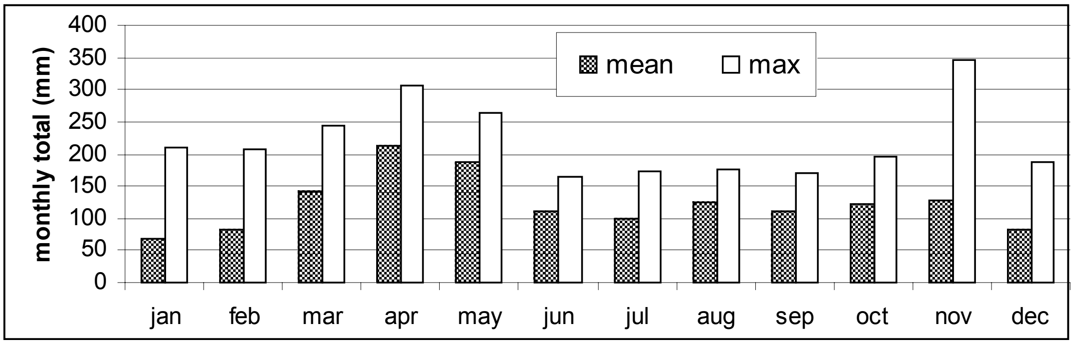


FIG. 16. Mean and maximum monthly totals of rain in Lake Victoria.

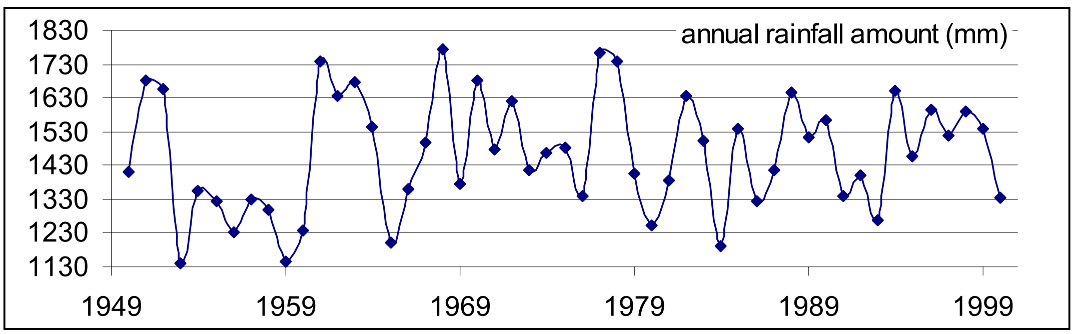


FIG. 17. Yearly total of rain in Kenya catchments of Lake Victoria.

Spatially, less rain falls near the lakeshore than upstream of the catchment (Fig. 18.). Over the years of record, it can be seen that the highest amounts have been recorded consistently in Alupe, Kisii and Kericho area. Alupe lies on the southern foothills of Mt. Elgon, while Kisii and Kericho lie on the peak of Manga hills and Mau ranges (at altitudes greater than 2000 m a.s.l) respectively.

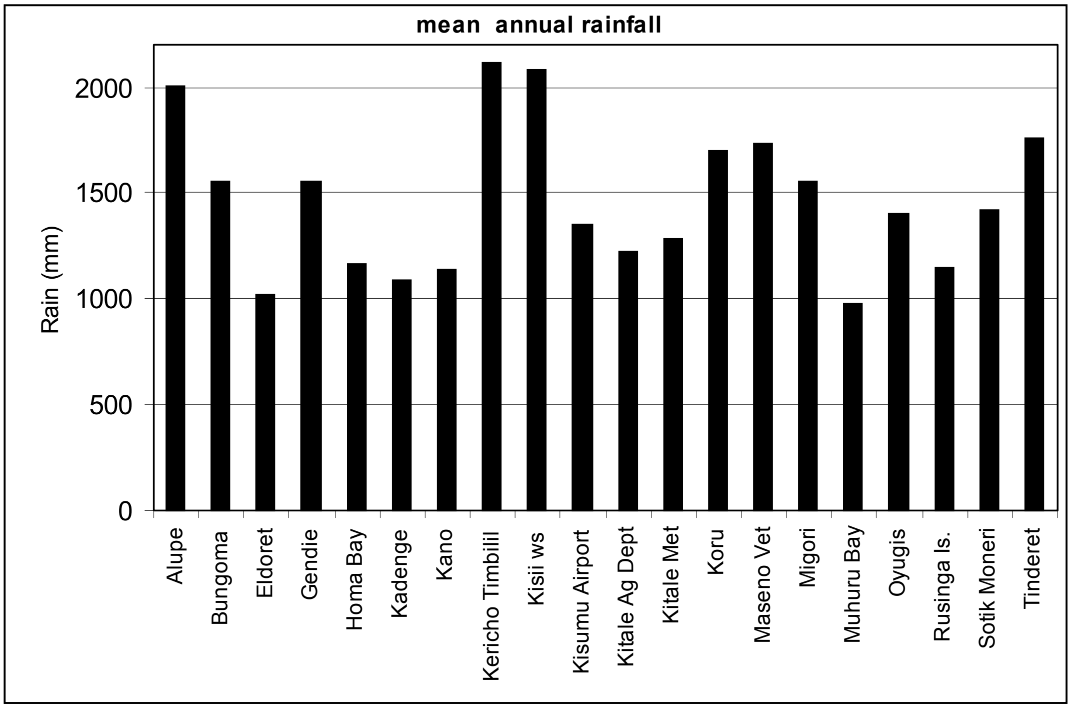


FIG. 18. Mean annual rainfall for stations in Kenyan Lake Victoria basin.

LVEMP period compared to 50-year record

By plotting on the same axis the first 60 monthly totals of each decade, the LVEMP period of record was compared to 50-year record to determine how representative it was of the longer period. Criteria for choosing the first sixty months were based on the fact that, this is the length of the period LVEMP has been collecting data. Fig. 19 and Fig. 20 shows there is no significant difference between decades in both upcountry (Kisii) and lakeshore (Kisumu) rainfall. Wet and dry months seem to occur at the same time as in every other decade. Rainfall totals for the months in the different decades do not seem different either. It was further shown that autocorrelation coefficient function for different decades have not changed significantly (Table 1 for Kisii station) which shows within decade autocorrelation coefficient as being strongest in the decade of the nineties and that of 60s which respectively gave a recurrence of 2 and 6 months period. H.M. Njuguna (pers. commun.) has found that rainfall of the 1960s and late 1970s was highest over the last half century. This is well reflected in the long term records of lake levels discussed later in this chapter.

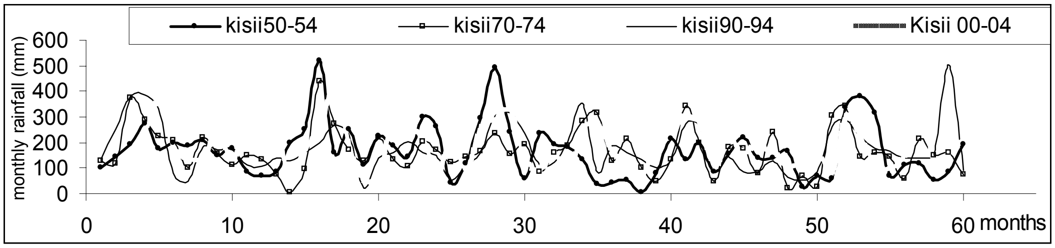


FIG. 19. Kisii station first sixty months of each decade monthly rainfall.

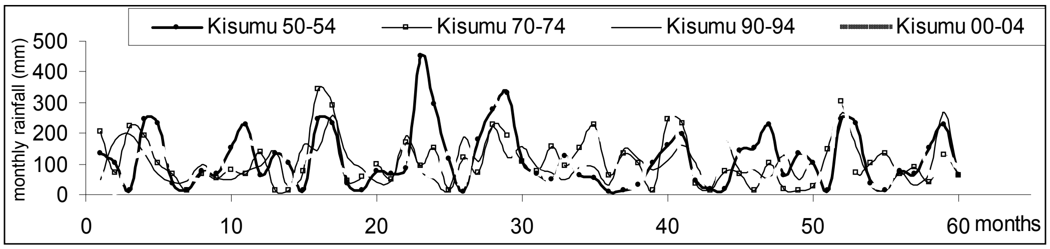


FIG. 20. Kisumu station first sixty months of each decade monthly rainfall.

Flow occurrence between decades

Total monthly flow for each decade was plotted for two rivers; Nzoia and Nyando (Figs. 21 and 22). This was done to assess whether wet and dry events occur at the same months and whether there is any significant difference in their magnitude. Nzoia depicts a regular recurrence of wet and dry seasons among the three decades though the nineties' wet season seems to have a longer duration than those of previous decades (Fig. 21). Nyando River also seems not to have had any significant difference in the frequency of wet and dry months occurrence, though the magnitude of the fifties appear smaller than the rest (Fig. 22). To assess which months among decades had close association, a cross partial correlation coefficient was computed. It can be deduced that for Nzoia River, the sixties and nineties were found to be significant after every 8, 10 and 14 months (95% confidence interval). Inter-decades analysis showed that a weak but nevertheless significant autocorrelation was present in the seventies after every 8 months, while the other two did not show any.

Nyando within decade autocorrelation was found significant after every 3 months for fifties, 4 months for sixties, none for seventies, 3 months for eighties and 8 months for nineties. Cross correlations between decades were found significant for month of fifties and sixties after every 5, 7 9 and 12 months and between eighties and fifties were strongest after every 6 months. Nineties and seventies and nineties and fifties were significant at 11 and 7 months respectively.

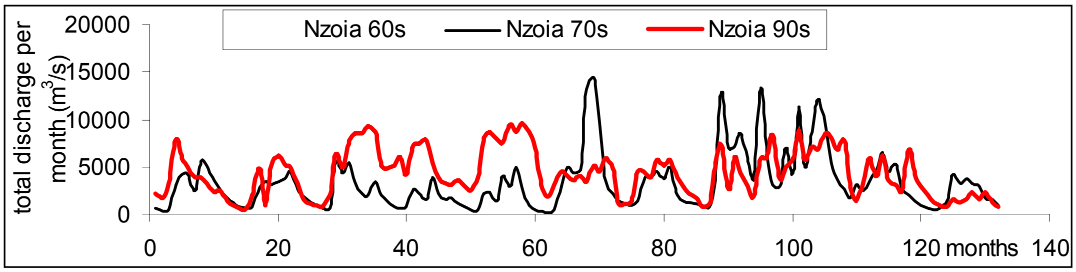


FIG. 21. Monthly Nzoia discharge compared for different decades.

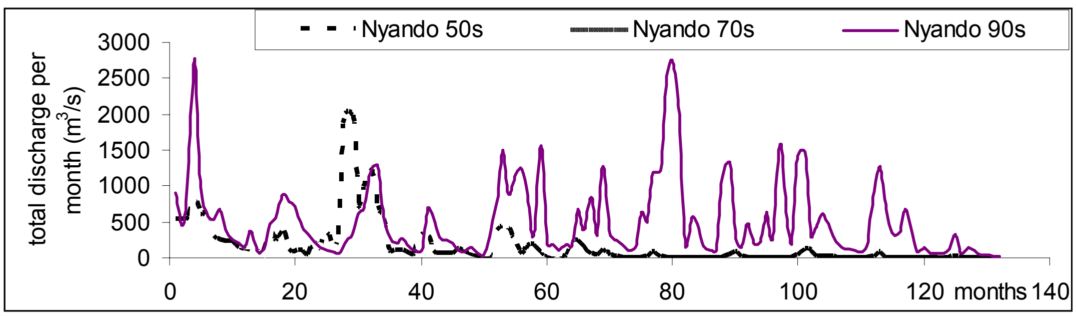


FIG. 22. Monthly Nyando discharge compared for different decades.

Lake level fluctuation

The mean lake level variability is dominated by a decreasing trend as reflected by Fig. 23, in which a high stand of 2.9 m has fallen to a low of 1.8 m (above datum); reflecting a fall of 1.1 m. Consistenct with rainfall records, water level peak is observed every May after that of peak rainfall in April, and a slight increase recurs in December. The lowest levels are measured in October and are usually about 18 cm above mean annual lake level. The months of May, June, July, January and December were found to be above mean annual lake level that has been computed as 2.45 m over the period of record. On a daily basis, highest water levels are observed at 1800 hours (6:00 p.m.) while the lowest are at 0200 and 0400 hours in the morning. Despite the seasonal rains experienced in the region, it has not been possible to restore the lake to year 1999 levels experienced after the El Nino events of 1997-1998. This means that 1997-1998 were exceptional years.

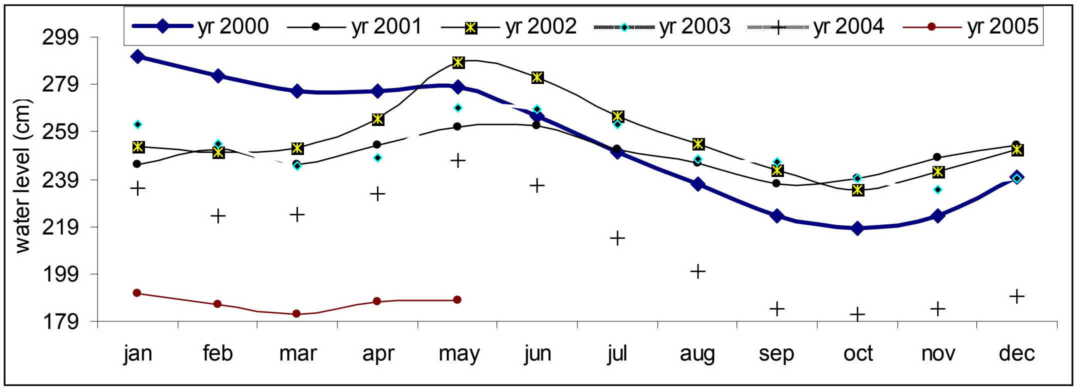


FIG. 23. Mean monthly lake level during LVEMP period.

At the level gauging site, water temperature has been on a rising trend since the year 2000 (Fig. 24). The highest rate of temperature increase occurs in the months of September and October while the rest of the months show a steady increase of 0.1 ^{o}C. The lake temperatures measured are apparently too high, probably because the level recording site is in protected and shallow water.

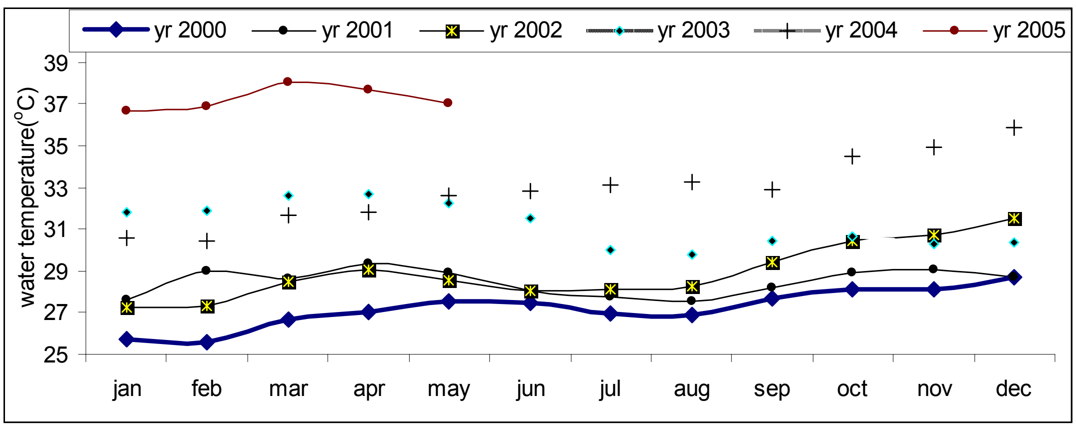
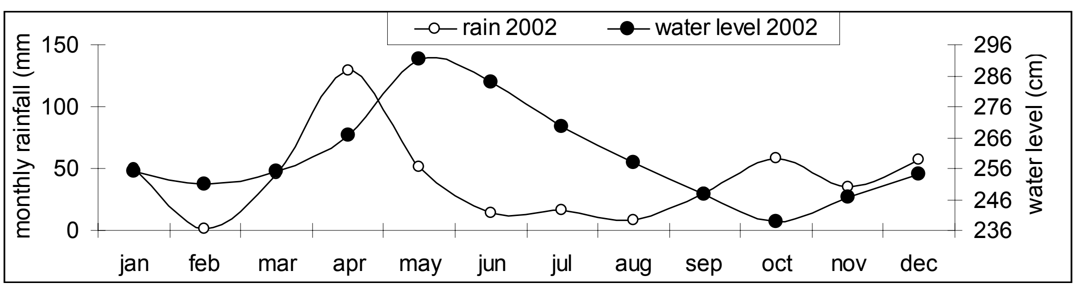


FIG. 24. Mean monthly water temperature at level gauging station.

Lake level and rainfall relationship

Reformat below

It has been acknowledged that rainfall over the lake as well as in its watershed are the fundamental causes for the accumulation of water in the lake (EAMD, 1974) and it is therefore expected that variations in the component rainfalls should be reflected in the lake level fluctuations. Peak rainfall and lake level are observed in April and May respectively. This was examined by cross-spectral analysis between the lake level and the rainfall series. Lake level lags the rain signal by a mean of 42 days emphasizing the peak occurrence of rain in April and that of the lake in May. An unusual phenomenon may have occurred b in May 2004 in which a sudden profound fall in lake level is observable in Fig?. Data of Yala swamp (where is this figure/data)show the rain signal to be dominated by a non-seasonal decaying exponential trend in which rain decreased from 1.47 to 0.695 mm per day (length of record October 2001 to December 2004). Fig ? shows the falling trend of the rain to be accompanied with reduced variability of the rain in subsequent years compared to initial years when the automatic Meteorological Station was installed. On a decadal scale, Fig current 11??? suggests a ten-year cyclic fluctuation. Others are 5.25 and 13.7 in decreased order of variance contribution. The results further show the lake level to have decreased from 2.97 in 1964 to 2.47 in 2004 a decrease of 0.5 m. EAMD (1974) observe that the highest peak was recorded in May 1964 and that level has not been recorded since the beginning of the century and monitoring records. The Lake level was lowest during May 1922 to April 1923 Compared to the 41 year record of 1923 to 1964 in which the lake experienced a rise of 2.57 m, and 2 m during 1961 to 1964 alone, the fall of 0.5 m over 40 years (1964 to 2004) is insignificant and therefore the lake is yet to resort back to previous low levels recorded prior to 1923. Kisumu's rainfall record at its airport from 1950 to year 2000shows the main component is low frequency additive season with no trend that has cyclic rain events lasting 17 years. The floods of 1997-1998 (1375 mm) were severer than those of 1961-1964 (1364 mm what are these data ? elevation change' rainfall? This section is hard to follow but important; please review for clarity) and those of 1978 -1979 (1347 mm). High frequency cyclic rain events were observed every 3.4, 8.5 and 5.1 years in that order of strength.



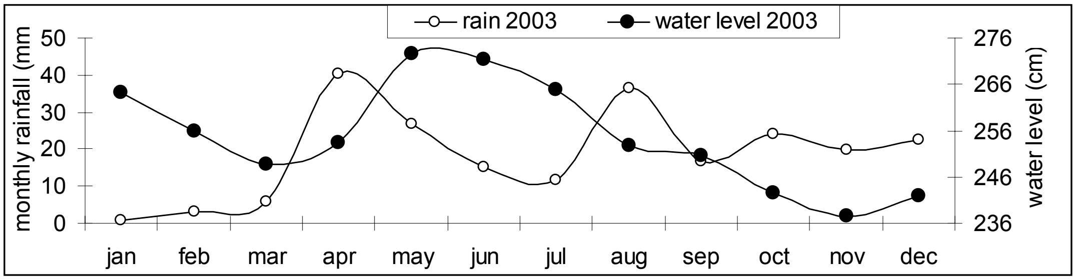


Figure ?? water level and rain signal co variation reflecting the one month lag between them

Rainfall / Run off relation

Rainfall is expected to generate run off that is reflected in the river discharge. Fig ?? shows a plot of the partial autocorrelation function of the series Kisumu rain and Nyando discharge for year 1990-1994 taken to represent this scenario. This section is very important yet it seems incomplete in presentation and is not mentioned in the Discussion below!! Is it possible to compare moden annual catchment rainfall and annual discharge (with appropriate lags if necessary) for Kenya catchments with historic data. It is often observed that land clearance for agriculture changes the rainfall-runoff relation and this in itself can cause increased sediment and pollution record. We need to examine this closely. It also can explain tendency to more severe flooding. Please comment on the stability of the rainfall-runoff relation over time or say that the data are inadequate to do such an analysis which would be unfortunate.

Rain over Lake Victoria

This represents the largest inflow of water to the lake. Just like in the earlier COWI/LVEMP study there still exists an insufficient number of rainfall stations over the lake area. With knowledge on the wind patterns, it follows that rainfall is highest along the West Coast followed by the North and lowest on the South. This has enabled estimates based on the few rainfall observation along the shore and on the islands. COWI REPORT make sure this is referenced (Pg. 69) Figure shows the rainfall stations in the lake basin used to estimate over-lake rainfall with their mean annual rainfall based on measurements above, their corresponding isohyets and divisions of the lake into a number of boxes that form the basins of estimating total rainfall over the lake. Each rainfall "box" has a reference rainfall station. Where mean rainfall is estimated on the basins of isohyetal curves respectively.

The daily rainfall in each box is calculated sing $R\ box = R\ ref^{*}\ MAR_{box}/MAR\ ref$

Where R_{box} = Daily rainfall in the box

R_{ref} = Daily rainfall in the box

MAR_{box} = Mean annual rainfall in box

MAR_{ref} = Mean Annual rainfall at Ref. Station.

The average daily rainfall for the lake is therefore calculated as the sum of the area weighted means of the daily box rainfall (R_{box})

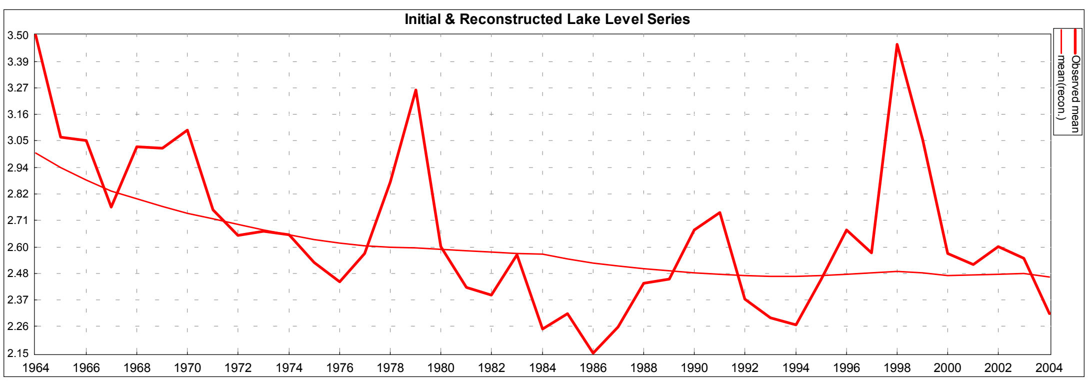
See table ??
Lake Rain = Σ (R_{box} weight)

Table:?? Shows rainfall figures for 2000-2004 in relation to the low term figures for 1950-2000

Rainfall over Lake Victoria (Kenya Side)

Box No.	Name	Wt	MAR_{box} mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean Annual Lake rain for each box
1	Muhuru	0.074				
15	ICIPE Rusinga	0.076				
16	Homa Bay	0.006				
17	Kisumu	0.01				

Table ?? shows rainfall figures for 2000-2004 in relation to the long-term figures for 1950-2000 for catchment rainfall.



Figure?. Long term lake level observed at Kisumu pier This is an important figure make sure the scales are legible

Evaporation

Evaporation data is essentially prepared and analyzed in the same way as rainfall. The only difference is that there are fewer evaporation stations with large distances between them hence it is inappropriate make correlations to extend records. Pan evaporation can vary significantly or a vary only a little on any given day. There is hardly any relationship between evaporation and the occurrence of wet and dry rainfall years. Therefore it was decided to use daily average evaporation to fill gaps in record eg the average of all records on January 1 is used to fill all gaps on January 1 evaporation figures for 2000-2004 in relation to the long term figures (1950-2000) and the boxes used for calculating average evaporation over the lake. In this table, the Muhuru Meteorological Station no longer exists. Because there is no met. station nearby, the average daily evaporation is used to fill the record.

Figure Final Evaporation For Bungoma

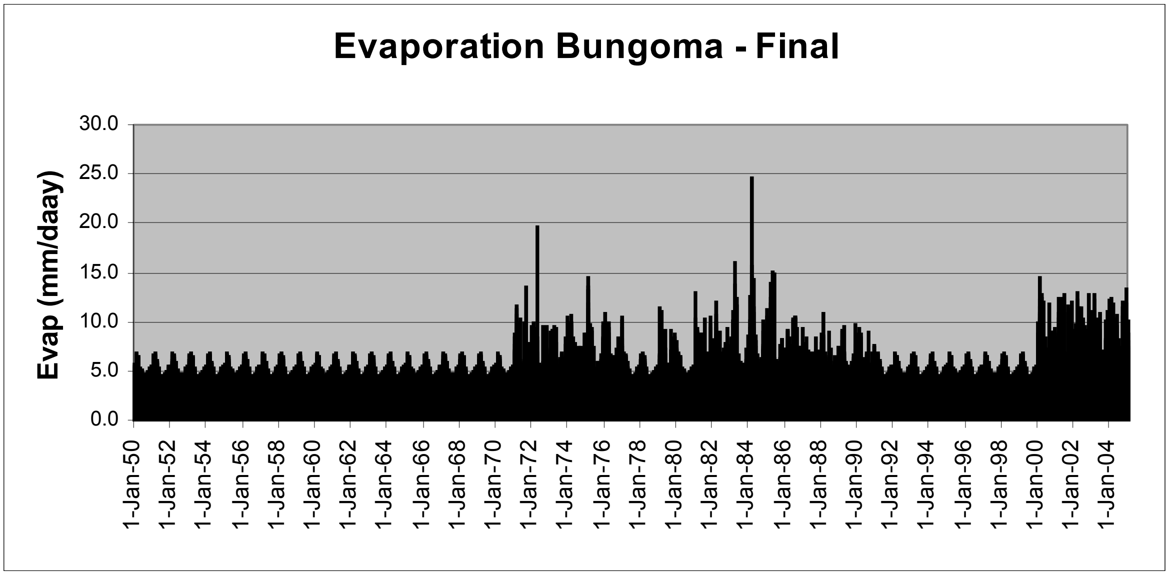


Table: Shows the evaporation boxes over Lake Victoria (Kenyan Side)

Box No.	Name	Wt	MAR box mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean + Lke rain for each box
1	Muhuru	0.041				
10	Rusinga (ICIPE)	0.124				
11	Kisumu	0.012				

Wind speed and direction

Wind was found to have a mean speed of 1.34 m/s and is greatest in February and March and again in September. July and November months have comparable speeds and represents lowest speeds for the series. Wind directions are represented by wind roses plotted (Fig 18) for the months of February, May and November by virtue of the other processes that occur during this time. Overall, the directions are dominated by flows from the south especially during the first six months.

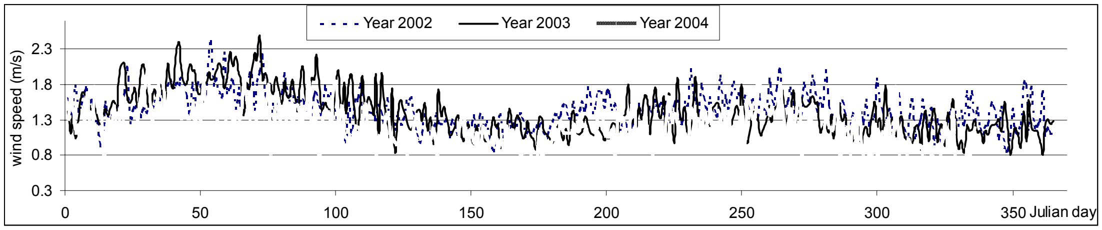
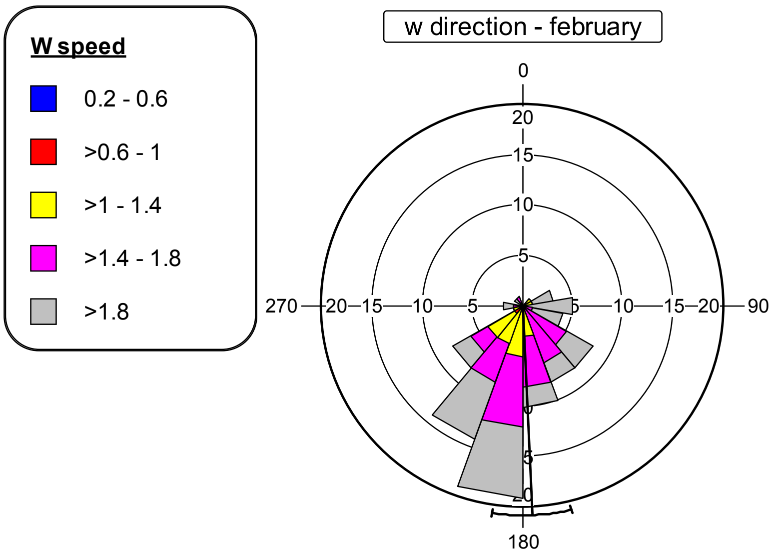
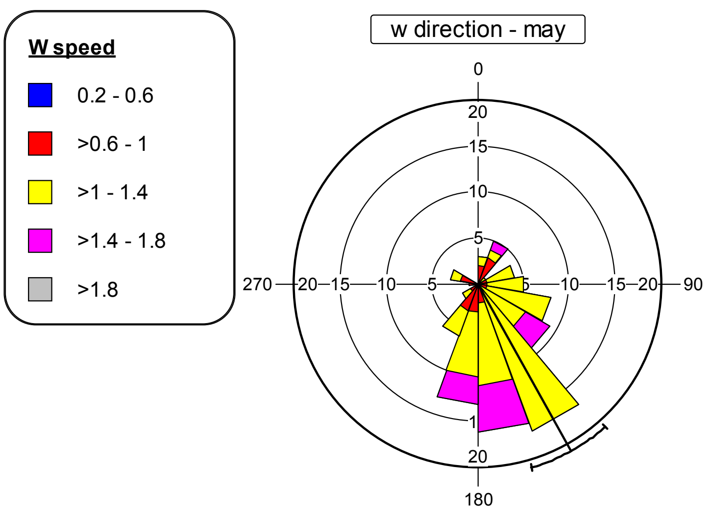
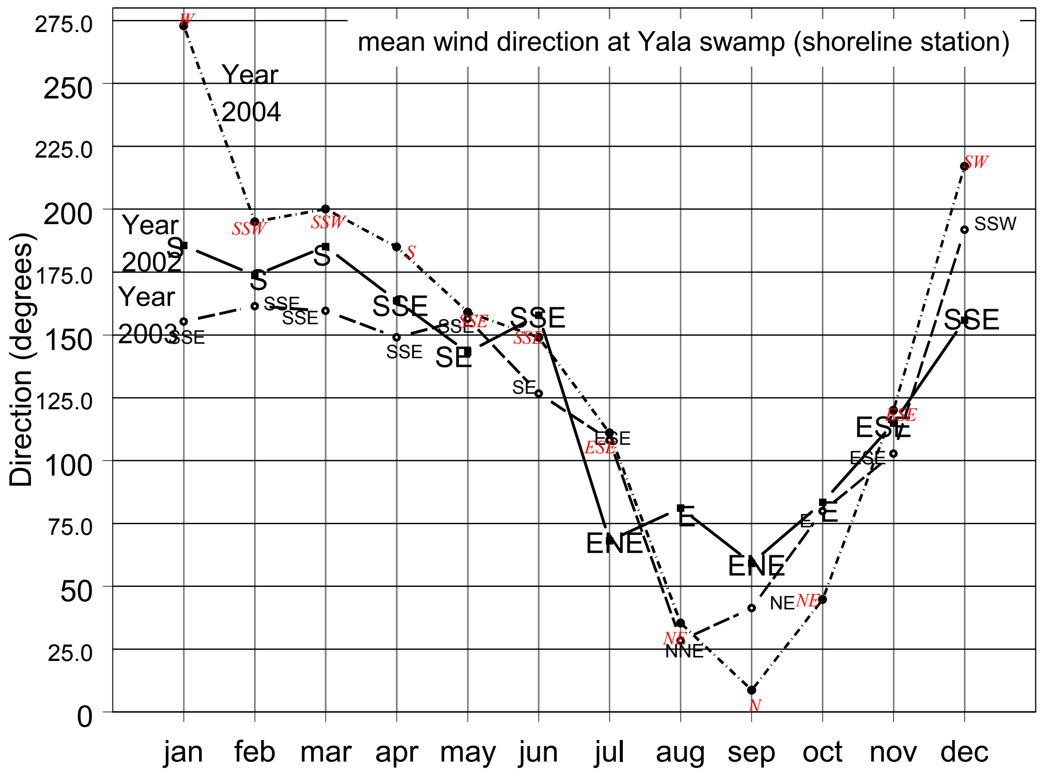


Figure ?? Mean monthly wind speed at Yala swamp





Figure??. Wind rose for the months of February and May. Constructed from 3 year wind series



Figure??. Mean wind direction measured at Yala swamp, shoreline station

Discussion

This study has presented and examined time series of river flows and lake levels, rainfall and wind as measured from the Kenyan catchment of Lake Victoria. This was done with an aim of elucidating trends and periods of meteorology and hydrology from which some plausible explanation on the variability in time of the eutrophication of Lake Victoria can be offered based on meteorology and hydrology processes.

Please comment on trends in rainfall, discharge, rainfall-runoff relationships for different basins (are they all similar or different?) You have done a lot of analysis but this discussion section is where you help the reader understand why you did all these analyses. What were you looking for; what did you find, do any trends or changes have significance to the lake. You do not want leave the reader wondering why all this was done. Discuss the data you have presented above to provide meaning to the reader.

Wind direction has been found to be south to southeasterly dominated during all the months except the period between July and November when the winds from the east. Low-level southeasterlies play an important role in the process of convection/rainfall formation by joining the over-lake convergence and by displacing the convergent center to the northwest of the lake (Nicholson and Yin, 2000).

An important finding concerning evaporation and solar radiation is the strong linear correlation coefficient during the months of April, June and July. This does not compare with the finding of Nicholson and Yin, (2000) who found evaporation to be high in the December-March season and around August, during which time the cloud cover is very low. During the three years the series used in this study was generated, evaporation was found to be high commencing November to March during which time ??? incomplete sentence

River Discharges

Gauging stations close to the mouth are chosen for this study. Table shows the list and location of gauging stations.

This whole section was presented above i.e. your methods Since the gauging stations are not placed exactly at the river mouth, the discharge is not representative of the entire basin area hence the need to calculate the discharge from the entire basin. For example is the un-gauged area represents 2% of the total basin area, then discharges are increased by a factor 1.02.

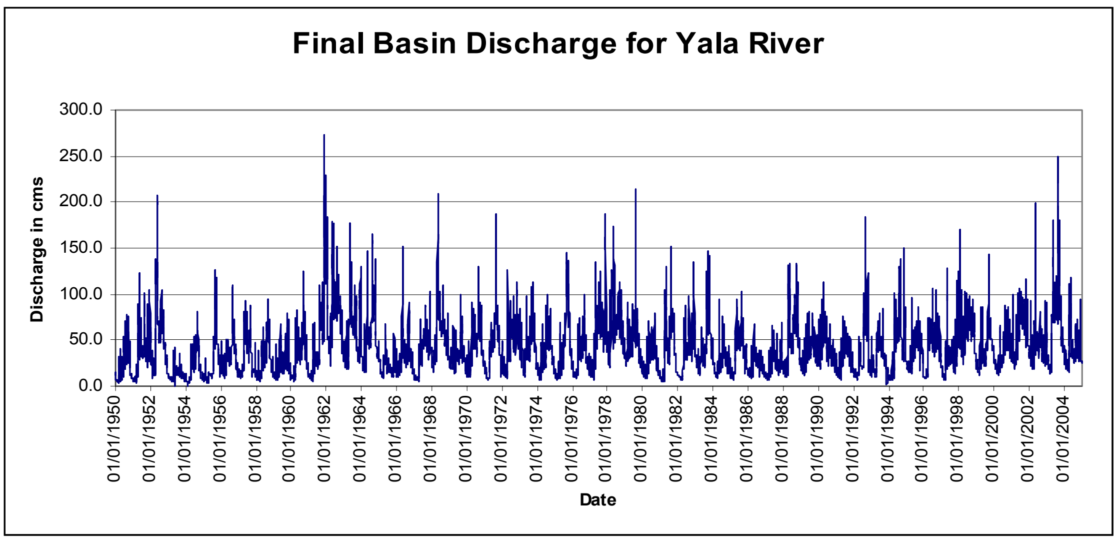


Figure ??…. Yala Basin Final Discharge increased by 1.40

Table …??…… shows the long-term average daily discharge from rivers **(M^3/s)**.

RIVER BASIN	**MEAN DAILY DISCHARGE 2000 – 2004 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2000 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2004 (M^3/s)**
SIO	9.1	11.4	11.5
NZOIA	112.5	115.3	118.7
YALA	47.8	37.6	39.3

N. AWACH	4.0	3.7	3.8
NYANDO	41.8	18.0	20.8
SONDU	41.8	42.2	43.3
S.AWACH	5.7	5.9	6.0
GUCHA MIGORI	38.8	58.0	57.9

Table ……

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sio	4.3	3.1	4.2	16.1	28.2	18.6	10.5	9.3	9.8	11.7	13.7	8.1
Nzoia	62.0	45.8	47.4	100.3	171.5	139.5	148.4	186.4	165.8	134.8	125.5	92.1
Yala	22.4	18.2	19.1	36.0	53.2	43.0	44.4	60.3	59.2	45.3	39.1	30.1
N. Awach	2.0	1.9	3.2	7.8	9.5	6.2	3.0	1.7	1.8	2.0	3.4	3.2
S. Awach	4.6	3.9	4.3	9.3	11.7	11.4	8.0	4.1	2.5	2.7	4.6	4.9
Nyando	15.1	9.3	9.9	32.8	46.8	22.8	21.3	25.9	21.1	12.7	17.4	13.3
Sondu	21.6	15.2	19.8	56.1	88.1	58.7	47.1	51.5	54.2	35.4	38.1	32.6
Gucha Migori	41.5	31.9	46.6	109.7	152.0	77.7	40.4	27.8	26.7	25.2	50.4	63.3

Figure ….shows mean monthly discharges for the Kenyan Basin ???

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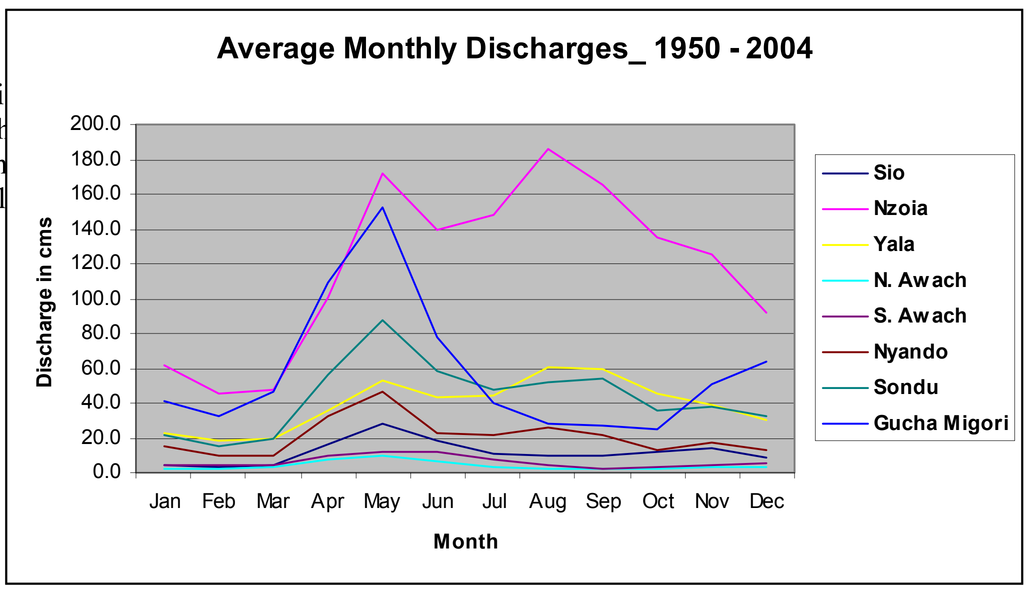
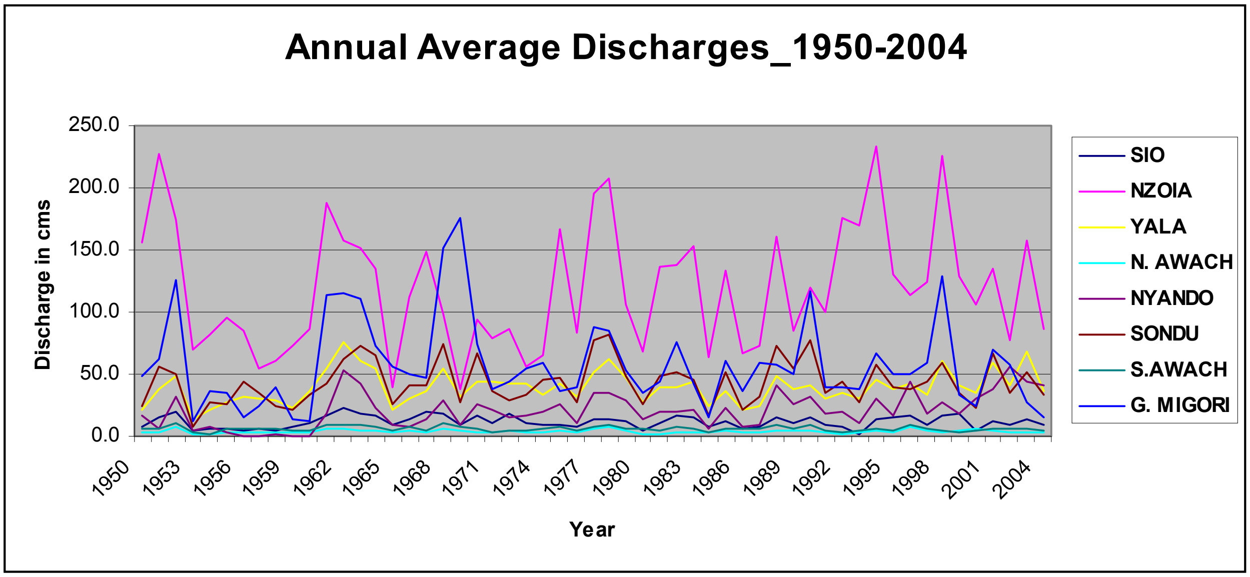


Figure …… Mean Annual Discharges ???

Also present data on runoff coefficient for each catchment i.e. discharge per unit area and discuss why they may be different in terms of the catchment characteristics. Also please comment on possibility that these runoff coefficients might have changed over time refer to Hecky et al in the special issue of the Journal of Great Lakes Research for possible discussion issues.



Conclusions and recommendations:

Conclusions (see comments above on topics to be covered in conclusion esp. concerning evidence of lack of evidence for trends in meteorology and hydrology).

- The method developed for generating discharge data is successful and quite ideal for use in such a study.
- Data gap filling techniques used have proved to be quite successful too.
    - Extension of rainfall and evaporation records by correlation to adjacent station
    - Insertion of typical evaporation data to fill gaps
    - Rainfall runoff modeling to extend discharge records.
- The time series of discharges rainfall and evaporation generated provides an important basis for water quality studies especially in assessment of pollution loads.

- The database so far generated in EXCEL spreadsheets is simple to understand and use in analytical work

- It is noteworthy and commendable that most of the currently operational meteorological stations are owned and run by agricultural based industries that have so far made a major contribution as a source of data to this study.

Recommendations:

- The institutional capacity of regional offices should be strengthened so as to continue filling data gaps with observed data and extending the studies.

- Capacity should also be increased so that more real/observed data is generated for the un-gauged catchment.

- There is need for further cooperation with private and quasi Government sector in data collection and dissemination.

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CHAPTER 4

The Contribution of Atmospheric Deposition to the Nutrient Budget of Winam Gulf of Lake Victoria

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Abstract

Concern has been raised about the contribution of atmospheric deposition to the nutrient flux of Lake Victoria. A few studies on the atmospheric deposition over the African Great Lakes have shown that the atmospheric deposition is a significant source of Total Nitrogen (TN) and Total Phosphorus (TP) to lakes and in fact by far the highest contributor of N and P on the lake surface.

This has been attributed to the large scale destruction of soil cover as a result of changes in the land use system, improper agricultural practices and transport from other regions through regional and global air circulation.

The objective of this study was to estimate the amount of TP and TN coming from the atmosphere and to compliment measurement from the catchment in order to estimate a nutrient mass balance for Winam Gulf. Two stations were selected for this study, Kadenge and Kisumu.

Both wet and dry atmospheric samples were collected in an acid rinsed bucket mounted on a metal structure 1.5m from the ground and analysed for TP and TN using standard methods.

It was observed that the annual dry deposition rates for both TP and TN were higher than the wet ones.

Dry TP. 575.2 tonnes/year, wet TP. 472.8 tonnes/year giving a total of 1048 tonnes/year with dry P accounting for 55% and wet P 45%.

Dry TN. 10289.98 tonnes/year, wet TN. 12133.6 tonnes/year and a total of 22423.6 tonnes/year and dry N accounting for 46% and wet N 54 %.

Compared with estimates of TP and TN from the catchment studies these represent about 38% TP and about 70% TN to the Winam Gulf (Kenyan side of L.Victoria)

If these rates are applied to the whole lake surface assuming that there is no major difference in deposition rates across the lake, it was estimated that 17515.5 tonnes of TP and 373727.2 tonnes of TN was deposited per year with dry P accounting for more than 50% of TP and dry N accounts for more than 50% of TN.

These estimates have been made from two land-based stations and therefore there is need for the inshore stations to be established.

It is therefore necessary as a management strategy to eutrophication in Lake Victoria, to address the atmospheric deposition alongside other sources of nutrients to the lake.

Key words

Wet deposition, Dry deposition, Nutrients, Eutrophication, atmospheric

Introduction

Interest in the factors that cause eutrophication and ecosystem changes in Lake Victoria has grown as the demand for its resources have increased.

The natural aesthetics of the lake have declined commensurate with deterioration in water quality.

The lake supports a huge riparian population estimated to be 30 million people. However, its ability to support domestic, industrial, recreational, energy, agriculture and food usage is threatened by human activities in the catchment. Industrial and municipal loading, improper land use practices, species introduction, siltation, soil erosion, climate change and demographic characteristics have been identified as factors linked to the observed environmental changes in the lake.

Some of the more dramatic environmental changes include oxygen depletion, increase in algal biomass, reduced transparency values, lower silicon concentrations, lower fish populations and species extinction, waterborne diseases and water hyacinth infestation

The literature on atmospheric deposition in the tropical Great Lakes is scanty and it therefore envisaged that the present data set would instigate more investigations into the contributions of the atmosphere to the eutrophication status of the lake.

A few studies on atmospheric deposition over the African Great Lakes have appeared (LVEMP *2002*, Tamatamah *2004*, Bootsma *1996*). These articles show that atmospheric deposition is a significant source of Phosphorus and Nitrogen to lakes. In fact it has been estimated that atmospheric input is by far the highest contributor of N and P on the lake surface (Boostma et al 1993). Scheren (*2001)* estimated that L. Victoria Nitrogen loads are due to 6% urban areas, 22% to agriculture and 72% to atmospheric deposition. The atmospheric Phosphorus and Nitrogen originate from biomass burning in the region or transport from other regions through the global air circulation system. This source was initially estimated to deposit as much as 24000 tonnes Phosphorus per year and 102000 tonnes Nitrogen per year. (LVEMP *2002*)

Objectives

There is therefore a growing concern to define more closely the atmospheric deposition of particulate and the major global transport of nutrients particularly to lakes. This research was conducted in order to estimate the amount of Nitrogen and Phosphorus coming from the atmosphere. In addition, the research aims to complement measurements from the catchment in order to determine a nutrient mass balance for Lake Victoria.

Atmospheric fall out may be divided into wet and dry deposition.

Wet Deposition

Wet deposition may occur by nucleation on particles and aerosols during the formation of rain or by transport to existing raindrops. Air near the lake condenses on airborne particles which act like cloud condensation nuclei forming cloud droplets which then fall on the lake surface in the form of rain.

Dry deposition

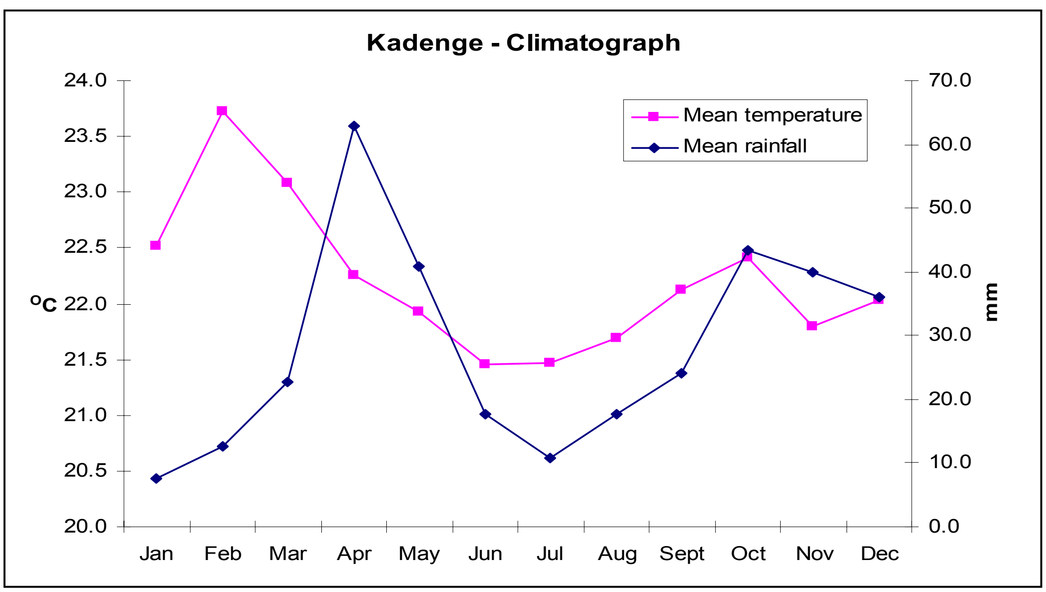
Dry deposition is composed of particles and gasses carried by wind or eddy diffusion to the free atmosphere where a net motion from a region of high pressure belt to low pressure belt facilitates their falling freely onto the lake surface. Turbulent wind eddies provide driving force for this motion.

Study Area

Lake Victoria is the largest tropical fresh water lake in the world and together with lakes Albert and Kyoga forms a chain on the upper Nile River containing an estimated 3200km^3 of fresh water (Kite *1981*). The lake lies in the midst of Equatorial Plateau, which includes the central plateaus of Tanzania, Kenya and Uganda (Rushdi *1992*). The lake receives nearly 80% of its water inputs directly falling on its surface. A similar amount is lost to evaporation (Bootsma and hecky *1993*). It has been established that direct rainfall on to the surface contributes most of the water input and R. Kagera accounts for about 35% of the total run off into the lake (LVEMP 2002*1*).

The land catchment of Lake Victoria has an area of 193,000 km^2 and the area covered by the lake is 68800 km^2 which gives a land to surface ratio of about 3:1 so the lake itself forms a major portion of the basin (Rushdi *1992*)
Rainfall is mainly convectional, resulting from the cooling of the air that rises from the heated land and water surfaces. Sudden showers are often accompanied by lightning and thunder and mostly in the afternoon. The catchment has a mean annual temperature in areas close to the lake ranging between 22.8 – 23.3 ºC and a mean daily temperature of the hottest month of 29.3-31-6ºC. There are two main rainy seasons; the long rains occurring in March-May and short rains from November – December (Lung'ayia et a*l 2000*). The hydrologic balance is dominated by rainfall, river run off and evaporation (Piper et al *1986*). Lake Victoria is affected by both local, regional and global wind systems. The prevailing winds mainly blow from south to southeast. Wind and rainfall pattern in the region are associated with Inter Tropical Convergence Zone (ITCZ), a zone of low-pressure belt (Tamatamah et al *2002*)

Figure I. Climatograph for Kadenge station



The lake has a great significance to its riparian population that is about 30 million people providing food from fisheries, water for agriculture, water for domestic and drinking use, and transportation for commerce and recreational purposes. It's shared between Kenya 6%, Uganda 43% and Tanzania 51%. But like any other resource, Lake Victoria has come under stress as human population in its catchment increase, demands for natural resources extraction grow and industrial impacts spread through economic development. The lake has therefore become a sink for all types of water and windborne materials

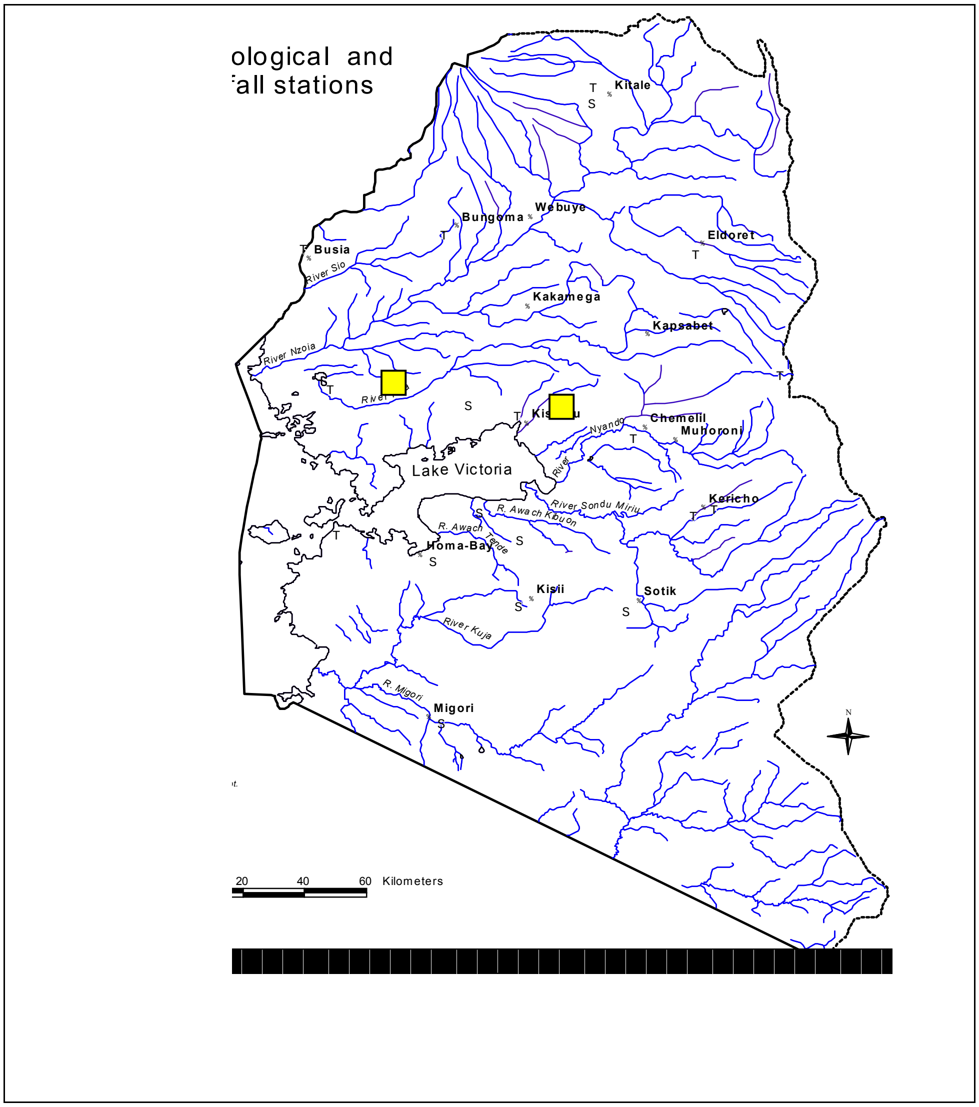


Fig II. Map showing Kenyan part of L. Victoria catchment and locations of sampling stations

Atmospheric samples were collected from two stations Kadenge and Kisumu. The areas around the two stations have different climatic conditions, population and land use systems. Kadenge is basically a rural station close to the expansive Yala Swamp, which extends up to the Lake. The Major activity in this area is subsistence agriculture dominated by slash and burn practice of land preparation. Artificial fertilizers are rarely used. Apart from bush clearing, fire is

widely used for getting firewood and rejuvenating wetland vegetation especially during the dry season so that when rains start fresh vegetation regenerates. Apart from the wetland, the area is covered with isolated bushes and thickets typical of tropical savannah vegetation. Because of the bimodal nature of the rainy season in the area, Kadenge experiences two planting seasons one in April and the other in October.
Kisumu is a fast growing city and a commercial centre for East Africa. It is located north of Winam Gulf of Lake Victoria and because of the rapid population growth rate (3% per year for the national) and increased industrialisation, Kisumu city and its environment has had a lot of degradation. Deforestation and land clearing for food production, settlement and wetland reclamation are some of the environmental degradations taking place in the area. The town is within the sugar belt and some of the wetlands have been converted to sugar farms. Like many urban centres in the region, both solid waste and wastewater handling facilities are inadequate and there is mushrooming of unplanned settlements, which add to the already grave solid waste situation in the town. Wetland burning in this region is very common during the dry period.

There is also the practise within the sugar belt of setting sugar farms ablaze to facilitate harvesting of the cane. This practise is very common and in most cases leaves a bare soil and dusts that are carried by strong winds to other areas.

METHODS AND MATERIALS

Wet Samples

Prior to each sampling, the sampling bucket was thoroughly cleaned with water, rinsed with 10% Hydrochloric acid and finally rinsed with plenty of distilled water.

Rain samples (wet deposition) were collected in a bucket with a surface area of 0.071 m^2 placed on a firm elevated structure 1.5 m above the ground level away from buildings, trees and any thing, which might be the source of interference. The bucket was placed immediately before a rain event and or late in the evening if rain was expected during the night. The bucket was retrieved immediately after a rain event or in the morning after a night rain and the volume of rain water collected was measured and recorded.

Samples were then put in acid rinsed plastic bottles and preserved with acid (Standard Methods*, 19th Edition 1996*). Where an immediate laboratory determination was not possible, samples were kept in the fridge below 4 ^{O}C.

Dry Deposition

The dry as in the case of wet sampling were collected over the same elevated structure using the same bucket. The sampling was random and did not follow any particular day of the week.
A known volume of nutrient free distilled water (confirmed by frequent analysis of TP and TN on the same) was put into the bucket, which was then mounted onto the structure. The bucket was left to stay for 24 hours after which the sample was collected and distilled water added to restore the volume lost as a result of evaporation. The sample was then put in acid rinsed plastic bottle, preserved with acid and taken for analysis in the laboratory. Again when the analysis could not start immediately, the samples were kept in the fridge under 4 ^{O}C

The volume of distilled water to be used for sampling depended on the ambient conditions. During dry seasons about 1 litre of water would be used because of the increased evaporation rate and a lesser volume e.g. 0.5 litre used during rainy and cool seasons when the evaporation rates were minimal. Due to complexities involved in sampling and the kind of specialised techniques so required, only the Kisumu station was sampled for dry deposition.

SAMPLE ANALYSIS

TP and TN analysis were done at the Water Quality Laboratory in Kisumu. TP was analysed by digesting the samples using ammonium persulfate in an autoclave at a temperature of 121^{o}C for 30 minutes. This was followed by colorimetric determination using ascorbic acid method (Standard Methods *19th Edition*) and Cecil 2000 Spectrophotometer.

TN was determined by the oxidation of samples with potassium persulfate at a temperature of 121 ^{o} C in an autoclave for 30 minutes. This was to bring all forms of nitrogen to nitrates. The resultant nitrates were then quantitatively reduced to nitrites using Copper-Cadmium reduction column, which was then determined using the colorimetric method. (Standard Methods *19th Edition)*

RESULTS

The concentrations of both TP and TN were expressed in mg/l. For wet TP and TN depositions, concentrations were expressed in Volume Weighted Mean Concentrations (VWM) using the formula below.

$$VWM = \frac{\sum VC}{\sum V} \qquad \text{.......}1$$

Where VWM is the volume weighted mean concentration in mg/l, V is the volume of rainfall collected per event in litres and C is the concentration.

For dry deposition, a mean concentration was calculated by using formula 2 below.

$$C = \frac{\sum C}{\sum V} \text{ ....2}$$

Where C is the mean concentration in mg/l and V is the volume of the sample after being compensated for the loss due to evaporation.
The measured concentrations were then converted to deposition per event or per day by dividing by the area of the collection bucket (0.071m2) to give rates in mg/m^2/event.

$$R = \frac{C}{A} \text{ ....3}$$

Where R is the deposition rate in mg/m^2/event, C is the concentration of TP or TN in mg/l and A is the area of the bucket in m^2.

Total deposition to the lake was done using the following formula:

$$D_{dep} = d._{mean.} * A * d \text{ ....4}$$

Where D_{dep} is the deposition in (ton/year P or N), d mean is mean deposition (mg/m^2/day), d is the number of wet or dry days in a year and A is the surface of the lake under considerations.

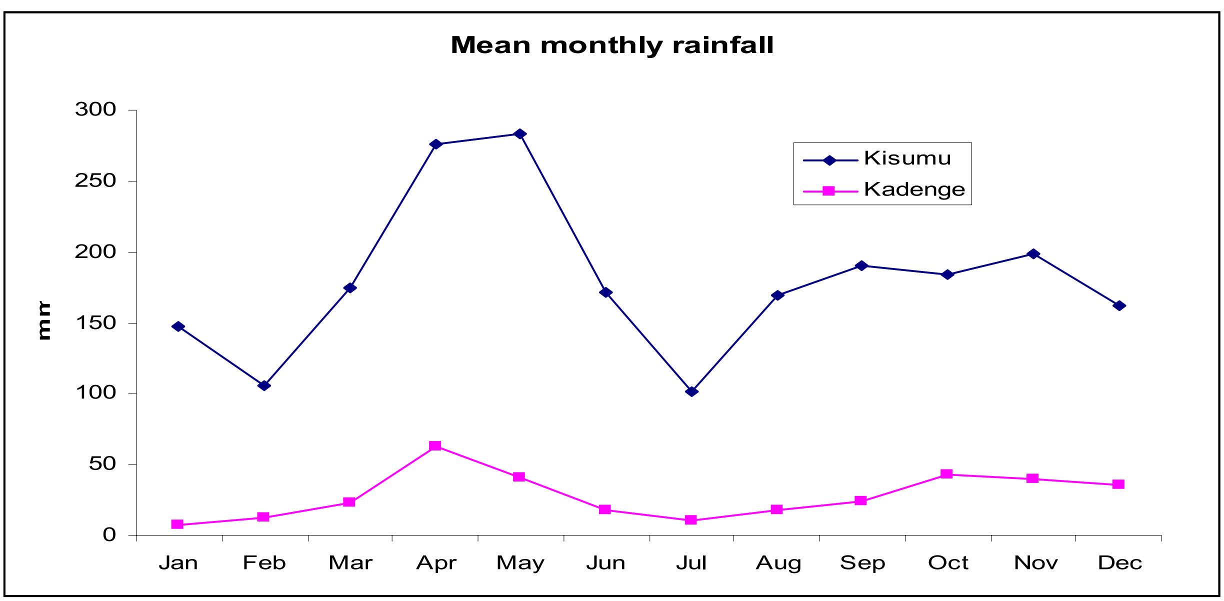


Fig. III. Comparison of mean monthly rainfall (mm) at sampling stations (2002-2004)

For final computation of the total deposition, only Kisumu station was used because it had both wet and dry deposition data. Because of the complexities of dry sampling, it was only possible to sample in Kisumu.

For dry deposition the results showed high rates in the months of January to March and July to September. Wet deposition rates were higher in the months of April and May and the rates tended to decrease as the rainfall events increase. The sporadic rain events within the dry periods produced high concentrations of both P and N. Mean daily dry depositions were higher than the mean wet ones. Kadenge had higher wet deposition rates of TP than Kisumu while Kisumu was leading Kadenge in TN. In terms of rainfall Kadenge is drier than Kisumu .

A summary of mean wet and dry Phosphorus and Nitrogen depositions measured at the two stations are given in table I

Table I

	Kadenge	**Kisumu**
No. of wet days	164	216
No. of dry days	201	149
Wet TP (mg/m^2/day)	0.59	0.53
Wet TP (mg/m^2/year)	97.1	115.3
Dry TP (mg/m^2/day)		0.94
Dry TP (mg/m^2/year)		139.3
Wet TN (mg/m^2/day)	10.5	13.6
Wet TN (mg/m^2/year)	1714	2940
Dry TN (mg/m^2/day)		16.7
Dry TN (mg/m^2/year)		2493

Kadenge was slightly higher in daily wet Phosphorus deposition rates but because there were more wet days in Kisumu than Kadenge , the yearly deposition rates were higher in Kisumu than Kadenge. It was also observed that the annual depositions for Total Nitrogen were higher in Kisumu.
When the measured rates are compared with similar measurements done in the regions, wet TP deposition rates were relatively similar to the deposition rates measured by Tamatamah 2002 and those estimated by Bootsma et al 1999 for Lake Malawi.

Table II

Station	**Dry P (µmol/m^2/event)**	**Wet P (µmol/m^2/event)**	

Kisumu	30.3	17.3	This study
Kadenge		19.2	This study
Bukoba	20.4	13.2	Tamatamah 2002
Mwanza	26.2	16.2	Tamatamah 2002
Seronera	17.4	12.4	Tamatamah 2002
Lake Malawi	24.7	14.2	Bootsma 1999
Jinja		13.8	Lindensmichdt 1998

When a mean wind speed was plotted from 2002 to 2004, (Figure II), it was observed that the wind speed was highest from Jan to March and that dropped gradually towards July and rose again in August to October just before the November –December rains. This could be attributed to the movement of Inter Tropical Convergence Zone.

Fig (iii) Mean wind speed for Kadenge from 2002 to 2004

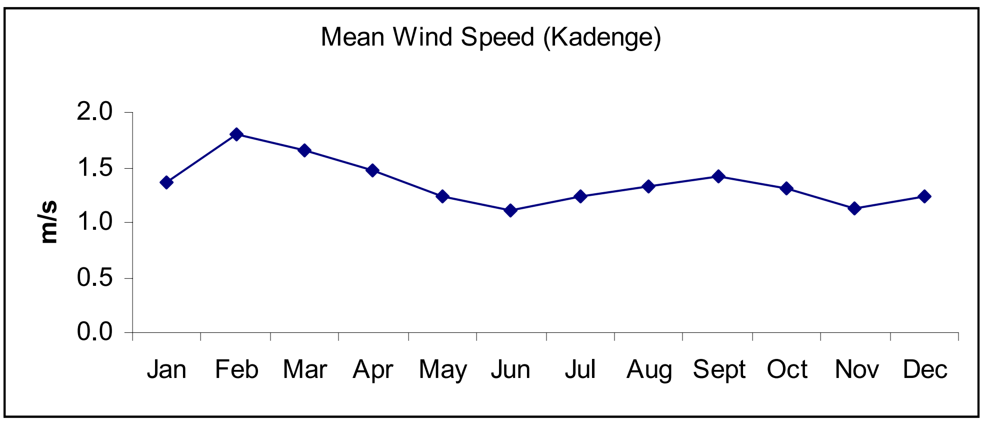
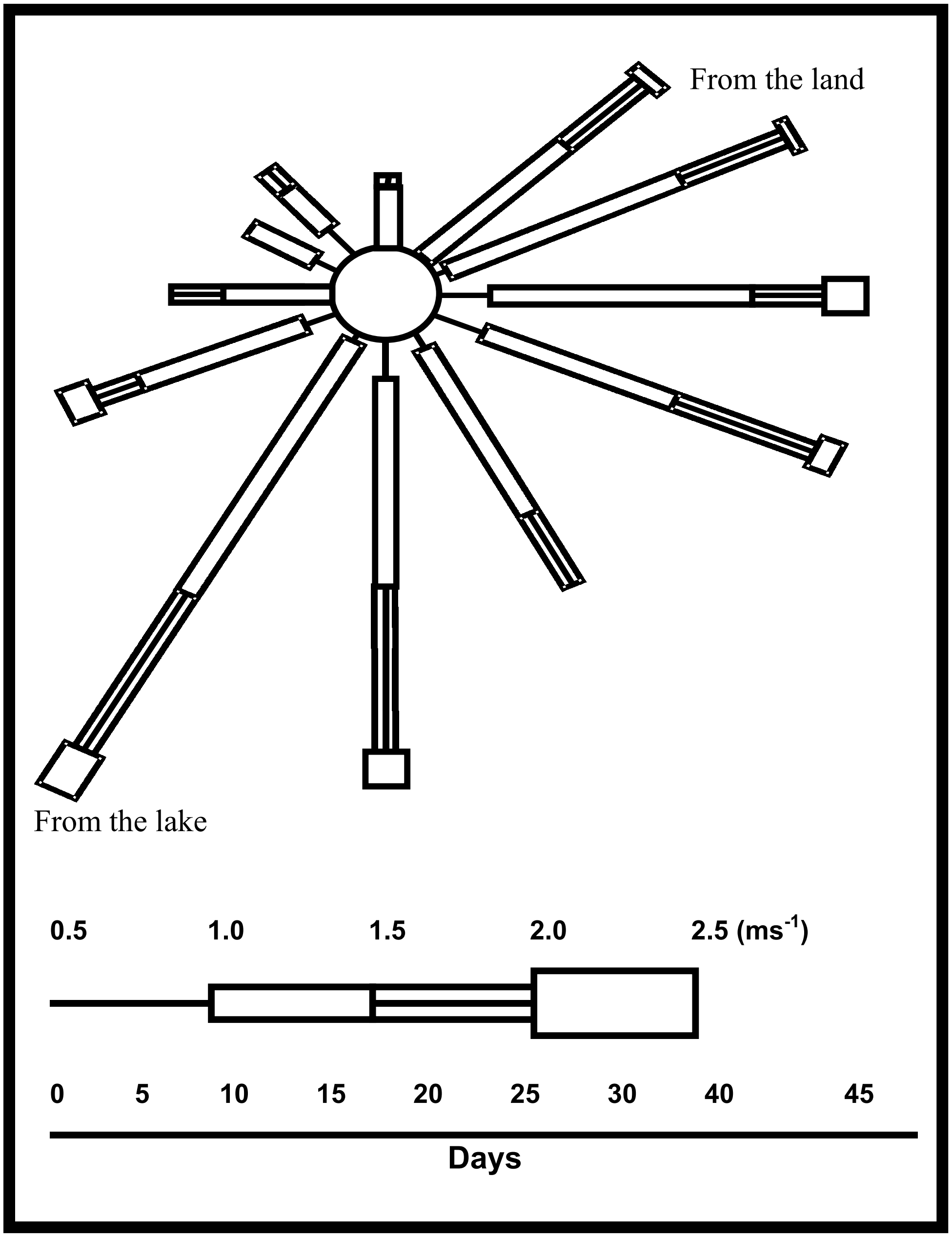


Fig. (iv) Annual wind rose recorded at Kadenge during 2003.

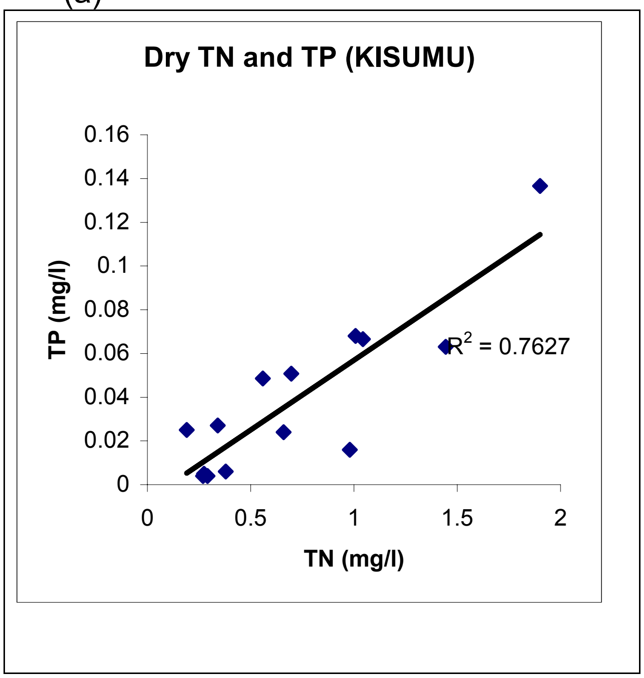


The wind rose above showed that the dominant wind is the southerly, which mainly flow from the lake, and southeasterly which is mainly from the land with the major wind speed between 1.5 to 2.0 m/s. Some of these winds originate outside the region and therefore the windborne materials may be from other regions. There is also weak wind blowing from the north and northwest. These may comprise mainly local breezes that come from the lake to the land and other regional winds. All these factors affect the type and rate of atmospheric depositions.

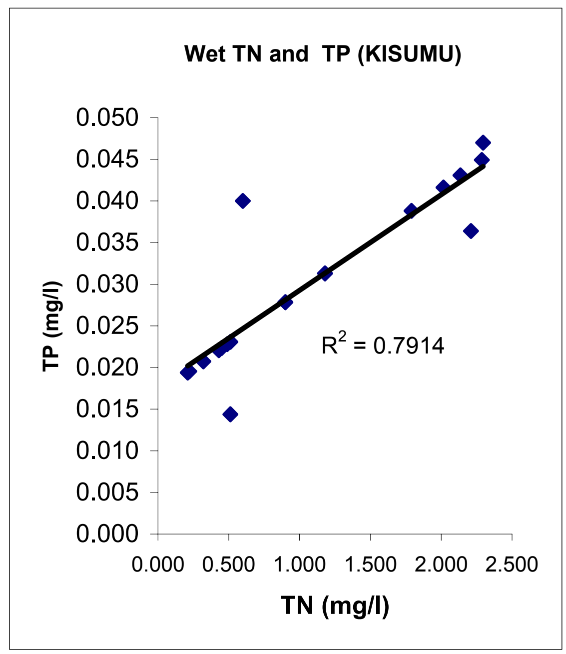
Linear regression of TP and TN yielded a significant correlation in both wet and dry deposition. Kisumu dry, r = 0.873, wet r = 0.764 and Kadenge wet r= 0.827. These relationships are significant at $p < 5\%$. However, the wet P against wet N showed a lower slope and higher intercept than the dry one. This may mean that the ratio of TN:TP in the dry deposition is smaller than the ratio in the wet deposition.

Fig. (V) shows correlation between (a) TP and (b) TN (c) for both wet and dry depositions at Kisumu and Kadenge

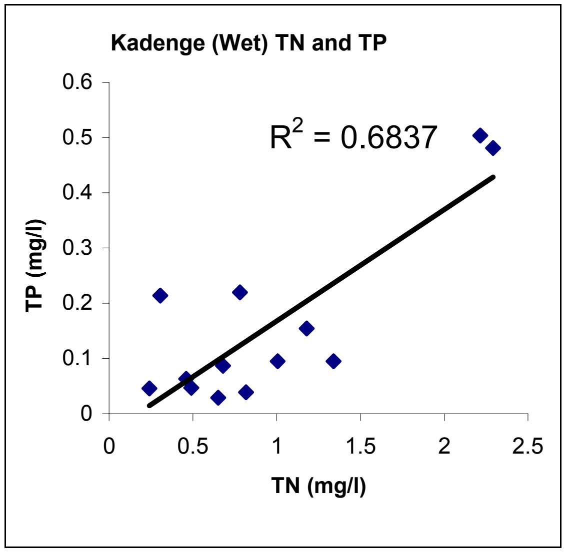
(a)



(b)



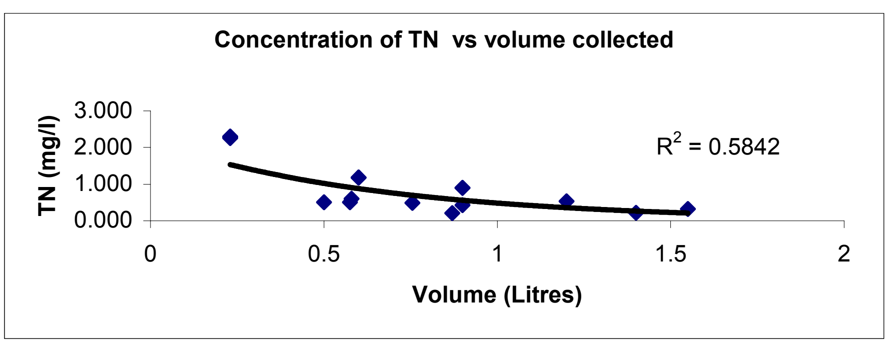
(C)



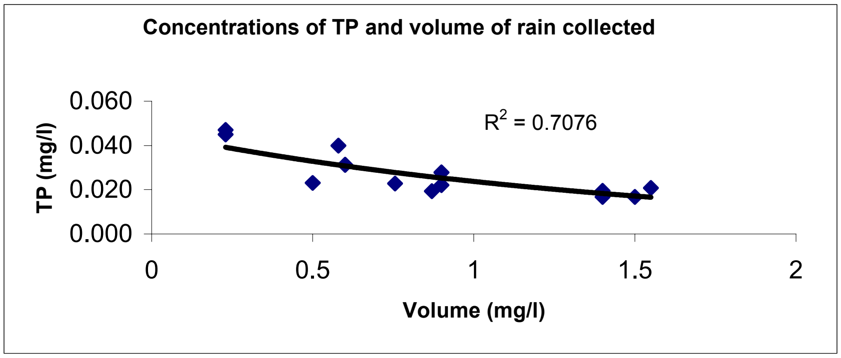
When volume of rain was plotted against the concentrations, significant exponential correlation was observed (r= 0.764, n= 11) and r = 0.841 n=? for TN and TP respectively. The correlations were significant at p< 5%. This implied an exponential decrease of concentrations with the amount of rainfall. The observations revealed that concentrations of P and N were higher during initial rains and these diminished with the subsequent increase in rain. Temporally most components decrease in concentrations over the course of rainy season. This according to Boostma et al (1996) might be due to the fact that rainfall per event tended to increase as the rainy season progressed rather than a change in atmospheric concentrations. Dust and other airborne particulate and matter from burning are expected to be washed out at the initial onset of rainy season (Andreae 1993)

Fig. (V1) Concentration of (a) TN and (b) TP and volume of rain collected

(a)



(b)



To determine whether there was seasonality in the overall deposition was, three seasons were identified. These were:

(a) dry season for the months of January, February, March, July and August
(b) Long rainy season for months of April, May and June.
(c) Short rains for the months of September, October, November and December.

The mean seasonal concentrations and depositions were then determined for both TN and TP and the results are as shown in the table below.

Table iii

		Concentrations (mg/l)		**Deposition (mg/m^2/season**	
SEASON	No. of days	TN	TP	TN	TP
Dry	152	1.14	0.16	2439.6	342
Long rains	91	1.17	0.04	1499.7	50.96
Short rains	122	1.47	0.08	2521.7	131.64

In terms of mean concentrations there was no significant differences between the seasons in TN although short rains was higher with dry season lowest. For TP concentrations, there was a significant difference between the seasons. Dry season was four times higher than the long rains and twice the short rains.

For seasonal TN deposition the trend was similar to the one for concentrations. There were however significant differences between seasons for TP. Dry season were significantly higher than the long and the short rains. The short rain was also higher than the long one.

Table # gives a summary of TP deposition rate as found by this study compared to those of Tamatamah et al 2002 and LVEMP 2002.

Table # is the results of the deposition rates for both wet and dry TN measured at two stations compared to those of LVEMP 2002.

Table (iv)

Wet TP deposition	**This study (Kisumu)**	**This study (Kadenge)**	**Tamatamah 2002**	**LVEMP 2002**
Mean deposition (mol/m^2/event)	17.3	19.2	12.4 –16.2	15.1
Kenyan part of the lake (ton/year)	472.8 (45%)	400.89		554.2 (31%)
Lake wide deposition (ton/year)	7930	6681.5	4200	11835
Dry TP deposition				
Mean deposition (μmol/m^2/event)	30.3		17.4 – 26.2	29.1
Kenyan part of the lake (tons/year)	575.2 (55%)			1222.4 (69%)
Lakewide deposition (tons/year)	9584		9300	12566.6
Total annual deposition rate to the Kenyan part of the lake (tons/year)	1048			1776.6
Total annual deposition rate to the lake (tons/year)	17514		13500	24402

Table (V)

Wet TN deposition	**This study (Kisumu)**	**This study (Kadenge)**	**LVEMP 2002**
Mean deposition	13.6	10.45	3.3

(mg/m²/event)			
Yearly deposition rate (mg/m²/year)	2939.4	1714.3	903
Kenyan part of the lake (ton/year)	12133.6	7076.6	2909
Lake wide deposition (ton/year)	202227.4	109313	62598.5
Dry TN deposition			
Mean deposition (mg/m²/event)	16.7		2.2
Yearly deposition rate (mg/m²/year)	2492.7		804
Kenyan part of the lake (tons/year)	10289.98		2983.3
Lake wide deposition (tons/year)	171499.8		39550.3
Total annual deposition rate to the Kenyan part of the lake (tons/year)	22423.58		5892.3
Total annual deposition rate to the lake (tons/year)	373727.2		102148

Discussion

The TP deposition rates for the two stations, Kadenge and Kisuum showed some slight differences in both mean daily deposition rates and the annual rates. Kadenge had higher TP deposition rates than Kisumu while Kisumu had higher deposition rates in TN. Being a rural station fire is extensively used both at home and in the farms during land preparation. Fire is also used in the Yala swamp to rejuvenate grass for grazing . Sufficient evidence have been established to the effect that burning of vegetation in the tropics results in an increased flux of fixed nitrogen into the atmosphere *Lewis (1981)* and *Andreae (1990*).

Climate wise Kadenge is very dry and dusty most of the time compared to Kisumu. Most land preparation is done during the dry period between January and March. During this time the wind speed is also high (See Figure) and most soil surfaces are exposed in readiness for planting once the rains commence. These factors facilitate wind erosion with the results that fine soil and ash particles are carried to the atmosphere. Soil exposure resulting from such events has been suggested to be the cause of increased P deposition in Uganda by Bootsma and Hecky (1993). Gabally and Gillette (*1988*) suggested that since gaseous P do not exist then P is associated with particulate matter. Hendry et al 1984 attributed the P deposition to the gravitational settling of atmospheric particulate phosphorus from localised sources and Tamatamah et al (*2002*) suggested that soil particles, dust, and fires are likely sources of elevated P deposition observed in the Lake Victoria region due to intensity of deforestation and biomass burning.

The decomposition of dead biomass in the Yala Swamp may be another major contributor to the amount of nutrient to the atmosphere especially Nitrogen by releasing volatile ammonia to the atmospheric nitrogen cycle. Previously it was assumed that only industrial activities are the major contributors to the atmospheric input as a result of acid rain observed in some major industrial centres, it is now becoming apparent that non industrial human activities can also have large impact on atmospheric chemistry in other regions (Crutzen and Andreae *(1990*).

Due to a quest for new lands for commercial, settlement and subsistence agriculture, and wood products by a rapidly growing population of Kisumu, significant land use changes have occurred. Deforestation, overgrazing and conversion of wetlands to irrigation are normal daily occurrence (*Awiti el al 2000*). Charcoal burning has reduced the nearby Nandi escarpment to bare and eroded soils. Soil is a potential source of P and N (Lindsay *et al* 1987)

Wet TN deposition rate was higher in Kisumu than Kadenge. Kadenge wet TN 10.45mg/m^2/day and Kisumu wet TN 13.6 mg/m^2/day. Kisumu like many of the urban centres in Kenya is characterised by lack of proper solid waste disposal system. This has led to situations where there is heaps of uncollected garbage decomposing within the estates and at times the residents opt for incineration. Normally complete incinerations of solid wastes require relatively high temperatures and a controlled operation, which may not be achieved by open-air fires. A poor incineration process may mobilise particles, gasses, volatile elements and unburnt wastes into the atmosphere.

Another possible source of P and N to the atmospheric deposition is the wastewater. Waste water handling facilities in Kisumu is inadequate and therefore many households do not access sewerage systems with the results that liquid wastes are disposed of in an unhealthy manner.
Previous studies have suggested possible sources of atmospheric fixed Nitrogen as emissions from soil bacterial processes, lightning, combustion of fossil fuels or biomass and ammonia volatilisation from human and animal wastes and decaying vegetation (Langenberg et al 2003). Boostma et al (*1996*) invoked biomass burning as mainly responsible for increased N concentrations found in L. Malawi. Those factors may explain the higher N deposition rate in Kisumu. Increasing human development of catchment areas and agricultural activities ultimately affect the dynamics and chemistry of atmospheric deposition (Galloway et al 1994)

There was predictable seasonality of the atmospheric fallouts. The concentrations of the dry fallouts were high during the dry months January to March and July to August and lowest during the wet months April and May while the wet depositions were higher during the rainy month of April. The overall TP deposition was highest during the dry season and lowest in the long rain season. During this time the wind speed is very low and therefore the effect of wind erosion is also reduced hence less dust particles and aerosols in the atmosphere. Although the process of deposition is not clear, it is though that it is a function of wind velocity and the mass of the particle. According to Murphy (1974)**,** large atmospheric particles that have a short residence time are a major contributor to dry fallout and are mainly of local origin while small particles with relatively long atmospheric residence times are removed chiefly by precipitation scavenging and can be of local or distant origin. Since TN exists in the atmosphere mainly in the gaseous form, example ammonia and other nitrogenous gases, it is less likely to be influenced by seasons.

Dry component contributed more than 50% of the total P contribution while wet N contributed about 55% of the total N. This is in agreement to an observation made by Tamatamah et al (*2002)* with reference to TP.
When the Total P and Total N to the lake from the catchment studies were used in estimating the nutrient balance for the Kenyan part of the lake, the atmospheric deposition contributed 38% of TP and about 70% of TN.

Table (V) The table shows the estimated nutrient budget for the Kenyan part of L. Victoria

	Catchment (Kenyan part)	**Atmospheric deposition**
TP (Tonnes/year)	1724 (62%)	1048 (38%)
TN (Tonnes/year)	9603 (30%)	22423.6 (70 %)
Total (Tonnes/year)		

Previous studies have suggested that about 80% of the P deposition into Lake Victoria is from atmospheric sources, however on the Kenyan side of the lake this is only 38%. This may be due to the small lake surface compared to large catchment area with high river discharges, which account for about 37% of the total river discharge to the lake. TP contribution from the catchment, which includes contributions from point and non point sources from the farms, is the major source of P in the Kenyan part of the lake. However, atmospheric deposition is the leading contributor of N onto Winam Gulf.
This means therefore that to manage eutrophication in the lake from Kenyan side, more efforts should be directed towards the activities taking place in the catchment such as agricultural practices, industrial and municipal waste handling facilities and the disposal of solid waste.

Conclusions /Recommendations

The studies so far carried out on the nutrient flux revealed that atmospheric deposition is the highest contributor of nutrients to the lake. However these estimations have been based on measurements made from land based stations and gives the estimates as they would appear at the shores. The potential of exploiting offshore stations have not been fully utilised. Considerations should be given to the installation of some stations in the islands a way from traffic and human influence to validate the extrapolation of shore based data across the lake.

Further studies in this area should take into account both wet and dry components of the atmospheric deposition. The previous studies have tended to concentrate on wet component particularly Phosphorus due to the importance attached to it as a limiting nutrient in the eutrophication of Lake Victoria. Measurements on dry depositions are very scanty especially TN. One major limitation of these estimates is the assumption that two stations that have been used in the estimation of the total loads onto the lake represent the conditions of the lake. This is an assumption that may not be correct as different areas of the lake have different mean annual rainfall, mean wind velocities and directions, factors that have been established to influence depositions. Many more stations spread over the lake region may give better estimates.

While it has been documented that burning of biomass is one of the major contributor to the nutrient flux into the African Great Lakes, both solid and liquid waste management within the region need to be addressed and policies and programs concerning proper land use systems should be put in place.

There is need for both local and regional interventions as evidence has shown that the depositions are influenced by both local and regional factors.
Therefore as strategies are being worked to reduce the problems of eutrophication in Lake Victoria, management of atmospheric deposition should be addressed.

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CHAPTER 5

Non Point loading from the Lake Victoria Catchment – Kenya Section

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ABSTRACT

There are nine major rivers traversing the lake Victoria catchment of the Kenya side. The river basin, which ranges from 1000Km^2 to 12,842km^2 is, characterize by hilly deforested slopes, human settlement and extensive agricultural activities. As the rivers traverse the entire catchment they receive pollutants from point and non-point sources, which are a result of the above activities. The pollutants not degraded find their way into the lake. To assess and characterize the quality of the rivers, two key nutrient parameters and suspended solids were monitored at fifty sampling stations for three years. During the same period river levels were also measured.. Mean Volume weighted concentration were calculated and discharges obtained from hydrological unit were used to calculate the total load to the lake. The results showed that high loads were recorded in the areas with larger catchment area, with dense population and characterized by intensive agricultural activities, while high concentrations were obtained in catchment areas with intensive agriculture hilly bare slopes and eroded falling river banks

Introduction

Lake Victoria is the second largest freshwater body in the world with a surface area 68,800kms. It is considered to be one the most productive freshwater ecosystem in the world with immense socio-economic importance to the riparian communities (Scheren et al., 2000). Of all the economic benefits derived from it, fishery resource ranks high, as its commercial yields have exceeded 500,000 metric tons annually. It therefore remains a major source of protein not only for the riparian communities within East Africa but also to the European Community (Migudes et al., 2003).

The lake and its ecosystem also support a diverse biological community which represents a global heritage in addition to providing water for both domestic and agricultural purposes for the constantly growing population within the basin (LVEMP 1995, Scheren et al., 1994)).

But in the last two decades it has undergone several changes due to population increase, direct disposal of human, agricultural and industrial waste coupled with the introduction of foreign organisms. These have impacted negatively on lake waters and its ecology having contributed to massive algal blooms, emergent water hyacinth which started choking important waterways and landing bays as well as blocking water supply intake, frequent outbreak of water born diseases (LVEMP 1995) The lake as a source of life for tens of million people and a habitat for millions of wildlife was therefore threatened.

It is against this background that a multi-disciplinary approach was conceived to study and manage the lake and its environment (LVEMP 1995). The problem facing the lake was not confined only to the areas bordering the lakeshores but originated from the entire catchment which is drain by several rivers and streams. The study of these rivers is quite necessary because they provide information linking the Lake Victoria and the activities on the surrounding catchment (Kingdon et al., 1999).

Although nutrients are essential for plant growth, they are only required in small or trace quantities. Their absence affect plants production and hence crop yields. The two major nutrients, which limit the crop yields, are phosphate and nitrogen. These are normally added through fertilizers to the agricultural fields to compensate for the losses. Excess Nitrogen (N) and Phosphorus (P) not taken by plants are washed away through surface run off. Landuse pattern and high population density are some of the factors that might affect the movement of these nutrients and sediments in river systems thus finding their ways into Lake Victoria waters. These may have impact on the lake water quality and other biological processes (Kingdom et al., 1999). These could be seen from the conclusion drawn from other past studies, which indicated that tropical lakes such lake Victoria might be more vulnerable to sediment loads laden with nutrients (Hecky et al., 2003)

Objective

The objectives of the study were therefore to

- Determine the concentration for TN, TP and TSS for individual rivers
- Determine the seasonal variation for the two nutrients in the representative rivers
- Estimate Pollution load of each river catchment
- Estimate the catchment yield (per unit catchment area)
- Estimate the total pollution load into the lake

Study area

Lake Victoria has a total catchment area of 194,000 km^2 which extends up to Rwanda and Burundi, of which Kenya side constitutes 42,480 Km^2, where the study was conducted.The area is further divided into the northern and southern catchment (Calamari, 1995).

There are several rivers, which drain the entire catchments, and pour their waters to Lake Victoria but the major ones are Nyando, Sondu -Miriu, Gucha Migori found in the southern catchment, primarily entering Winam Gulf while Nzoia and Yala drain the Kenya catchment directly into the lake

The catchment climatic condition is well defined by the rainfall distribution based on the data collected by metrological unit and also as observed by Calamari et al.,(1995).

The area experiences mean annual rainfall of 1300 mm. Most of it occurs during the long rains, which start around March and extend up to May. The long rains usually goes up to 2000mm. This is experienced on the upper elevation of catchment in areas such as Kericho, Kisii, Nandi and Kitale. Around the lakeshore (lower part of the catchment) is generally dry and experiences low annual rainfall; as low as an annual mean as 100 mm. short rains occurs from October to December with a peak in November.

There is a wide variation in temperature because of seasonal changes in the catchment. The temperature ranges from 0 ºC to 26º C throughout the year. Daily average temperature also fluctuates widely that is from 15ºC to 30ºC, the highest temperature being recorded between January to April and the lowest recorded from June to August.Highest temperatures are mainly experienced along the lakeshore, which is the lower part of the catchment.

Evaporation and evapotranspiration rates are high during January to April since it is influenced by temperature; this in turns affect water resources and vegetation cover. The mean annual potential evaporation from the open waters (area) has been estimated to be 220 mm.

The main land use activities are settlement, agricultural and livestock rearing. Agricultural, activities accounts for 32.5% while vegetation and forest cover 61.8% (Calamari et al., 1995). Agriculture whose overall objective is to increase food production, contributes high proportion of surface run off which has a high proportion of water contaminants like sediments, nutrients and pesticides. On the upper catchment, there are tea and coffee estates, maize, pyrethrum, while on the middle and lower catchment there are mixed farming which include sugar cane, maize, sorghum, millet, groundnuts, rice especially in irrigated schemes, and cattle grazing.

The other land use activity in the catchment is infrastructures namely: road network, homestead, industrial establishment, and institutions. Most of them generate wastes, which are discharged into water sources hence impacting negatively its quality.

Methods

The study was conducted between 2000 and 2004. During this period seven major rivers namely: Nzoia, Yala, Nyando, Sondu-Miriu, Gucha- Migori,Mara, Sio and six small ones which include Awach Tende, Awach Kibuon, Awach Kano, North Awach were sampled. But for this report, only the results for nine rivers have been reported because of their bigger catchment coverage and land use activities. These are River Nzoia (12,842Km^2), River Gucha.Migori (6,600Km^2), River Nyando (3,652Km^2), River Sondu Miriu 3,405Km^2), River Yala 3,354Km^2. River Sio (1,437Km^2, Southern Awach that is mainly Tende and Kibuon (1,985Km^2). A total of 358 and 181 nutrient and sediments samples were collected respectively from fifty sampling stations distributed in the entire catchments. Sampling was arranged in such a way that it covered wet seasons when the high flows were recorded and during dry seasons when minimum flows were registered.

Nutrient samples were collected by filling plastic bottles by wading where flows were low but where the river depths were high, a diggi was used. In all cases, care was taken to ensure that a well-mixed sample representing the river cross section was obtained. The rivers sampled are characterized by their turbulence, hence facilitating the collection well mixed samples. Sample bottles were rinsed three times with the river water to be sampled before the final one was obtained.

In the case of suspended sediment samples, the width of the river was measured first and the river divided between three to five segments depending on the flow distribution. Well-mixed suspended samples were then collected along three to eight vertical profiles of river the depending on the river cross section. These samples were analysed, and their average taken thus providing data representing the entire river cross-section. In both cases, the sampling points were the same that is the national established gauge station. Discharge measurements were also taken at the same time sampling was done. Samples were kept in the cold boxes before being taken to the Ministry of Water and Irrigation laboratory in Kisumu for analysis.

Total Phosphorous (TP) was analysed using ascorbic method, while Total Nitrogen (TN) was analysed using persulphate method (Standard Method for Water and Wastewater Analysis 19th Edition.)

The estimates of pollution load for TN and TP from the rivers to the lake were calculated using volume-weighted concentration from river water quality and total annual discharges calculated from hydrology. The calendar year 2003 was chosen for this calculation because of the availability of daily flow data and high frequency sampling accomplished in the year.

Data analysis was done using Excel Linear Regression, Minitab Statistical Programme.

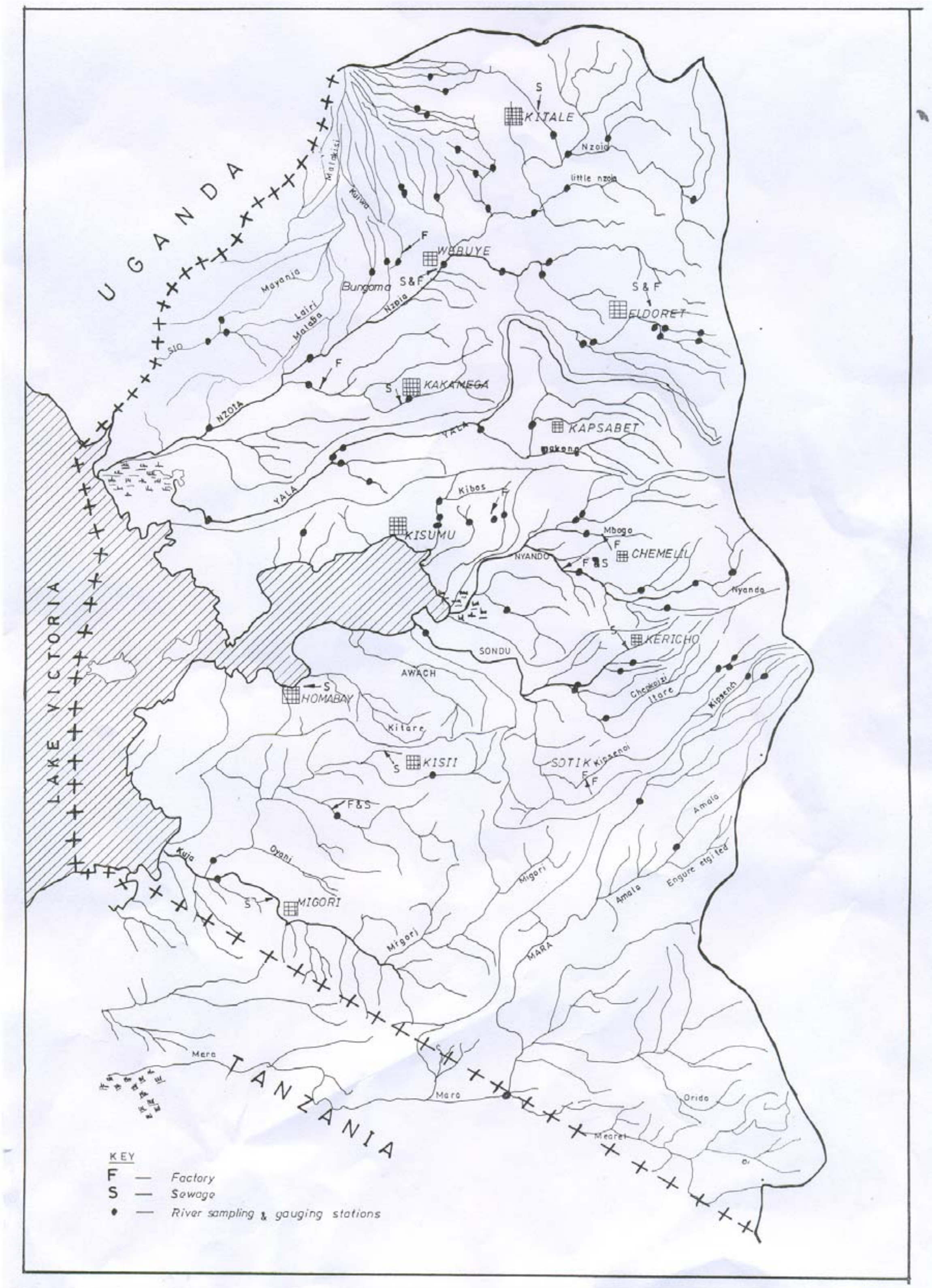

Fig 1. Lake Victoria Drainage Area (Kenya Side)

Results

Both the nutrients and the sediments showed a strong seasonal variation as shown in figure 2 The variation is a reflection of the region's climatic pattern, where long rains are experienced from March to May, followed by cool dry season which starts from June to September with short rain falling again between October to December. But due to changes in the weather, this annual climatic cycle at times changes, such that in 2002, and 2003, the long rains started in April. The average concentration for suspended sediments for the whole period of study was 142.8mg/L with a standard deviation of zero. The highest recorded value was 1080mg/L and this was obtained in August at the last station of Nzoia River System, and the minimum value recorded was obtained in Sondu Miriu of 10mg/L in March 2003. Concentration for TN and TP also followed the same pattern as that of sediment where highest concentrations were recorded during the onset of long rains and short rains simultaneously. Average concentration for TN for the three years was 1.320mg/L with a standard variation of 0.69. The highest value recorded during the entire period was 4.8 mg/l at Nyando (down stream of Muhoroni sugar factory). in March 2003, while lowest value was recorded at river Kimondi in Yala system in May 2004.

The average concentration for TP was found to be 0.187 mg/L with a standard deviation of 0.2. The highest value of the same was recorded at Wathonger, which is the last station of Gucha Migori system with value of 0.43 mg/l in July 2003, and the lowest value of 0.03 mg/Lwas recorded at Daraja, last station of Yala River System.
Generally low concentration were observed during the dry months which was also the case suspended concentrations.

Total Suspended Sediments

Total annual discharge recorded in the year 2003 and the volume weighted mean annual concentration for the last stations for each river system were used to calculate the total load to lake as their load depended on the discharges

Nzoia transported the largest suspended sediment load followed by Gucha-Migori, while North Awach contributed the least.

However, when you considered yield per unit area, Gucha Migori contributed the largest followed Nzoia, while N. awach still yielded the least.
There was a relationship between the sediment load and the catchment area. The load tend to increase with the increase in drainage area (y=51.173x, R^2= 0.866), where y is the sediment load in tones/yr and the x is the catchment area in Km^{2} (Figure 3)

TABLE 1.Total annual discharge, and mean volume weighted concentration (VWC) for nine monitored rivers in the Lake Victoria Basin

R. System	Total Discharge (m^3/s	TN (mg/L)	TP (mg/L)	TSS (mg/L)
Nzoia	57498.12	1.09	0.12	136.50
Gucha Migori	27,094.70	1.36	0.32	199
Nyando	5,040	1.9	0.4	213.9
Yala	17,564.84	1.06	0.09	115.5
Sondu-Miriu	17,726.45	1.22	0.12	94.8
Awach Tende	1832.34	1.68	0.18	188.4
Awach Kibuon	1,354.14	1.5	0.13	229
North Awach	726.00	0.77	0.12	110.6
Sio	4,722.81	0.85	0.13	77.6

TABLE 2.Total annual discharges and loads for TP, TN and TSS for nine rivers in the L. Victoria Basin

R. System	Total Discharge (m^3/s)	TP (tones/yr	TN (tones/yr)	TSS (tones/yr)
Nzoia	57498.12	844.53	5,414.53	678,109.83
Gucha Migori	27,094.70	842.773	3,090.02	465,855.43
Nyando	5,040	340.2	1615.95	93,144.04
Yala	17,564.84	136.58	1,608.66	175,283.10
Sondu-Miriu	17,726.45	183.59	1,821.75	145,192.40
Awach Tende	1832.34	28.5	265.95	29,826.39
Awach Kibuon	1,354.14	15.21	175.5	26,792.00
North Awach	726.00	7.5	48.3	6,937.54
Sio	4,722.81	53.05	346.84	31,664.74
Total	**133,559.40**	**2,451.93**	**14,387.50**	**1,652,805.47**

TABLE 3. Catchment area, yields for TP, TN and TSS for eight rivers monitored

R. System	Catchment Area(Km^2	TP ($Kg/km^2/yr$	TN ($Kg/km^2/yr$	TSS ($Kg/km^2/yr$)
Nzoia	12,842	65.76	421.63	52,804.07
Gucha Migori	6,600	127.69	468.18	70,584.16
Nyando	3,652	93.15	442.48	25,504.94
Yala	3,357	40.68	479.2	52,214.21
Sondu-Miriu	3,508	52.33	519.31	41,388.94
South Awach	3,156	13.84	139.88	17,939.92
North Awach	1,985	3.78	24.33	3,494.98
Sio	1,437	36.91	241.36	22,035.31
Total	36,537	434.14	2,736.37	285,966.55

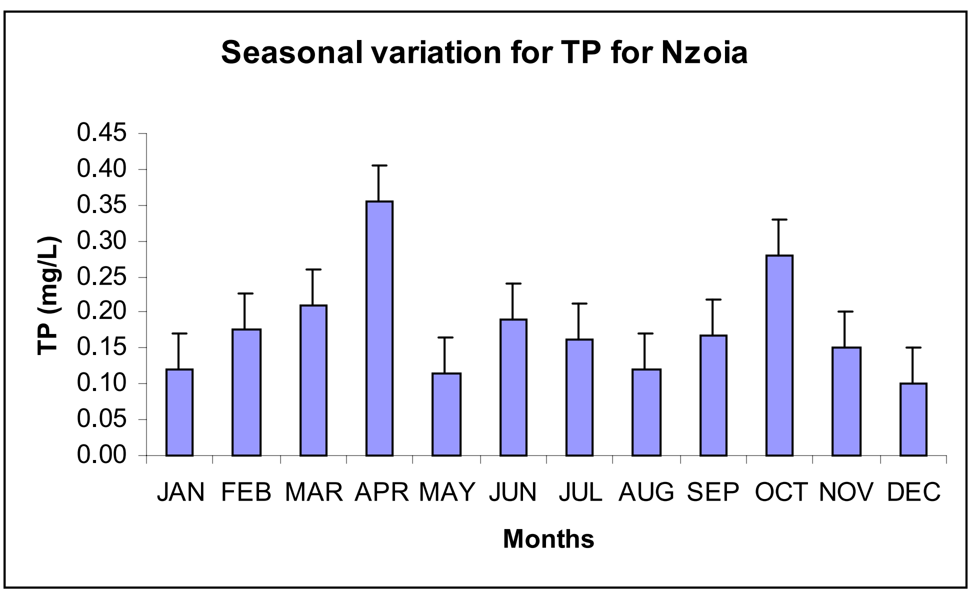

FIG 1. Seasonal variation for TP for Nzoia

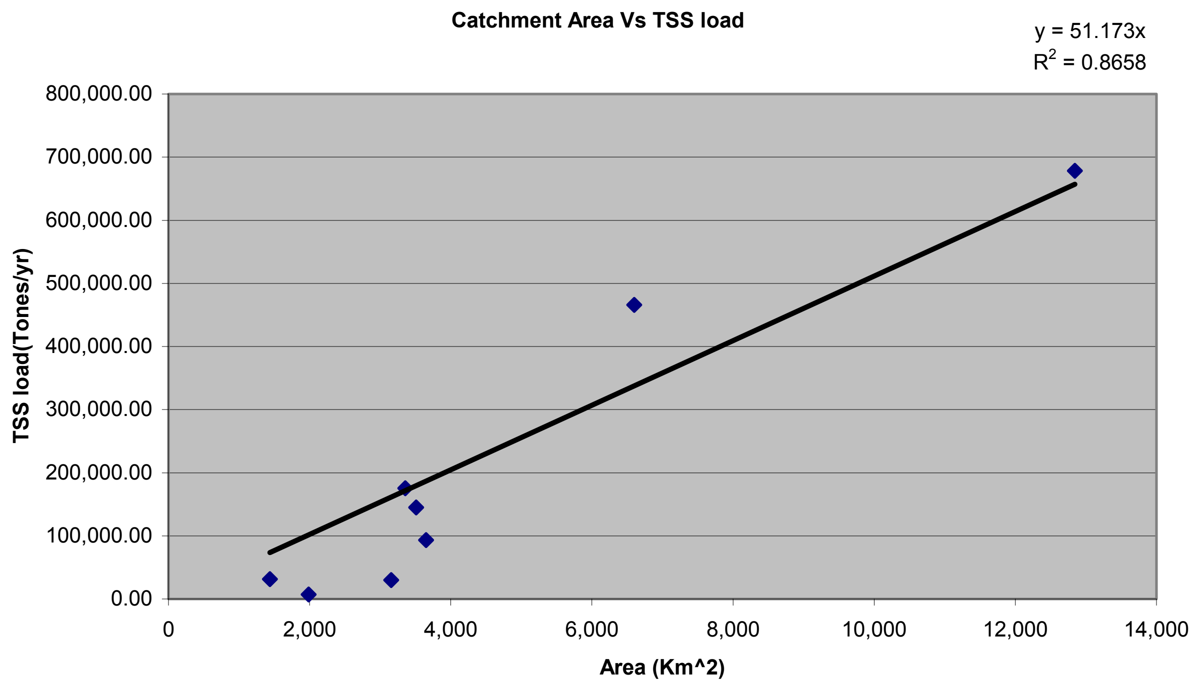

FIG 2. Catchment Area Vs TSS loads

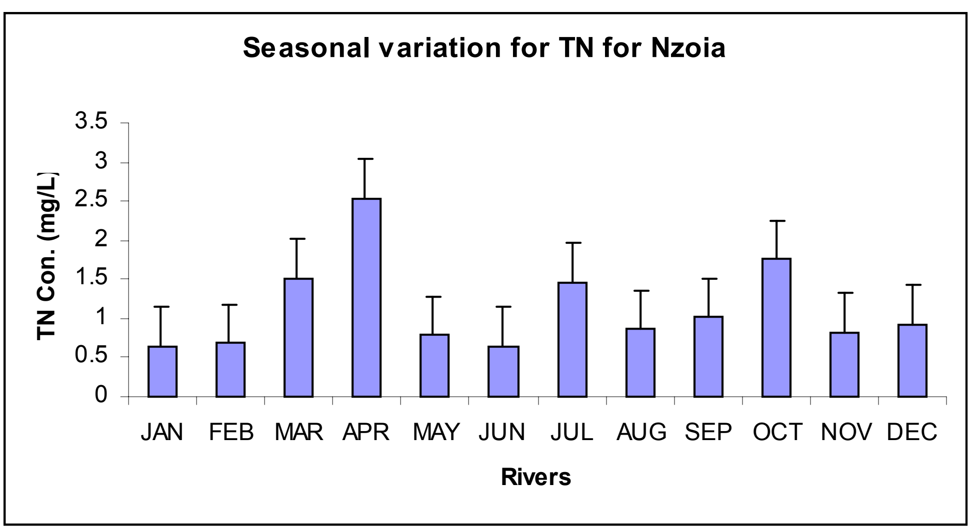

FIG 3 Seasonal variations for TN for River Nzoia

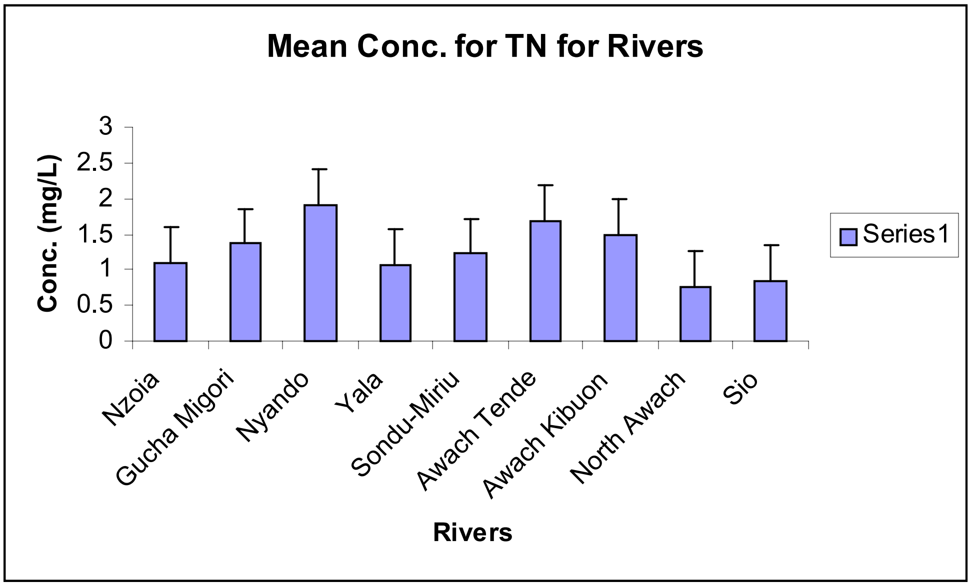

FIG 4 Mean Volume weighted Concentration for TP for nine rivers in L.Victoria Basin

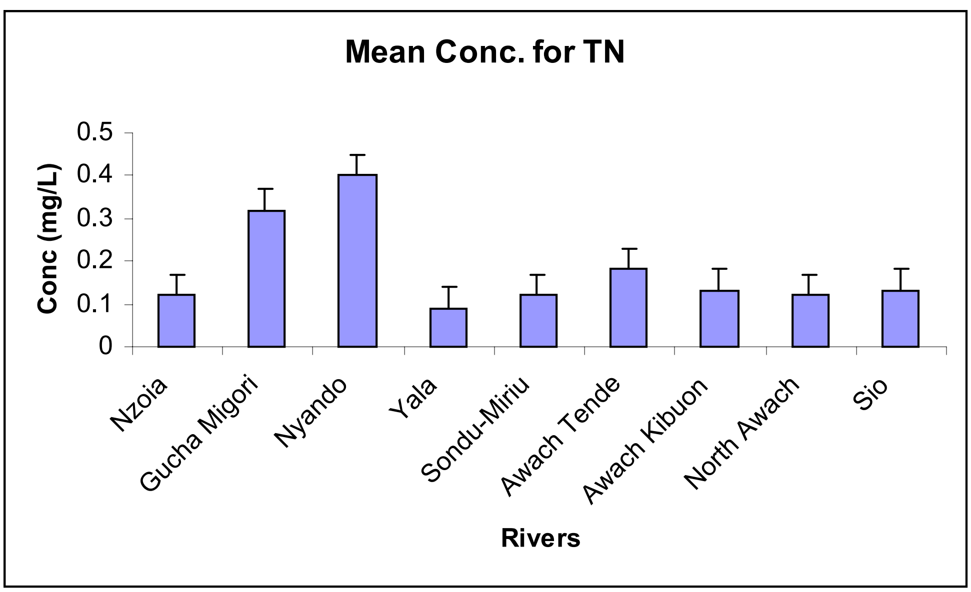

FIG 5 Mean Volume weighted concentration for TN for nine rivers in L.Victoria Basin

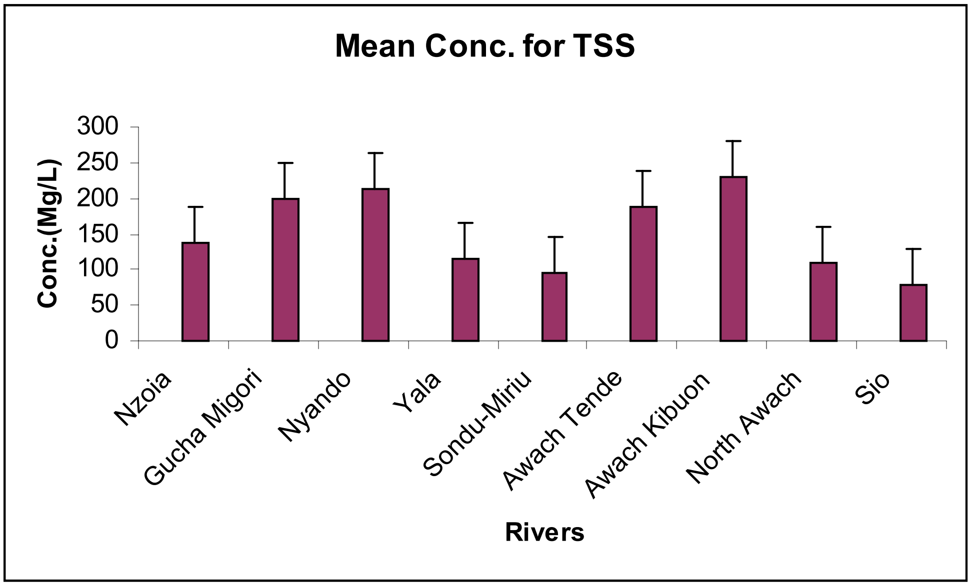

FIG 6 Mean Volume weighted concentration for TSS for nine rivers in L.Victoria Basin

Discussion

River water quality is normally influenced by different factors, such as anthropogenic activities, climatic and geographical. Rivers mentioned gave different concentration, which to a large extent were influenced by the above factors.

From the observation, it shows that Awach Kibuon, Nyando and Gucha – Migori recorded highest concentration value of suspended solid followed by Nzoia, while Sio and Sondu-Miriu recorded the least.(Fig 5.) TSS is mainly composed organic and inorganic material transported in water column and originates from surface run off and erosion from the river banks (Chapman 1999). Gucha and Awach tende which registered the highest sediment concentration originates from Kisii highland, which is has got hilly bare slopes, because of widespread clearance for settlement, agriculture and charcoal burning thus accelerating the loss of top soil from the surface area. The catchment also records the highest annual rainfall in the region. This is in agreement with what Chakela and Stocking (1988) found out, that topography and rainfall are key factors that Influences the variation in soil erosion. In addition the catchment is one of the areas with high population density (758 pp Km²) according to the last census report of 1999. This further exerts more pressure on the limited overused and poor cultivated land hence possiibly accelerating soil erosion from the slopes and the riverbanks. Other studies have also indicated that most of sediments originate from the mountainous areas (Milliman and Svitszki 1992), and Amazon, which is widely quoted, has 80% of sediment originating from Andes Mountains, which only constitute 10% of the total drainage area

Nzoia has the largest catchment with an elaborate network of tributaries. It drains some of the areas where intensive agriculture is being practiced, for example a large portion of Cherangani Hills have been exercised for agriculture. There has also been uncontrolled cutting and grazing that has resulted in reduction in vegetation cover which facilitate the surface run off thus possibly explaining the high suspended solids experienced especially during peak flow.

On the other hand Nyando registered the highest concentration for TP and TN followed by Gucha – Migori. According to Odada et al., (2004), the sediment load in River Nyando has increased by 7.5 times in the last 16 years. This could be to due to the fact the fact, Nyando receives very strong industrial effluent from Agrochemicals and Food Company and Muhuroni Sugar Company and also urban effluent from Muhuroni urban council. The factories discharges huge quantities of partially treated effluent with high content of nutrients and suspended solids downstream which is only 50Km from where the monitoring station is installed. The river also traverse big sugar cane plantation and rice schemes on its lower parts, and because of poor soil fertility, there is a possibility that a lot of fertilizers are being applied to enhance production. Chances are that excess fertilizer find their way in the water course hence an increase nutrient concentration. Its lower basin is also characterize by eroded and falling banks thus contributing high-suspended sediment loads as observed also by Odada et al., (2004), this enhanced erosion directly contributes sediments load to the river and finally to lake

Seasonal Variation

The concentration of three parameters were statistically analysed to assess their temporal variation. All three parameters exhibited a strong seasonal variation, Figure 1 and 2. Low levels of TSS, TN and TP were recorded between January and March, and a steep rise in April followed again low concentration between May and September TSS and TP, and another steep rise in October before dropping down during November and December. TN registered some rise in July.

But statistically only four rivers were found to be having a significant difference for TSS, that is April and December ($p > 0.05$) Although there was some difference among other months, but they were not significant..

For TN, four months were found to be having significance difference, that is January and April and between April and September ($p > 0.05$)
The months which registered significance difference for TP concentration was April and January at $p > 0.05$)

It is noted that April and October are the months, which showed major difference with other months. These are months with long and short rains start simultaneously.

Climatic factors controls agricultural activities in this region, just as Hecky et al., (2000) found in Malawi. During the spell of long dry season (January to March), there is an extensive land preparation, which involve clearing and burning of biomass to renew soil fertility. The field are ploughed a waiting the onset of the rains to plant. Ploughing of farmland and grassland particularly during dry cool period expose large quantities of soil nitrogen (Helman and Hesphanhol eds, 1997), so with the falling of heavy rainfall on the exposed bare soil, at the onset of rainy seasons late March or early April and October) probably causing substantial leaching of nitrates, some of them probably finding their way into the river incase no dentrification occurs. Equally large of sediment laden with phosphates are transported during this particular time thus making April and October, to record high concentration of the above parameters.

During the growing seasons, there is less release of sediments and associated nutrient.

This could be because of the increased uptake of water and nutrients by increased vegetation cover (Hecky et al 2000). However, there was an unusual increase of TN during the month July, possibly because, in July farmers do top dressing using urea or calcium ammium nitrogen (CN). These are nitrogen based compound. Excess are leached into the water course, hence could be what is causing the high rise of TN during this period

Comparison for inter-riiver variation, the significant difference was observed between Gucha-Migori and Yala at p- value >0.05 and also between Yala and Nyando at p-0.01 for TN and TSS. The rest had no significant difference Fig 4-6.

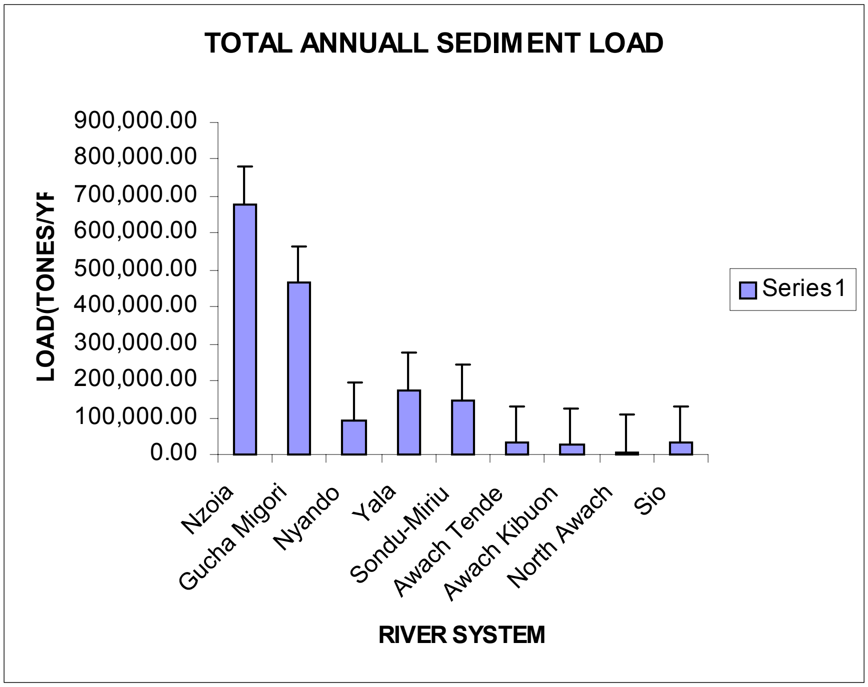

FIG 7Total annual load for TSS for Rivers the in lake Victoria basin

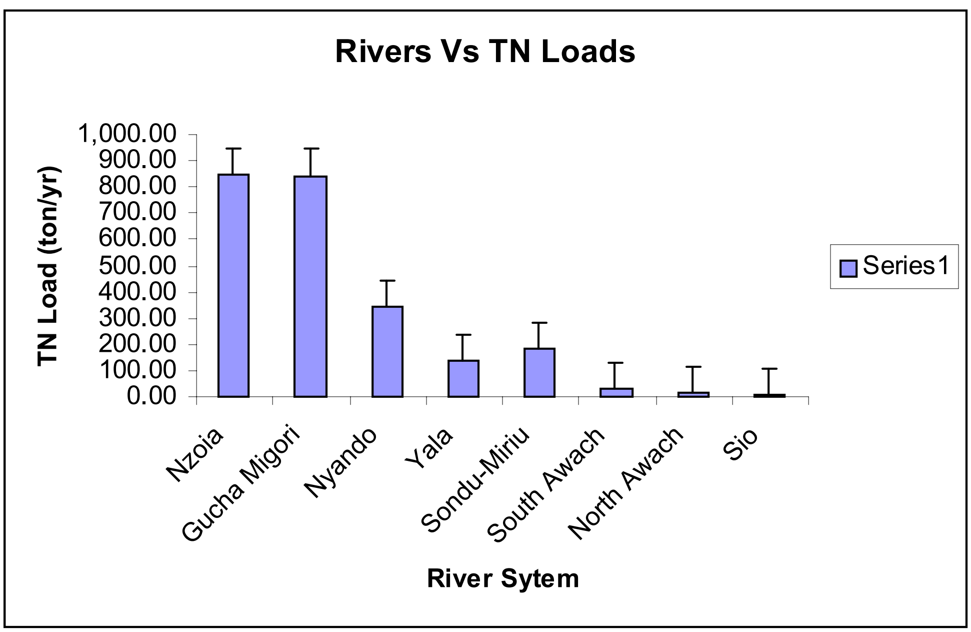

FIG 8 Total annual loads for TN for the Rivers in lake Victoria Basin

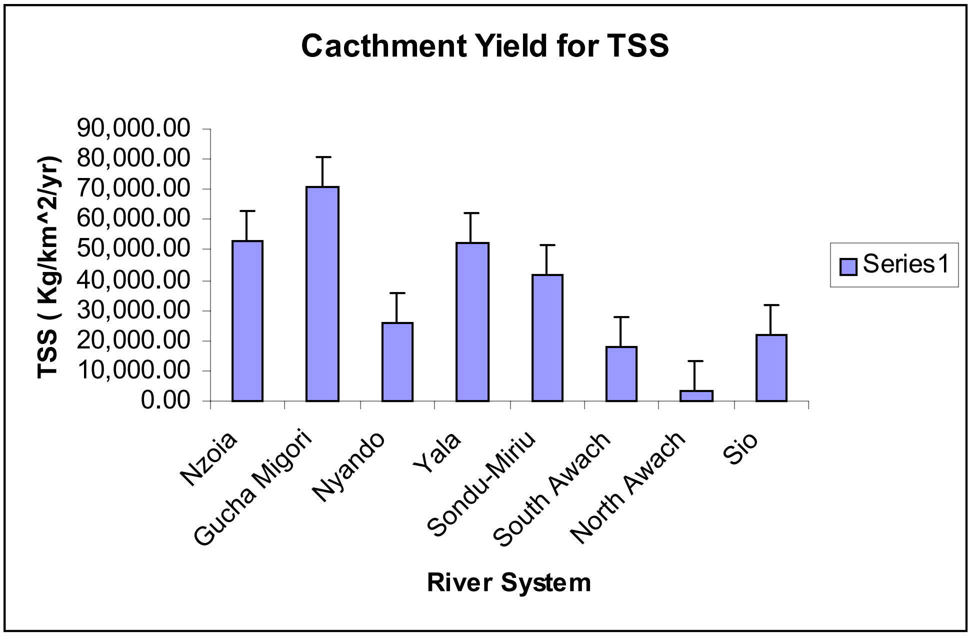

FIG 9 Catcment yields for the Rivers in the Lake Victoria Basin

Sediment load and yield

The load transported by the rivers to the Lake Victoria is influenced by the activities in the catchment, drainage area and river discharge. Table2 summarizes the total load for TP, TN, and TSS for the whole year on the Kenya catchment side of lake Victoria. This load has taken into consideration the contribution of point sources from the ccatchment, which might have not been degraded by the time it reaches the last sampling station.

Compared with studies conducted in 2002 which estimated the load for TP and TN at 1,724 and 9,603 tones/year, the current loads are comparatively higher possibly because the figure used then were mainly typical values as actual measurement were minimal compared to the current estimates where most of the estimates has been calculated using actual measurement. However it corresponds well when the percentage contribution of each element is considered. In LVEMP 2002 studies, the contribution from phosphorus was 10% while the current one the contribution from phosphorus is 14% (Table 4).

However when sediment yield is considered Gucha- Migori was leading (fig 9), while North Awach recorded the least. Sediment yield of large catchment areas are normally influenced by the interaction of a range factors namely: climatic, precipitation, discharge, basin geology and area (Milliman and Syvitski, 1992), compared to the rivers with smaller catchment areas which probably could only be controlled by a single parameter like the type of geology or climate. The drainage of Gucha- Migori is affected by the above factors; by being characteristics by hilly steep slopes with extensive agriculture and this could be the possible reason its high yields

North Awach transported the least TSS load followed by Awach Kibuon. This indicates that sediment load is influenced mainly by two parameters namely: discharge and drainage. Since the two rivers has got least drainage area. This is opposed to Malawi's case where sediment load and yield were mainly influenced by land use activities, such that where there was less vegetation cover, the yields were extremely high.

Table 4 Comparison between LVEMP 2002 and 2005.

	TP t/yr	TN t/yr	TSS t/yr
LVEMP (2002)	1,724	9,603	
LVEMP(2005)	2,451.93	14,387.5	1.652,805.47

	TP%	TN%
LVEMP (2002)	10%	90%
LVEMP(2005)	14%	86%

Comparing the values with the ones Hecky et al, (2000) obtained in Malawi rivers, it seen that the Kenya catchment been mostly interfered with.

CONCLUSIION AND RECOMMENDATION

The study has shown that the water quality of the rivers in lake Victoria Basin catchments continues to deteriorate as observed from the levels of nutrients and detected in the waters. Equally the loads of nutrients and sediment being transported to lake continue to increase, an indication that the rate at which environment is being destroyed is increasing instead of decreasing.

It is therefore recommended that the core activities geared towards addressing environmental restoration and conservation like a forestation and soil and water conservation should be intensified.

Monitoring of the river waters should continue and the focus should be in the micro-catchments.

CHAPTER 6

Industrial and municipal effluent loadings into the Lake Victoria catchment, Kenya

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INTRODUCTION

The population in the entire Lake Victoria basin is estimated to be 30 million in 1995 continues to increase. This has triggered increased urbanization and invariably increased demand for water, various resources and services including manufactured goods. Increased demand for processing water, has concomitantly led to increase in effluents discharged directly into the lake or into rivers and their tributaries which in turn discharge into the lake.

The environmental and socio-economic consequences of the above scenario abound. One of the consequences is polluted water resources that are costly to treat for domestic purposes and industrial use. For instance, chlorine used for disinfection of drinking water combines with organic matter to form chloramines, reducing the chlorine available to effectively kill disease-causing organisms such as viruses, and bacteria. This may pose the risk to consumers of contracting water-borne diseases such as cholera, typhoid and shigellosis. Alleviating this problem would require an increase in the quantity of the disinfectant (chlorine) with concomitant increase in the cost of water treatment. Similar problems are encountered in other consumptive water uses such as beverage and pharmaceutical industries.

Effluent discharges deplete oxygen in the Lake due to the presence of oxygen consuming organic and inorganic substances. Low oxygen may result into fish kills (Hecky *et al.,* 1994) or interference with the reproductive function of fish and other aquatic organisms or migration of oxygen dependent species. Consequently, availability of fish and fish products to consumers is reduced.

Enrichment of the lake water results in the proliferation of algal blooms and noxious weeds such as the water hyacinth. The blooms and weeds are a manifestation of eutrophication. These clog water supply intakes and pumps and impart undesirable taste and odour to water for domestic and industrial use. This also results in increased cost of water treatment and consumer complaints. Impact of untreated waste on water quality is also manifested through aesthetic effects, leading to loss of scenic beauty with water becoming unsuitable for recreation and water rights conflicts due to shortage of water of suitable quality for domestic, industrial and irrigation purposes.

Study objectives

Implementation of the subcomponent on Management of Industrial and Municipal Effluents (MIME) under the LVEMP project was aimed at addressing various deficiencies, which contribute to the overall problem of deterioration of the Lake water quality. The main tasks were to identify and catalogue industries and municipalities that produce organic and inorganic pollutants including nutrients; to collect pertinent information relating to each industry such as industry location, process water requirements and inputs, outputs, by-products (effluents and solid wastes), and their environmental impacts and to sensitize stakeholders to take a lead role in promoting cleaner technology.

Past policy and management deficiencies especially in the legal and institutional framework have largely been addressed or are being addressed. The enactment of the Environment Management and Coordination Act 2000, the Water (Amendment) Act 2002, and the formation of the National Environment Management Authority and the Water Resources Management Authority is seen as a major step in the right direction towards addressing, *inter alia*, the problem of water resources and environmental quality degradation.

The specific objectives were: (1) to establish geographical location, activities and particulars of each municipality and factory/industry in the Kenyan Lake Victoria catchment; (2) to classify the factories on the basis of those with and those without effluent treatment facilities and the watercourse into which they discharge (3) to assess the degree and/or efficiency of treatment of the effluent before discharge (4) to assess the contribution of urban runoff to Lake pollution; and (5) to assess the efficacy of a pilot scale constructed wetland in purifying wastewater at a tertiary level.

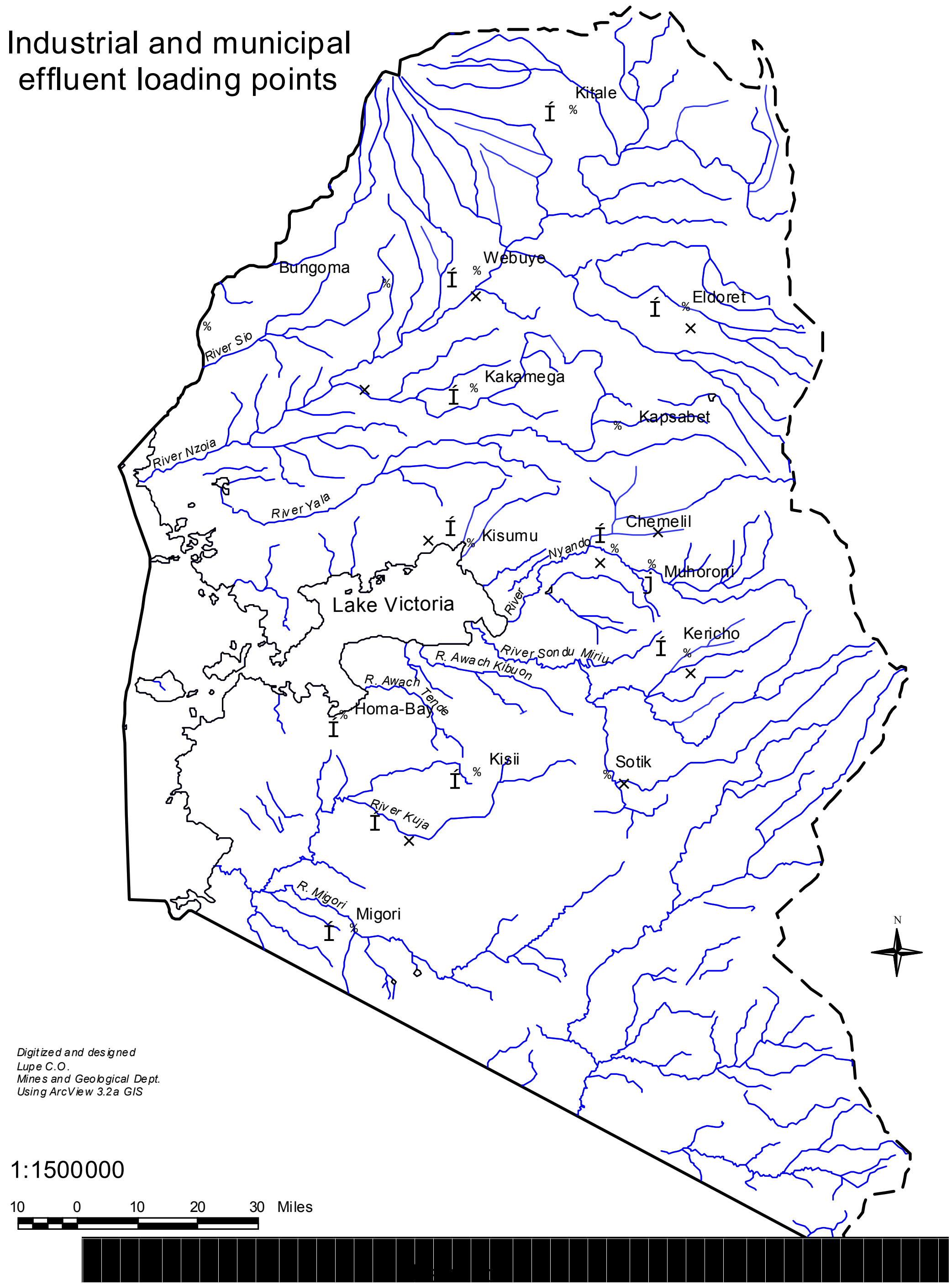

Figure 1: Distribution/location of municipalities and industries in the Lake

Victoriacatchment

Types of point sources and parameters measured

By definition, a point source is a pollution input that can be related to a single waste water outlet. Point sources of pollution consist of industrial and municipal sites with defined effluent discharge points to a watercourse or sewer. Some point sources are characterized by a relatively constant discharge of the polluting substances over time such as domestic sewers, whereas others are occasional or fluctuation discharges, such as leaks and accidental spillages (Chapman, 19??).

Municipal sources are sewage treatment facilities both conventional type and waste stabilization ponds (WSPs). Some urban centers have no sewerage systems and rely on septic tanks, soak pits and pit latrines for domestic waste disposal. The distribution/ location of major industries and urban centers is shown in Figure 1.

Industrial sources of pollution

Majority of industries in the catchment use agricultural products as raw materials. The most important pollutants in the wastewater emanating from the agro-based industries are organic compounds. Most industries employ wet processing methods thus producing liquid waste and solid waste in the form of sludge. Some industries e.g. tea-processing use dry methods and generate mainly solid waste except during the washing of machinery and floors. Leachates from solid waste dumps are a source of pollution to both ground and surface water by way of infiltration and run-off respectively. Liquid waste was the focus of the Lake Victoria Environment Management Programme (LVEMP) in the first phase.

Various categories of industries exist in the Kenyan Lake Victoria catchment namely, sugar manufacture, textile, dairy, pulp and paper, tea, coffee, food processing, distilleries, jageries, slaughter houses, fish processing and beverage.

Sugarcane factories

The sugar industry processes sugar cane to manufacture edible sugar. There are six operational sugar factories in Kenya's Lake Victoria catchment. They use vacuum pump boiling processes. Major factories (refer to Annex 2) producing large amounts of sugar include Mumias (700-800 t/d), South Nyanza (SONY) (300 t/d) and Chemelil (295 t/d). Others are West Kenya, Muhoroni and Nzoia. The Miwani Sugar factory has closed down. Wastes generated from sugar processing comprise bagasse, fuel oil, mud, molasses and some sugar losses during production. The factories use waste stabilization lagoons to treat their wastewater. Besides the lagoons, SONY and Nzoia also have an aeration pond.

Textile mills

The stages in textile production include fibre production, fibre processing and spinning, yarn preparation, bleaching, dyeing, printing and finishing. Each processing stage generates wastes. Liquid waste is generated during washing, bleaching, dyeing, printing and finishing. These stages are the main focus of wastewater monitoring (World Bank, 1999).

Textile mills in the Lake catchment are mainly located in Eldoret (Nzoia River catchment). Only (Ken Knit) is currently fully operational. Heritage Garments (Rupa) operates on a small scale after closing down for some time. Rivatex closed down completely. The two operating industries discharge their wastewater into the municipal sewer. Wastewater from Ken Knit undergoes pre-treatment before discharge into the municipal sewer. There is, however, no pre-treatment for wastewater from Rupa.

Dairy industry

Dairy industry involves processing of raw milk into consumer milk, butter, cheese, yogurt, dry milk, and ice cream. The dairy industries in the lake catchment produce mainly consumer milk, butter and to some extent fermented milk with fruit concentrates.

The wastewater generated from the raw milk processing contains dissolved sugar and proteins, fats, fruit concentrate residues and pathogens. Wastewater from Kenya Cooperative Creamery (KCC)-Eldoret and KCC-Kitale are discharged into their respective municipal sewers. Premier Dairy-Kericho uses anaerobic digesters together with lagoons for wastewater treatment while KCC-Sotik uses an aerated lagoon. Aeration takes 12-14 hours followed by settling 2-3 hours and finally discharged for about 1 hour into the nearby Kipsonoi River.

Fish processing

Fish processing involves cutting of fish in order to produce fish fillets. Typically, the process uses large quantity of water with liquid waste generation of $20m^3$/ton (Scheren et al., 1994). Fish remains after filleting are used as cattle feed or local human consumption. Most of the fish processing industries are located in Kisumu, namely Afro-Meat, Sea Foods and Food

Processors (FP) 2000. Capital Fish Processors and Prinsal Fish Processing Company are located in Homa-Bay and Migori respectively.

Wastewater from fish production contains fat, blood, scales, and fleshing. All of the industries discharge their wastewater into municipal sewers except Prinsal factory that uses overland disposal, without pretreatment.

Pulp and paper

The manufacture of paper can be divided into two phases: pulping the wood or other material and making the final paper product. The raw materials generally used in the pulping phase are wood, cotton, linen, straw, and hemp or waste paper (Nemerow, 1978). The materials are reduced to fiber, which are subsequently refined sometimes bleached and dried. At the paper mill the pulp is combined and loaded with fillers; finishers are added and the product transformed into sheets.

In the pulp and paper industries two main wastes are produced, namely pulp-mill and paper-mill waste. Pulp-mill waste contain sulphite liquor, fine pulp, bleaching chemicals, mercaptans, phenols, sodium sulphide, carbonates and hydroxides, sizing casein, clay, ink dyes, grease, oils, and fibers. Paper mill wastes contain fine fibers, sizing, dye and other loading materials (Nemerow, 1978). There is only one integrated pulp and paper mill in the lake catchment namely Pan African Paper Mills (E.A) Ltd (PANPAPER). It uses wood to make pulp and recycles waste paper to make unbleached grade paper. Highland papermill in Eldoret utilizes waste as raw material to manufacture unbleached paper grade.

Slaughter houses

The term “slaughter house” as used in this text refers to an abattoir for slaughter of beef animals, goats and sheep; bleeding and carcass separation. Washings take place that give rise to dirt dung, grit etc., in the effluent. Blood is normally kept separate in deep pits. The animal paunch (stomach) is removed and washed. The carcass preparation produces blood, tissue and fat that form part of the wash water. The resulting organics, dissolved and suspended are the main pollutants.

Large urban centers within the Lake catchment have at least one slaughterhouse. The wastewater composition, biochemical oxygen demand (BOD) and solids concentration, depend on number and type of animals slaughtered, in-plant control of water use, by-products recovery, waste separation at source and plant management (Polprasert, 1996).

Coffee processing factories

Coffee processing involves removal of husks (pulping process), removal of the mucilage covering the seed (fermentation process), washing and drying to obtain coffee beans. The fermentation process produces wastewater with high organic content.

The Lake catchment has numerous coffee factories located mainly in the Rift Valley districts of Kericho and Bureti; and Kisii and Nyamira districts in Nyanza province. Most of the factories discharge fermentation and washing water into dug pits while pulps are spread on land for use as manure. Coffee wastes therefore pose less risk of surface water pollution. They can however be a source of pollution to groundwater.

The general characteristics of effluents from major industry types are presented in Table 1. The characteristics give the picture of the kind of waste expected to be released into the environment from industrial establishments in the lake Catchment that, if not properly managed, may lead environmental degradation.

Table 1 Main types of industries found in the Kenyan Lake Victoria Catchment. General characteristics of similar wastewater types from literature are presented (concentrations are in mg/l)

Industrial sector	Typical characteristics from literature	Source
Sugar	BOD_5: 1700-6000 COD: 2300-8000 TSS: up to 5000	World Bank, 1999
Fish Processing	BOD_5: 300 COD: 700 SS: 400	Scheren *et al*.,1994
Paper manufacture	BOD: 100-300 TSS: 75-300	Nemerow, 1978
Textile	BOD: 700-2000 COD: 1400-2400	World Bank, 1999
Dairy	BOD: 0.8-2.5kg/t milk COD: 1.2-3.75 kg/t milk TSS: 100-1000 Phosphorous: 10-100 Nitrogen: 0.048-0.15kg/t milk	World Bank, 1999
Coffee	BOD: 5000-9000 PH: 4-5	World Bank, 1996
Slaughter houses	BOD_5: 600-8000mg/l TSS: 800mg/l Offensive odour Pathogens e.g. salmonella, amoebic cysts, shigella	World Bank, 1999

COD = chemical oxygen demand; TSS = total suspended solids

Municipal sources of pollution

Municipal wastewaters consist of sewage effluents, urban drainage and other collected wastewaters. They usually contain high levels of organic matter and faecal material. Depending on the collection and treatment systems in operation, municipal wastes may contain various other organic and inorganic contaminants of industrial origin. In addition, garbage dumpsites contribute various pollutants into surface and groundwater.

The study considered municipalities with population of 10,000 people and above. The Kenyan Lake Victoria catchment has about 50 such municipalities (Annex 1).

Parameters measured

The most important indicators of organic and nutrient pollution measured include BOD, COD, Total Nitrogen, Total Phosphorous and Total dissolved solids. Other in-situ parameters include pH, temperature, DO, Conductivity. The same indicator parameters were used to assess industrial effluent quality. Besides the above parameters, phenols were determined in pulp and paper wastewater.

Strategies to reduce effluents

One of the guiding principles that present a sound basis for management of water pollution is the 'pollution prevention' principle (Helmer and Hespanhol, 1997). The principle gives prominence to pollution prevention (internal control) rather than treating systems (External or end-o-pipe control). The latter is much more expensive depending on the choice of technology especially once large ecosystems are affected.

Cleaner technology

Internal control measures focus on wastewater minimization, in plant refinement of raw materials and production processes, recycling of waste products among other things. Pollution prevention and waste minimization is referred to as cleaner technology. Cleaner technologies are implemented in the industrial sector. Minimisation of wastewater from domestic sources is possible to a limited extent only (Helmer and Hespanhol 1997).

One of the critical success factors for cleaner technology is external incentive. An appropriate policy and regulatory framework must be in place. Although this is present in Kenya lack of a credible enforcement system has been exploited by industries that continue to generate large amounts of pollutant-laden effluents.

Tertiary treatment by wetland

In recent years both natural and constructed wetlands have found prominence as low cost eco-technological solutions in pollution control. Constructed wetlands are engineered systems that are dominated by emergent macrophytes. They are sometimes referred to by different names for instance 'reed beds' (Cooper *et al*., 1996), or treatment wetlands (Hammer and Bastian, 1989). They have been used in Europe and America (Kadlec and Knight 1996) to treat a variety of wastewaters both domestic and industrial. Wetland systems have been reported to treat various wastewaters with varying efficiencies.

In East Africa, with itstropical climate favoring year round plant growth, natural wetlands have received wastewaters for decades and they are natural candidates for tertiary treatment of waste waters. Examples are the Nakivubo wetland in Kampala (Kansiime and Nalubega 1997), the Kahawa West wetland on the outskirts of Nairobi (Chale, 1985). However, constructed wetland technology is relatively new. One of the oldest full-scale systems for domestic wastewater is located in Nairobi and treats wastewater from a large restaurant and children's recreation park (Nyakango and van Bruggen, 1995). Since then other full-scale systems have been established at Masaka in Uganda, at Moshi in Tanzania, among others.

Several pilot-scale studies with domestic wastewater have been carried out at Kirinya Sewage works in Jinja Uganda (Okurut 2000), Dar es Salaam University (Mashauri et al., 1995) and Jomo Kenyatta University in Kenya. The performance has been found satisfactory. Under the LVEMP project, a pilot treatment wetland for domestic wastewater was constructed and studied in Mwanza while a natural wetland was biomanipulated to treat municipal wastewater in Jinja (Kansiime 2002). However, published data on constructed wetlands for industrial wastewater in the tropics are still sparse.

In the LVEMP project in Kenya it was decided to undertake a pilot study namely "Integrated Tertiary Industrial Effluent Treatment" to establish the efficacy of a constructed wetland to treat effluent emanating from the present lagoons of Pan African Paper Mills (E.A.) Ltd in Webuye.

METHODS

Methods adopted for loading estimates

Measurements

This involved the use of actual concentration and discharge measurements to determine the loads. Field portable meters (YSI, Model 610-DM), pH meter, DO meter, Conductivity meter) were used for in-situ measurements of pH, electrical conductivity, dissolved oxygen and temperature. Samples for laboratory analysis were taken, stored at 4°C and analysed following methods described by APHA (1995).

Discharge measurements were made on-site using a current meter (tamaya-UC2) and where applicable were read off installed measuring devices such as weirs.

$$Q_d = 0.0864 q_s c$$

Where:

Q_d = pollutant load in kg/day
q_s = discharge in litres/second
c = concentration in mg/l

Standard figures for municipal Loads

For urban centres where waste disposal is done through septic tanks and pit latrines, wastewater pollution loads were estimated using, the following standard figures:

- BOD: 30-40 g/person equivalent/day
- Total Nitrogen: 5 g/person equivalent/day
- Total Phosphorous: 2 g/person equivalent/day

These figures reflect the levels for population in developing countries with relatively low protein intake (LVEMP/COWI (2002).

Rough estimates

Where neither wastewater production nor industrial figures were available, rough estimates were given. For example, 70% was used as load reduction percentage through discharge system for towns or urban population served by septic tanks and pit latrines to obtain final loads into the Lake Victoria, catchment (LVEMP/COWI (2002).

Industrial Pollution load based on production figures

Where no measurements were available for industrial wastewater production, the assessment of wastewater pollution loads were based on standard loads per production unit for a given industry type and the actual production figures (World Bank, 1999). Industry Sector Guidelines has been used as the main reference for determination of industrial wastewater pollution based on production figures.

Pilot scale constructed wetland

Preliminary investigations with various local macrophytes in bucket mesocosms were carried out as described by Abira *et al.* (2003). The results obtained provided the basis for design, construction and operation of a small-scale pilot wetland to study its efficacy for removal of phenols among other pollutants from the pulp and paper mill effluent (Abira *et al*., 2004). This pilot study wetland was the object of a PhD study by one of the project staff, Mrs. Abira.

RESULTS

Inventory, and discharge location

A full inventory, global positions, catchment and receiving watercourse for municipal sources of effluents is given at Annex 1. Among the municipalities, only Homa Bay and Kisumu (conventional system) discharge directly into the lake. The latter however does so via a small stream (Kisat river) some 200m from the lake.

The inventory for industries indicating effluent treatment types is presented at Annex 2. Majority of the industries do not discharge directly into the Lake. The Kisumu distillery (molasses) plant, a new establishment was not covered during this study and it would be interesting to establish its activities including waste management given its proximity to the Lake.

Variations in measured concentrations

Municipal

Table 3 shows the measured concentration ranges for selected towns. The period covered in most cases is 2000 to 2004.

Table 3 Variation in measured concentration for discharges from selected municipal wastewater treatment facilities. (Concentrations are in mg/l except for EC, which is in µS/cm)

Town	Effluent type	Concentration range					
		EC	BOD	COD	TN	TP	Data sets
Kisumu conventional (Kisat)	Raw	830-1200	318-629	624-2105	22-68	8.4-18	4 – 7 *[1]
	Final	880-1060	100-370	180-890	14-63	8-12	
Kisumu Nyalenda WSP	Raw	490-850	115-270	310-825	7-110	1.2-8.1	3 – 6 *[2]
	Final	200-600	4-27	28-140	0.7-7.1	0.4-2.6	
Busia WSP	Raw	540-1380	95-330	360-880	73-90	10-15	3 – 5*[3]
	Final	200-740	13-70	70-180	10-50	2.5-4	
Homa Bay	Raw	1740-1870	670-983	600-1700	30-110	20-26	3 - 4*[4]
	Final	1625-2010	21-58	130-220	13-55	17-26	
Kisii WSP	Raw	514-1240	155-400	530-1200	31-80	7-19	3 – 6*[5]
	Final	340-507	12-45	144-203	8-18	1-18	
Eldoret conventional	Raw	560-1950	190-2200	436-5412	25-85	6.5-8.5	5 – 7*[6]
	Final	374-1702	20-240	112-490	13-16	3-6	
Eldoret WSP	Raw	315-1440	250-1070	400-2200	14-84	1.3-21	6 – 9*[7]
	Final	512-910	7-108	52-340	6.6-33	0.4-7.6	
Kakamega WSP (Shirere)	Raw	800-1710	330-504	807-1920	90	13-19	3 – 4*[8]
	Final	567-1180	5-29	28-64*[8b]	43-58	7-17	
Kericho	Raw	920-3960	570-1860	690-3920	95-146	2.5-146	4 – 6*[9]
	Final	780-1710	29-150	128-380	40-61	2.6-16	
Mumias Sugar (Central)	Raw	307-457	46-190	80-372	14-16	2.9-3.9	3 – 4*[10]
	Final	207-305	3-24	7-63	2-14	1.9-2.5	
Kapsabet	Raw	270-675	40-150	305-560	6-51	1.4-7	3 – 4*[11]
	Final	250-500	15-18	120-145	1.1-8.7	1.9-2.8	

WSP = waste stabilization ponds
The data sets refer to no. of data holdings in the period specified below:
[1] years 2001 to 2003; [2]years 2001, 2003 to 2004; [3]years 2001 & 2003; [4]years 2001, 2003 to 2004
[5]years 2001 to 2003; [6]years 2001 & 2003 n=2 for TN & TP, not operational in 2002; [7]years 2001 to 2004; [9]Years 2001 to 2003; [8]years 2001 to 2004, [8b]during a storm COD rose up to 137 mg/l; [10]years 2001, 2003 to 2005; [11]years 2001, 2003.

Industrial Establishment

Large variations were noticeable in the measured concentrations of parameters indicative of pollution. Examples are given in Figure 2 and Tables 4 &5.

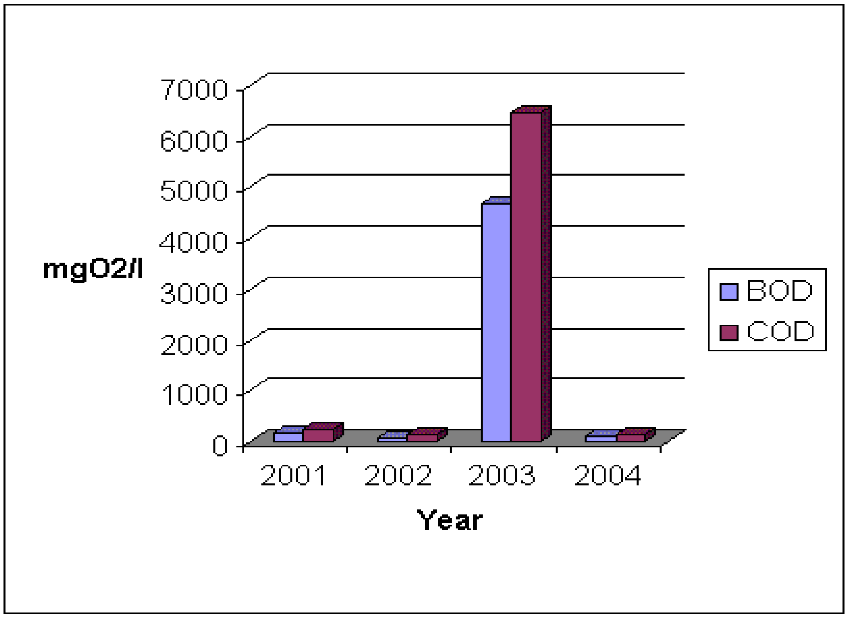

Figure 2. Temporal variation in BOD and COD concentrations at SONY sugar factory.

Table 4: Measured concentration of various parameters in the final effluent of some sugar industries. (Concentrations are in mg/l except for EC, which is in µS/cm).

Industry	Concentration range					
	Chemelil	SONY	Mumias	Nzoia	Muhoroni	Kenyan discharge* Guidelines
EC	920-2450	1141-2560	2040-3200	1112-1734	670-740	-
BOD	9-48 (4800)	55-155	15-100 (2500)	200-3400	6-140	30
COD	73-970 (6100)	128-2000 (16400)	190-2640	1185-3273	41-750	50
TN	5-63	1.3-12	10-25	6.7-14	5-21	-
TP	1-101	0.6-11	5-19	0.6-5.8	2.7-9.8	-

One-time maximum-recorded values are in parenthesis

*Source: National Environment Management Authority – NEMA (proposed)

Table 5: Measured concentration of various parameters in the final effluent of other industries (Concentrations are in mg/l except for EC, which is in µS/cm).

Parameter	Pan African Paper Mills[1]	Agrochemical and Food Co.[3]	Premier Dairies[4]	Prinsal Enterprises[5]	Kenyan discharge Guidelines[6]
EC	1320-1750	1200-13200	137-859	890-1050	-
BOD	27-100	800-4000 (18500)	195-1160	220-550	30
COD	190-490 280-620[2]	8200-24000	400-1330	180-15000	50
TN	0.9-3.1	352-1160	26	36	-
TP	0.5-1.4	3-136	7.3-31	2.3-18	-
Phenols	0.43-0.64 [2]	-	-	-	0.05*

One-time maximum-recorded values are in parenthesis
[1] pulp and paper manufacture; [2]data source Abira *et al*, 2004; [3] yeast production and molasses distillery; [4] milk processing; [5] fish processing; [6] source: NEMA
*Newly proposed value (earlier value was 0.1mg/l)

Organic and nutrient loads

Organic and nutrient loads released into various bodies of water by municipalities and industries are presented in Figures 3 - 6, and Annex 3 and totals are given in Table 6.

Municipal and industrial waste loads

Table 6: The distribution of total BOD, TN and TP loads released from industrial and municipal point sources into the Lake Victoria Catchment of Kenya.

Point source type	BOD (kg/day)	TN (kg/day)	TP (kg/day)
Municipal	25104	4479	1689
Industrial	8538	1698	201

Municipal point sources release higher organic and nutrient loads (BOD-25104kg/day;TN-4479kg/day;TP-1689kg/day) than industrial establishments (BOD-8538;TN-1698kg/day;TP-201) in the lake catchment.

Table 7: Distribution of BOD, TN, TP loads released into Lake Victoria catchment from point sources, by catchment

Catchment	Loads(kg/day)		
	BOD	**TN**	**TP**
Gucha-Migori	8021	1281	513
North Awach	2749	548	166
South Awach	1599	299	126
Sondu	1763	335	126
Nyando	4521	1615	207
Yala	4635	776	310
Nzoia	9760	1219	403
Sio	593	104	40
Total Loads	**33641**	**6177**	**1891**

Nzoia catchment contributes the highest organic loads (BOD-9760kg/day) with municipal and industrial establishments contributing almost the same amount of loads (BOD-5062kg/day and 4698kg/day respectively). The catchment is the largest in the lake Victoria catchment and has many industrial establishments based in Eldoret. There is also and a pulp and paper mill based in Webuye. However, the highest nutrient load is released into the Nyando catchment (TN-1615 kg/day). Main contributor of nutrient loads in Nyando catchment is the industrial sector (TN-1414 kg/day). The catchment has 2 sugar companies (Chemelil & Muhoroni) and a distillery (Agro-Chemical & Food Co.). The second contributor of the largest organic load is Gucha-Migori catchment (BOD-8021 kg/day). The loads contribution is mainly from municipal establishments (BOD-7564 kg/day). The catchment has one sugar company (SONY Sugar Co). Loads from North Awach (BOD-2749 kg/day; TN-548 kg/day;TP-166 kg/day) are mainly contributed by municipal establishments. Most of the industries in Kisumu City discharge into municipal sewer. There is however, a newly established distillery in Kisumu, which was not covered in the study.

Municipal waste loads

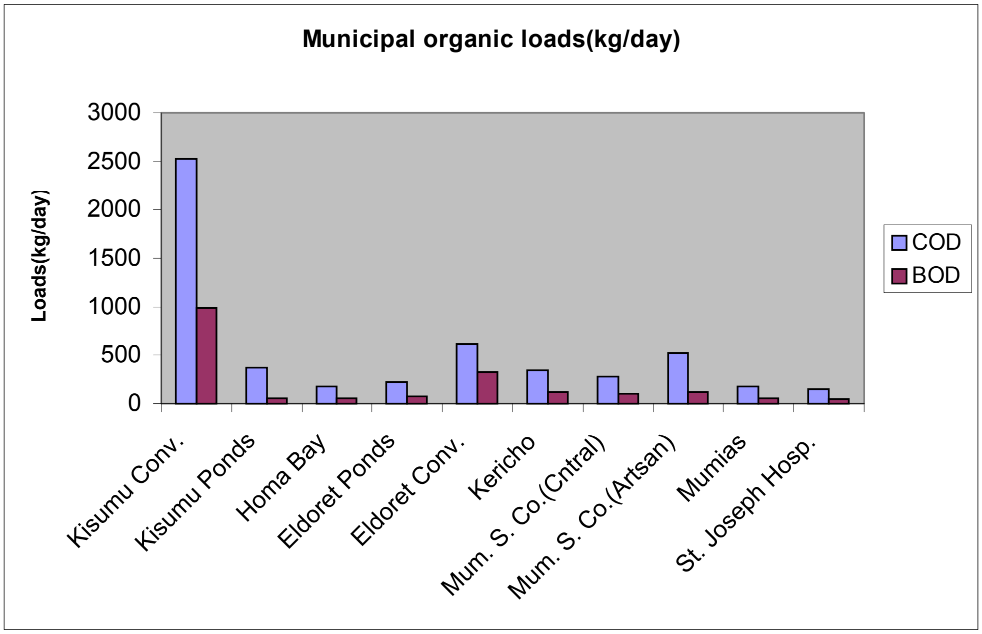

Figure 3: BOD and COD loads released by various municipalities in the Kenyan Lake Victoria catchment. Data are in Annex 3.

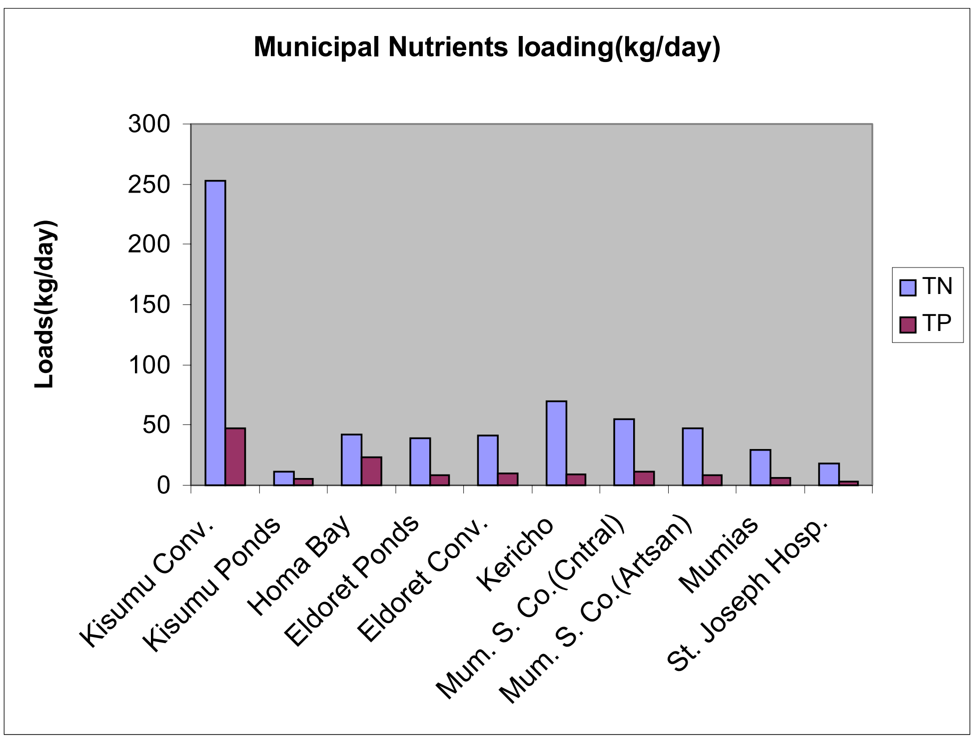

Figure 4: TN and TP loads released by various municipalities in the Kenyan Lake Victoria catchment. Data are in Annex 3.

Industrial waste loads

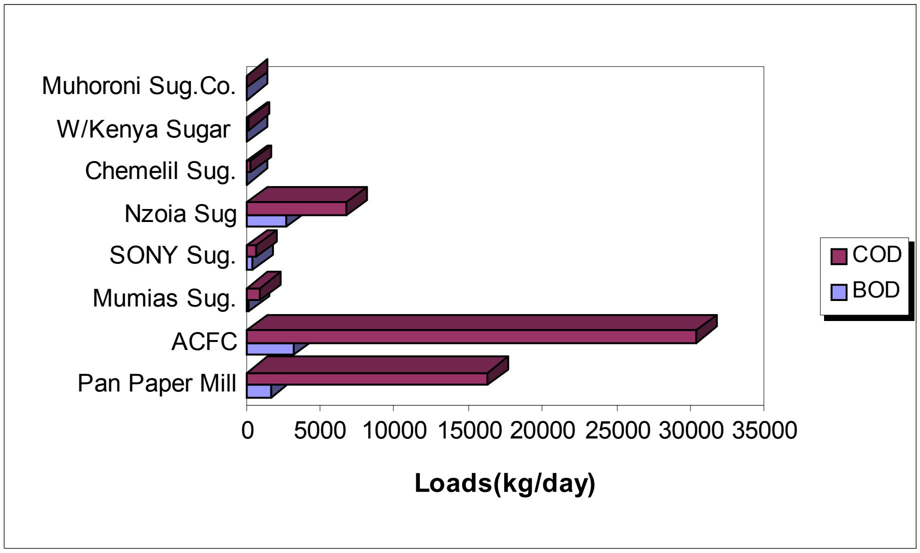

Figure 5: BOD and COD loads released by various industries in the Kenyan Lake Victoria catchment. Details are in Annex 3.

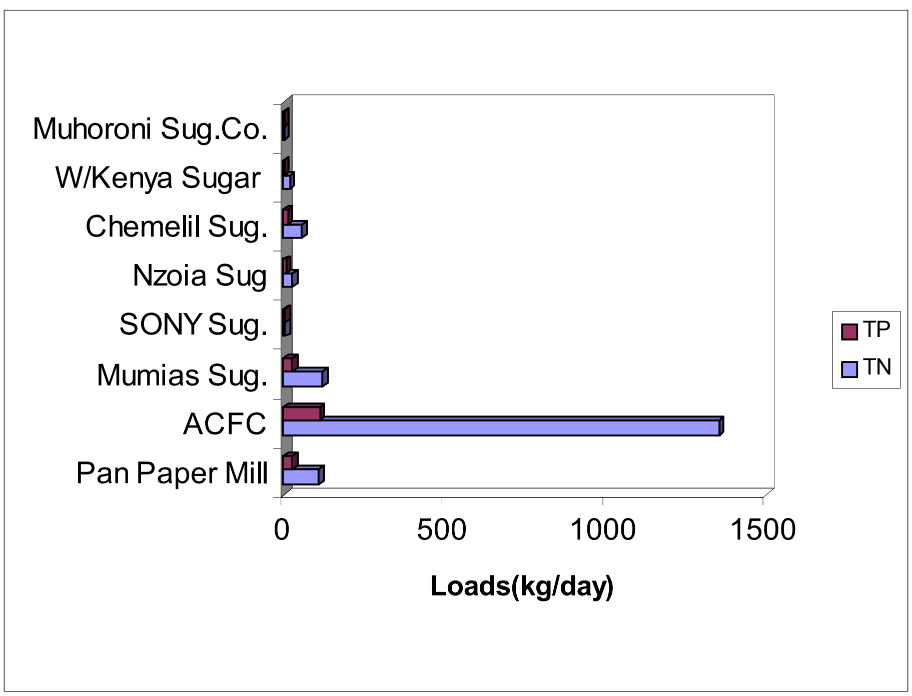

Figure 6: TN and TP loads released by various industries in the Kenyan Lake Victoria catchment. Data are in Annex 3.

Constructed wetland performance

Abira *et al.* (2005) have reported initial results of a 15-month wetland operation indicating that removal efficiencies for phenol were variable but were up to 77% giving better quality effluent. However the wetland effluent did not consistently meet set national guidelines. Further experimentation was conducted for a period of 16 months to determine the phenol removal processes and wetland efficiency in removal of organic matter under various flow regimes. The results of this latter study will be published in the PhD thesis of Mrs. Abira (in preparation).

DISCUSSION

Loading of nutrients and organics from point sources

Industries

The observed variations in discharged effluent quality may be attributed to various things. The composition and quantity of raw effluent entering the effluent treatment facility; in industry this depends on the predominant process in operation, level of production and status of internal controls practiced. For municipal treatment facilities, population, water usage, and quality of effluent received from sewered industries are important factors (Metcalf and Eddie, 1991).

The status and efficiency of the waste treatment facility; for instance, in the case of waste stabilization ponds the level of sludge accumulation if high, could give rise to short-circuiting thereby reducing hydraulic retention time and forming anaerobic/anoxic zones.

High hydraulic loads (overloading) and shock loads of toxic substances (biocides) lower system performance. Maintenance activities such as de-sludging increase organic matter and nutrients content of the discharged wastewater due to particle resuspension. This was clearly observed when the treatment facility at SONY was being rehabilitated in 2003 (Figures 2). A COD of 1640mg/l was recorded in the final effluent. During such periods, water bodies become heavily loaded with pollutant-laden effluents. The body of water takes long to recover as rehabilitation and stabilization of the treatment facility usually takes long. This demonstrates that operational aspects of wetland tertiary treatment programs are as important as the on-line steady state performance of the wetland. This requires continuous monitoring of the management cycle of the wetland over several treatment cycles.

There has been a problem of oil in the primary pond at Nzoia, which occasionally finds its way into the waste stabilization ponds. This has constantly lowered the system's performance, resulting into high organic loads (BOD-2667kg/day).

Wastewater generated from the manufacture of yeast and spirits at Agro-chemical Food and Company (ACFC) is composed of complex organics including melanoid compounds that impart a distinct brown color. ACFC records the highest mean organic loads (BOD-3249kg/day). High nutrient loads, especially total nitrogen (TN-1353kg/day) are also observed (Figure 6). Although the treatment facility achieves 89 % BOD removal, the final effluent is far from meeting the Kenyan discharge guideline.

The nature of the pulp and paper wastewater is both organic and inorganic. The wastewater contains toxic substances such as phenols and resin acids. Such substances act as biocides and are likely to adversely affect benthos and other aquatic organisms in the receiving stream. Lignin and its derivatives are slowly biodegradable giving a high COD but contributing little to BOD (Nemerow, 1978). Pan paper's waste treatment facility's has mean BOD concentration (48mg/l) which is lower than those of most sugar industries. However, the wastewater released from Pan paper's treatment facility is of such enormous quantity (mean of 35,000 m^3 /daythat high organic loads (well reflected by COD load of 16291kg/day) are released into River Nzoia (comment on relevance to Kenya standards?).

Municipalities

Kisumu's conventional sewage treatment works receives both domestic and industrial effluents. The main industries discharging to the municipal sewers include fish processing and a brewery. Secondary treatment takes place in the trickling filters. The trickling filters are currently malfunctioning and overloaded. This has resulted in effluent of high organic and nitrogen loads (BOD-988kg/day;TN-253kg/day) being discharged into Kisat River. Generally all the units of the treatment facility require rehabilitation, expansion and a regular maintenance program to reduce the high loads discharged into Kisat River.

Eldoret's conventional sewage treatment works discharged large organic loads mainly due to the nature of wastewater from industrial establishments discharging into the municipal sewer such as Ken Knit textile industry and Rift Valley bottlers. The conventional treatment works is currently not operational and Eldoret Water and Sewerage Company has constructed alternative lagoons besides the existing waste stabilization ponds.

Other municipalities that release significant organic loads include Mumias Sugar company's artisan domestic sewage treatment works, Kisumu's waste stabilization ponds, Kericho's sewage treatment works and Mumias Sugar company's central domestic sewage works. The significant organic loads observed from Mumias artisan WSPs are mainly due to algal blooms in the final waste stabilization pond. There is need to incorporate a biofilter such as a macrophyte-based pond to avoid excessive algal growth and reduce nutrients in the final effluent stream released to the river.

CONCLUSION

Municipal point sources release higher organic and nutrient loads than industrial establishments in the lake catchment. 15 out of 50 urban centers covered in the study (i.e. population>10000) and institutions own either conventional treatment plants or waste stabilization ponds. The rest are served by septic tanks and pit latrines. 8 of municipal/institutional effluent treatment facilities are properly functioning, producing BOD of 30mg/l and below. Out of the remaining 7 facilities, Kisumu conventional treatment works, can be considered as a hotspot, with mean final effluent BOD of 181mg/l. Out of 11 industrial wastewater treatment facilities (discharging waste direct into water body), 1 produces final effluent of mean BOD below 30 mg/l. Out of the remaining 10 facilities discharging BOD>30mg/l, 3 are considered as hotspots due to their frequency of exceedance of the effluent discharge guidelines. On most occasions, while carrying out maintenance work, raw or semi treated effluent is usually channeled into the receiving watercourse direct. Most of the wastewater treatment facilities are in poor state and the final effluent being discharged into water do not meet effluent discharge guidelines (refer tables 4&5).

RECCOMENDATIONS

Appropriate environmental performance indicators should be selected and continous monitoring carried out in order to bring clearer picture of the operational status of the point sources wastewater treatments.
There is need for installation of flow measuring devises at the entries and exits of the treatment plants in order to collect discharge data.
Awareness among stakeholders (industrialists and municipal authorities) should be created for harmonious approach to waste management.
Assessment of the contribution of urban run-off to lake pollution, though was not undertaken, is an important aspect of pollution and should considered for future study.

Internal control measures focusing on wastewater minimization, in plant refinement of raw materials and production processes and recycling of waste products should be considered by industrialists, to run hand in hand with the normal end-of-pipe wastewater treatment.

Each wastewater facility should do an annual environmental audit and practice continual improvement through a dynamic Environmental Management Plan.

Industrialists and municipal authorities should practice self-audits on their respective facilities.

What is the role of the new water authorities or other regulatory mechanisms referred to in the introduction that will lead to improvement of current routine (continuous) excedance of national standards by municipalities and industries. I did not get a clear understanding as to what the subcomponent has decided about the possible role of constructed wetlands, their process and cost efficiency. Is this something to be recommended. What scale of investment (and land) would be required for this approach to allow effluent streams to meet national standards. LVEMP 2 can only be mobilized if clear instructions and recommendations can be made for the next phase to incorporate. The recommendations sound rather "status quo" is acceptable.

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Annex 1 List of municipalities, towns and institutions indicating global positions and discharge- receiving watercourses

Municipality	Catchment	Town	Global Positions	Receiving watercourse
Kisumu City Council -conventional	North Awach	Kisumu	00°05'007"S 34°45'242"E	Kisat Stream
Kisumu City Council –WSP	North Awach	Kisumu		River Auji
Homa Bay Municipal Council	South-Awach	Homa Bay	00°31'197"S 34°27'704''E	Lake Victoria
Kisii Municipal Council	Gucha-Migori	Kisii	00°39'500"S 34°42'205"E	River Riana
Kisii High School	Gucha-Migori	Kisii		Kachupa river
Bondo Town Council*	Yala	Bondo	00°05'528"N 34°15'276"E	
Bondo T.T.C	Yala	Bondo	00°05'528"N 34°15'276"E	Sub-surface infiltration
St. Joseph Hospital	Gucha-Migori	Migori	01°04'030"S 34°28'357"E	River Migori
Kakamega Municipal (Shirere)	Yala	Kakamega	00°15'920"N 34°44'896"E	River Isikhu
Kakamega Municipal (Scheme)	Yala	Kakamega	00°17'190"N 34°44'800"E	
Bungoma Municipal Council	Nzoia	Bungoma	00°33'817"N 34°33'887"E	Kalaba River
Mumias Municipal Council	Nzoia	Mumias	00°21'191"N 34°29'679"E	Simiche stream & Nzoia
Webuye Municipal	Nzoia	Webuye	00°34'886"N 34°46'949"E	Webuye River
Kitale Municipal Council	Nzoia	Kitale	01°02'322"N 35°01'420"E	
Kericho Municipal Council	Sondu	Kericho	00°23'341"S 35°16'506"E	River Dionsoyet
Kericho Teachers College	Sondu	Kericho		River Kimugu
Kapsabet Municipal Council	Yala	Kapsabet	00°10'366"S 35°05'403"E	Iruru Stream
Mosoriot Health Centre	Yala	Mosoriot		
Chepkoilel Campus	Nzoia	Eldoret	00°35'050"N 35°18'908"E	Chepkoilel River
Eldoret Municipal -Conventional	Nzoia	Eldoret	00°30'889"N 35°15'439"E	River Sosiani
Eldoret Municipal –WSP	Nzoia	Eldoret	00°31'895"N 35°14'220"E	River Sosiani
Moi university Main campus	Nzoia	Eldoret	00°17'160"N 34°17'655"E	
Busia Municipal Council	Sio	Busia	00°26'930"N 34°06'835"E	
Bomet Municipal Council*	Mara	Bomet	00°05'631"N 34°32'479"E	
Siaya County Council*	Yala	Siaya	00°03'922"N 34°17'198"E	
Yala county Council*	Yala	Yala	00°05'631"N 34°32'479"E	
Ogembo Town Council*	Gucha-Migori	Ogembo	00°47'815"S34°48'413"E	
Suneka Town Council*	Gucha-Migori	Suneka	00°39'500"S 34°42'205"E	
Muhoroni Town Council*	Nyando	Muhoroni	00°09'730"S 35°10'469"E	
Ahero Town Council*	Nyando	Ahero	00°07'538"S 34°59'995"E	
Ugunja Town Council*	Nzoia	Ugunja	00°08'317"N 34°16'166"E	
Bondo Town Council*	Yala	Bondo	00°05'528"N 34°15'276"E	
Funyula Town Council*	Nzoia	Funyula		
Kipkelion Town Council*	Nyando	Kipkelion		
Nambale Town Council*	Sio	Nambale	00°29'242"N 34°18'804"E	
Nyamache Town Council*	Gucha-Migori	Nyamache		
Malava Town Council*	Nzoia	Malava		
Sirisia Town Council*	Nzoia	Sirisia		
Port Victoria Town Council*	Nzoia	Port Victoria		
Kendu Bay Town Council*	South-Awach	Kendu Bay		
Moi's Bridge Town Council*	Nzoia	Moi's Bridge	00°55'127"N 35°07'953"E	
Msimba Town Council*	Gucha-Migori	Masimba		
Bumala Town Council*	Nzoia	Bumala		
Matunda Town Council*	Nzoia	Matunda		
Londiani Town Council*	Nyando	Londiani		
Kehancha Town Council*	Gucha-Migori	Kehancha		
Vihiga Town Council*	Yala	Vihiga		
Nyamira Town Council*	Gucha-Migori	Nyamira		
Awendo Town Council*	Gucha-Migori	Awendo		
Rongo Town Council*	Gucha-Migori	Rongo		
Nandi Hills Town Council*	Yala	Nandi Hills		
Kimilili Town Council*	Nzoia	Kimilili		

Nyamarambe Town Council*	Gucha-Migori	Nyamarambe		
Luanda Town Council*	Yala	Luanda		
Oyugis Town Council*	South-Awach	Oyugis		
Mbita Town Council*	South-Awach	Mbita		
Keroka Town Council*	Gucha-Migori	Keroka		
Nyansiongo Town Council*	Gucha-Migori	Nyansiongo		
Lumakanda Town Council*	Nzoia	Lumakanda		
Butere Town Council*	Yala	Butere		

WSP = waste stabilization ponds

* Towns with population>10,000 served by septic tanks and pit latrines

Annex 2 List of industries, factories and establishments indicating global positions, type of treatment facility and discharge- receiving watercourses

Industry/Factory Name	Type	Catchment Name	Town or Province	Global position	Type of Effluent Treatment Facility	Receiving Watercourse
Homa Bay Slaughter House	Meat Processing	South-Awach	Homa Bay	00°31'445"S 34°27'450"E	Sewered; pits for blood	L. Victoria
Kenya Breweries (KSM)	Brewery	North Awach	Kisumu	00°06'240'S 34°44'330"E		
A.C.F.C.	Distillery	Nyando	Muhoroni	00°09'730"S 35°10'469"E	Fermentors & aerated lagoons	River Nyando
Capital Fish	Fish Processing	South-Awach	Homa Bay	00°31'424"S 34°27'461"E	Sewered	L. Victoria
Sony Sugar Co.	Sugar manufacturing	Gucha-Migori	Awendo	00°53'258"S 34°31'404"E	Aerators & Lagoons	
Kisii Bottlers Co.	Soft drink bottling	Gucha-Migori	Kisii	00°40'810"S 34°47'330"E		
Webuye Slaughter House	Meat Processing	Nzoia	Webuye	00°34'886"N 34°46'949"E	Sewered; pits for blood	Webuye River
Pan African Paper Mills (EA) Ltd.	Pulp & paper	Nzoia	Webuye	00°35'440"N 34°47'110"E	Clarifiers, Aerated lagoons	River Nzoia
Mumias Sugar Co.	Sugar manufacturing	Nzoia	Mumias	00°22'006"N 34°29'533"E	Lagoons	River Nzoia
Nzoia Sugar Co.	Sugar manufacturing	Nzoia	Nzoia	00°33'841"N 34°39'771"E	Aerated lagoons	River Kuywa
Highland Paper Mills Ltd.	Paper	Nzoia	Eldoret	00°31'887"N 35°16'232"E	Municipal sewer	Sosiani River
E.A. Heavy Chemicals.	Sulphuric Acid & Alum	Nzoia	Webuye	00°35'280"N 34°47'019"E	Dry process	Air ?
West Kenya Sugar Co.	Sugar manufacturing	Nzoia	Western	00°23'009"N 34°49'861"E	Lagoons	River Mwera
Kericho Slaughter house	Meat Processing	Sondu	Kericho	00°23'341"S 35°16'506"E	Sewered; pits for blood	Dionsoyet River
Eldoret slaughter house	Meat Processing	Nzoia	Eldoret	00°31'787"N 35°16'473"E	Sewered; pits for blood	Sosiani River
Ken Knit	Textile	Nzoia	Eldoret	00°30'755"N 35°17'371"E	Sedimentation & Sewered	Sosiani river
C.P.C. Chemical Industry	Corn oil manufacture	Nzoia	Eldoret	00°30'002"N 35°18'234"E	Sedimentation & Sewered	Sosiani river
Arkay Food processing	Cooking oil	Nzoia	Eldoret	00°31'915"N 35°16'133"E	Sewered	Sosiani river
Raiply Wood products	Board manufacture	Nzoia	Eldoret	00°30'002"N 35°18'234"E	Sewer	Sosiani river
Eldoret Steel Mills	Steel rolls manufacture	Nzoia	Eldoret	00°30'002"N 35°18'234"E	Trenches 7 overland flow	Sosiani River
Premier Dairies	Dairy	Sondu	Eldoret	00°30'002"N 35°18'234"E	Anaerobic tanks & Lagoons	Ainabkoi River
Donyo Lesses Creameries	Dairy	Nzoia	Eldoret	00°30'002"N 35°18'234"E	Sewered	Sosiani River
Prinsal Enterprise	Fish Processing	South-Awach	Migori	01°05'213"S 34°27'568"E	Overland	??
Muhoroni Sugar Co.	Sugar manufacturing	Nyando	Muhoroni	00°09'730"S 35°10'496"E	Lagoons	Nyando River
Chemelil Sugar Co.	Sugar manufacturing	Nyando	Chemelil	00°04'692"S 35°08'203"E	Lagoons	River Mbogo
KCC-Sotik	Dairy	Sondu	Sotik		Aerated lagoon (one)	Kipsonoi River
KCC-Eldoret	Dairy	Nzoia	Eldoret		Municipal sewer	Sosiani river
KCC-Kitale	Dairy	Nzoia	Kitale		Municipal sewer	
Sea-Food	Fish Processing	North Awach	Kisumu		Municipal sewer	Kisat River
Afro-Meat	Fish Processing	North Awach	Kisumu		Municipal sewer	Kisat River
Kisumu Molasses Plant	Distillery	North Awach	Kisumu			??

Annex 3: Mean organic and nutrient loads discharged into surface water by various municipal and industrial wastewater treatment facilities.

Municipalities	Population	Mean Flow(l/s)	Mean BOD(mg/l)	Mean COD(mg/l)	Mean TN(mg/l)	Mean TP(mg/l)	BOD Load(kg/day)	COD Load (kg/day)	TN-Load(kg/day)	TP Load(kg/day)
Kisumu (Conventional)		63.2	181	462	46.3	8.6	988	2523	253	47
Eldoret(Conventional)		32.6	117	219	14.4	3.7	330	617	41	10
Kericho		17	84	236	47.7	12.8	123	347	70	19
Mumias S. Co.(Domestic-Artsan)		42.8	33	140	12.8	2.1	122	518	47	8
Mumias S. Co.(Domestic-Central)		58.2	20	56	10.9	2.1	101	282	55	11
Eldoret(Ponds)		22.7	37	113	19.7	4.1	73	222	39	8
Mumias		5.3	126	392	62.4	13	58	180	29	6
Homa-Bay		12.6	50	164	38.5	21.4	54	179	42	23
Kisumu (Nyalenda Ponds)		42	15	102	3	1.5	54	370	11	5
St. Joseph Hospital		14.4	37	118	14.1	2.5	46	147	18	3
Webuye		10.6	30	194	7.1	2.6	27	178	7	2
Kapsabet		3.5	17	123	5.5	2.2	5	37	2	1
Chepkoilel Campus		0.3	25	110	8.4	3	1	3	0	0
Kisii		6	30	170	13	8.2	16	88	7	4
Kakamega(Shirere ponds)		0.7	12	89	48.1	9.7	1	5	3	1
Busia Ponds		3.2	37	152	25	3	10	42	7	1
Bungoma		3.2	7	61	6.3	0.3	2	17	2	0
Kitale(Bidii)		1	18	72	3.58	1.07	2	6	0	0
Kitale(Matisi)		0.4	63	104	9.27	12.6	2	4	0	0
Kisumu(septic tank & pit latrines*	189589						1706		284	114
Busia(septic tank & pit latrines*	37365						336		56	22
Homa Bay(septic tank & pit latrines*	33743						304		51	20
Kisii(septic tank & pit latrines*)	23746						214		36	14
Eldoret(septic tank & pit latrines*)	38513						347		58	23
Kakamega(septic tank & pit latrines*)	57566						518		86	35
Kericho(septic tank & pit latrines*)	82555						743		124	50
Mumias(septic tank & pit latrines*)	99079						892		149	59
Kapsabet(septic tank & pit latrines*)	15916						143		24	10

Municipalities	Population	Mean Flow(l/s)	Mean BOD(mg/l)	Mean COD(mg/l)	Mean TN(mg/l)	Mean TP(mg/l)	BOD Load(kg/day)	COD Load (kg/day)	TN-Load(kg/day)	TP Load(kg/day)
Bungoma(septic tank & pit latrines*)	49904						449		75	30
Kitale(septic tank & latrines*)	37781						340		57	23
Migori(septic tank & latrines*)	64637						582		97	39
Siaya(septic tank & latrines*)	45003						405		68	27
Bomet(septic tank & latrines*)	92144						829		138	55
Yala(septic tank & latrines*)	43882						395		66	26
Ogembo(septic tank & latrines*)	47353						426		71	28
Suneka(septic tank & latrines*)	34712						312		52	21
Muhoroni(septic tank & atrines*)	34063						307		51	20
Ahero(septic tank & latrines*)	33188						299		50	20
Ugunja(septic tank & latrines*)	32278						291		48	19
Bondo(septic tank & ltrines*)	31938						287		48	19
Funyula(septic tank & ltrines*)	31787						286		48	19
Kipkelion(septic tank & ltrines*)	29295						264		44	18
Nambale(septic tank & ltrines*)	27377						246		41	16
Nyamache(septic tank & ltrines*)	26757						241		40	16
Malava(septic tank & ltrines*)	26519						239		40	16
Sirisia(septic tank & ltrines*)	25723						232		39	15
Port Victoria(septic tank & ltrines*)	25165						226		38	15
Kendu Bay(septic tank & ltrines*)	24113						217		36	14
Moi's Bridge(septic tank & ltrines*)	23890						215		36	14
Masimba(septic tank & ltrines*)	23207						209		35	14
Bumala(septic tank & ltrines*)	21645						195		32	13
Matunda(septic tank & ltrines*)	12264						110		18	7
Londiani(septic tank & ltrines*)	37387						336		56	22
Kehancha(septic tank & ltrines*)	165654						1491		248	99
Vihiga(septic tank & ltrines*)	119767						1078		180	72
Nyamira(septic tank & ltrines*)	109458						985		164	66
Awendo(septic tank & ltrines*)	98599						887		148	59

Municipalities	Population	Mean Flow(l/s)	Mean BOD(mg/l)	Mean COD(mg/l)	Mean TN(mg/l)	Mean TP(mg/l)	BOD Load(kg/day)	COD Load (kg/day)	TN-Load(kg/day)	TP Load(kg/day)
Rongo(septic tank & ltrines*)	87275						785		131	52
Nandi Hills(septic tank & ltrines*)	84776						763		127	51
Kimilili(septic tank & ltrines*)	78157						703		117	47
Nyamarambe(septic tank & ltrines*)	72820						655		109	44
Luanda(septic tank & ltrines*)	72499						652		109	43
Oyugis(septic tank & ltrines*)	72067						649		108	43
Mbita(septic tank & ltrines*)	41727						376		63	25
Keroka(septic tank & ltrines*)	44107						397		66	26
Nyansiongo(septic tank & ltrines*)	35331						318		53	21
Lumakanda(septic tank & ltrines*)	12453						112		19	7
Butere(septic tank & ltrines*)	10686						96		16	6
							25104		**4479**	**1689**

Note: Assumption made for towns or part of the population served by septic tanks and pit latrines have organic and nutrient load reduction of 70% (COWI 2002).

Industries										
Pan African Paper Mill		419	48	450	3	0.8	1738	16291	109	29
ACFC(Muhoroni)		18.8	2000	18737	833	69.4	3249	30435	1353	113
Premier Dairies		1.17	662	972	25.9	18.4	67	98	3	2
Mumias Sugar Co.		44	55	243	31.9	7.3	209	924	121	28
SONY Sugar Co.		12.6	420	608	5.4	4.3	457	662	6	5
Muhoroni Sugar Co.		2	46	99	13.2	9.8	8	17	2	2
Nzoia Sugar Co.		34.6	892	2257	9.3	2.8	2667	6747	28	8
Chemelil Sugar Co.		26.5	26	144	25.6	5.6	60	330	59	13
West Kenya Sugar Co.		6.3	155	292	33.4	3	84	159	18	2
							8538	**55662**	**1698**	**201**

CHAPTER 7

Hydrodynamics and Thermal Cycles in Winam Gulf of Lake Victoria

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INTRODUCTION

The hydrodynamic and thermal cycles of lakes respond to meteorological and morphological characteristics. Past physical limnological studies carried out in the 1950s to 1960s (Graham 1929; Worthington 1930; Fish 1952 and 1957; Newell 1960; Talling 1957 and 1966) show that the pelagic (offshore) waters of Lake Victoria underwent two cycles of thermal stratification and mixing during the long and short rains with oxygen levels dropping to below 1mg/L the oxycline depth of 50m. Since 1980s, the deeper parts of the lake have experienced more prolonged anoxia (Hecky 1993) and littoral (inshore) areas such as Winam Gulf recorded fish kills (Ochumba 1996).

While substantial amount of work has been done on water column temperature and oxygen measurements in Winam Gulf and Lake Victoria, more knowledge is required to understand the hydrodymic and thermal cycles of the two water bodies because conditions are quire different (Offer a table) between them . ?

The water circulation patterns and exchange dynamics between Lake Victoria and Winam Gulf are clearly influenced by the adjoining narrow 2.6km constriction of Rusinga Channel. One possible explanation to the exchange dynamics was suggested as being the temperature differences between the gulf and the main lake (Ochumba 1996). Knowledge on the hydraulic conditions phenomena of Winam Gulf is important in understanding the processes that influence the production of this vital embayment of Lake Victoria. This is partly because the gulf receives relatively higher quantities of nutrient, sediment and pollutant loadings through its numerous streams, than any other gulf of the lake and these may be linked to the continued eutrophication of Lake Victoria (Hecky, 1993). The water balance of Winam Gulf is dominated by rainfall falling on the lake and evaporation while river inflows from Nyando, Sondu and other smaller streams have a significant influence on its water quality.

The collection of meteorological and hydrodynamic data in the period 2000-2005 has contributed to our understanding of the water circulation patterns in Winam Gulf and Lake Victoria. Water movement in the two water bodies respond to a complex interaction of the local (land-lake breezes) and global wind field and the resulting hydrodynamics. The strong afternoon lake breezes pile up water on the eastern part of the gulf and during calm conditions at night the water finds its way back to the main lake. The thermal structure is characterized by diurnal thermoclines in the gulf whereas the open lake experiences both the diurnal and seasonal thermoclines. In terms of dissolved oxygen concentrations, there are occasional anoxic conditions beyond 30m in the offshore while the gulf is generally well oxygenated.

In this study, meteorological and hydrodynamic data were collected using automated instruments. Meteorological conditions data were logged at 1-hour intervals at the shoreline land station of Yala Swamp. A pressure sensor installed at Kisumu pier recorded lake level data at 2-hour intervals. Lake conditions were sampled in Winam Gulf, Rusinga Channel and Lake Victoria on nineteen cruises from December 2000 to March 2005. Water column currents, temperature, oxygen, pH and conductivity parameters measurements were conducted longitudinally and across transects along Rusinga Channel, Winam Gulf and Lake Victoria. Results of the analysis of diel and seasonal changes in meteorological conditions and the resulting thermal stratification and water circulation patterns are reported here and compared with previous findings on Lake Victoria. A brief historical perspective of the annual thermal cycle of stratification of pelagic waters of Lake Victoria is given.

MATERIALS AND METHODS

Meteorological and hydrodynamic data were collected using automated instruments at offshore, inshore and shoreline land stations over Lake Victoria and Winam Gulf in the period 2000-2005.

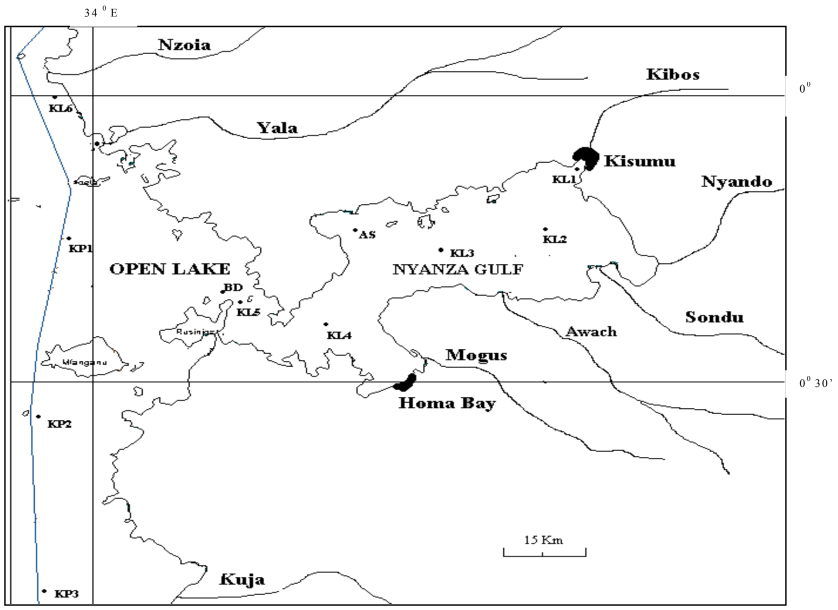
Wind speed and direction, relative humidity, rainfall, solar radiation, air temperature data were measured at 1 hour intervals by an automatic weather station located at a shoreline land station situated 50km north of Rusinga Channel. Seasonal trends in climatic variability for the period Jan 2002-Sept 2004, were assessed using time series scatter plots for the measured meteorological parameters. The monthly contributions of the four wind components were calculated using the method adopted by Verburg and Hecky (2003) for Lake Malawi. The E/W and N/S wind speed vectors of each daily averaged measurements of wind speed (a, m/s) and wind direction (b, in degrees clockwise from the north) were calculated as a*sin(b) and a*cos(b) respectively. The vectors were then separated into four east, west, north and south wind components. The west and south components were assigned negative values.

Wind speed and direction data for the year 2002 were used to plot wind roses in order to investigate the hourly variations of the local wind field (land and lake breezes). The roses were prepared by grouping wind directions into 18 zones and wind speeds scaled at 0.8m/s intervals.

Water column currents, temperature and oxygen profiles were measured along and across transects at pelagic and littoral stations. Currents were measured with the three dimensional, 1200 kHz broadband RDI® Acoustic Doppler Current Profiler (ADCP). The bin size was set at 0.5m, blanking distance at 0.8 m, maximum range at 60m and a ping rate at 2 Hz. At each location of profiling, the instrument was switched on and left to drift for a distance of 20 m as it recorded data for 2 to 3 minutes.

Water column temperature and oxygen profiles were measured using the Hydrolab Survevor II or YSI Instrument readable up to 0.01°C and calibrated in the Kisumu Laboratory using the Winkler titration method against known, freshly made standards before going out in the field.

A pressure sensor installed at Kisumu pier has been logging water level fluctuations and surface water temperature at 2-hour intervals for the period Dec 1999-2005.



Map??

Fig. 4. Location map of Winam (Nyanza) Gulf and open Lake Victoria

HISTORIC DESCRIPTION OF ANNUAL THERMAL CYCLE OF PELAGIC STATIONS

Historical information on the physical limnology of Lake Victoria is limited and not easily accessible. Past studies show that in September 1927-28 Graham (1929) and Worthington (1930) studied lake-bottom temperatures across the lake while in 1952-54 Fish (1957) and in 1961-62 (Talling 1966) monitored seasonal changes of thermal stratification of an offshore station of Bugaia in the northern main basin. Newell (1960) studied temperature transects across the main basin in 1957-8. These studies led to the conclusion that Lake Victoria had three phases of thermal stratification (Talling 1966). *Phase I* (Sep-Dec.) was marked by surface warming and small thermal gradients over most of the water column. *Phase II* (Jan –May) was characterized by a well-defined seasonal mixed layer with a deep thermocline while *Phase III* (Jun-Aug.) had occasional complete holomixis at a particular location, and small temperature differences were observed within the water column. In 1989-1991, Hecky et al (1994) measured water column temperatures and oxygen conditions at the same station as Talling (1966) and compared them with the 1960-61 observations by Talling.

The seasonal changes in the three phases the thermal structure was documented at the 'standard' long-term offshore station south of Bugaia Island in 1952-1954 (Fish 1957), 1960-61 (Talling 1966) and 1994-96 (Romero et al.

submitted). Its stratification shows pronounced seasonal changes, and can vary between inshore and offshore regions (Fish 1957) and between different offshore areas of the lake (Graham 1929, Newell 1960). Near-isothermal conditions in the deep offshore waters, indicative of complete vertical mixing, were recorded by Graham (1929) and Fish (1957) during and immediately following the coolest and most windy season. In other seasons and localities varying conditions of stratification have been observed.

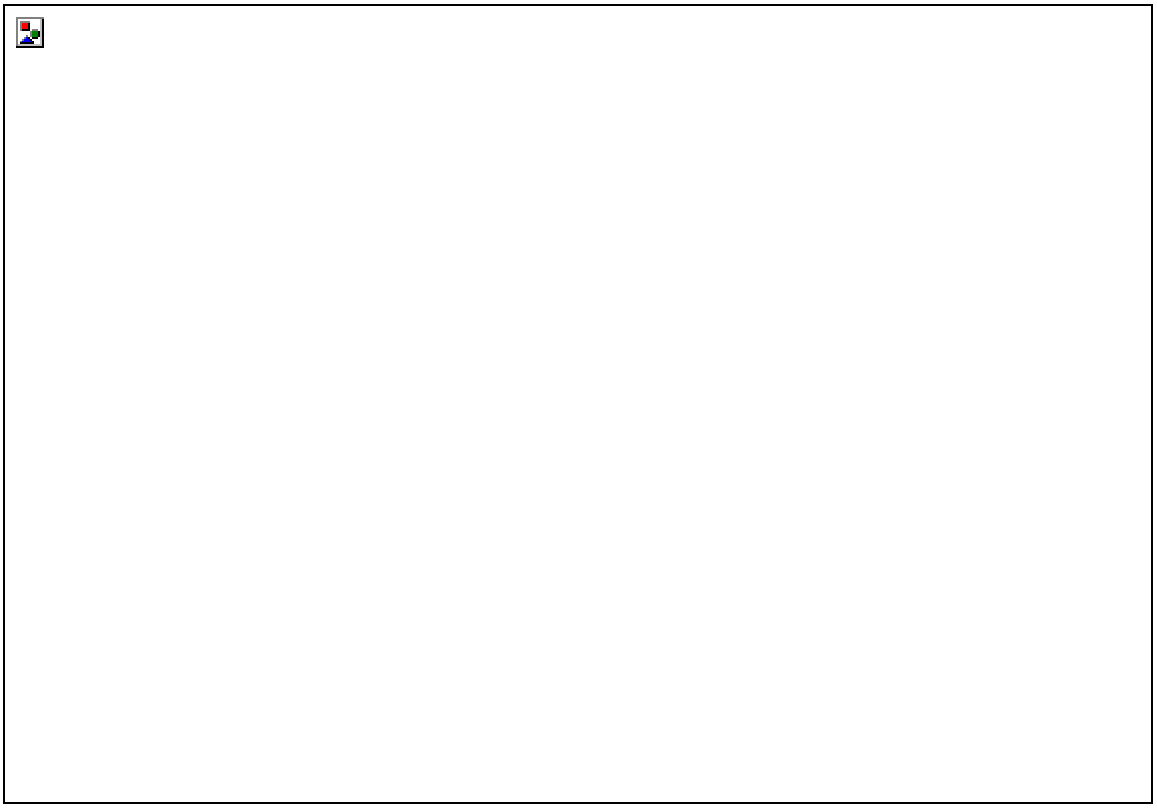


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Fig.2. Isotherms at the northern offshore stations (after Fish, 1957; Talling, 1966; and Romero submitted, 2004)

Coulter and Spigel (1996) provide scaling analysis of dominant hydrodynamic characteristics for all the East African Great Lakes based on regional meteorology, earlier measurements of the lake thermal structure, and Wedderburn numbers. Hecky et al's (1994) comparison of measurements of temperature and oxygen stratification taken during different phases of the annual thermal cycle in 1989-1991 with Talling's (1966) results indicate mixed layer depths are shallower now and the water column is more structured.

Isotherm plots as observed by Newell (1960) throughout the main basin and reported as offset profiles by Talling (1966) are reproduced here to illustrate the seasonal lake-wide thermal stratification dynamics of Lake Victoria.

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Fig. 3. Lake-wide transects during 1957-58 collected by Newell (1960) and reported by Talling (1966) as profiles and reproduced here as isotherm plots.

The lake-wide vertical stratification through June-September is considered to be the 3rd phase of thermal stratification. Stratification on lakewide basis was greater during June (3B), August (3C) than September (3D). Well mixed profiles were only observed at 150 and 175km in the southern sector at noon on Sept 6 and the morning of Sept 7 (3D).

The two east-west transects on April 13 (3A) and August 24-25 (3C0 both had a downward easterly tilt of the isotherms from Bukoba (west) to Musoma (east). Wind-induced downwelling along the eastern sector or differences in the rates of heating and cooling are possible mechanisms of these horizontal thermal gradients. The Nov 9-10 transect illustrates a diffuse and relatively horizontal thermocline at 40m (3E) whereas it has deepened to 45-50m by Feb 17-18 (3F). The 1996 transects across the main Lake Victoria basin illustrated lake-wide metalimnetic deflections prior to the monsoon (April 1996, 4B). During both transects the mixed layer was warmer and deeper in the northern main basin than the southern sector. High monsoon (May 1995) led to complete downwelling in the northern basin with seasonal thermocline (4A) intersecting the bottom between 70-100km. The horizontal temperature gradient in April 1996 (4B) prior to the monsoon was similar to that in May 1995 (4A). The seasonal thermocline was sharper and deeper in the northern basin and more diffuse and shallower in the water column to the south. The seasonal thermocline rapidly shallowed by ca. 10 m from 110 to 130m this does not make sense what is 110 and 130 referring to? in April 1996. Possible mechanisms that caused this feature include a large internal wave or partial upwelling at the mid-lake location. See paper by Kitaka on this phenomenon Kitaka, G.E.G.

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Fig. 4. May 20-24 1995(A) and April 5-9 (B) main basin transects of CTD temperature with secchi depths the north (Jinja, Uganda) to south (Mwanza) transect of the lake.

In summary the recent transects during the end of phase II before the onset of the monsoon had a substantially warmer mixed layer and a downward metalimnetic deflection in the north from the prevailing southerly winds.

RESULTS

Meteorological Conditions

A typical record of meteorological conditions at the shoreline land station of Yala Swamp over a two and half yearly period is presented in figure 5. It is evident that there was a regular variation of the recorded climatic parameters over the study period. Wind speeds were strongest in February-March and September-October and weakest in June-July and November through December. The southeasterly winds were more persistent during the time of the study period Jan 2002 to September 2004.

(**Show mean speeds**)

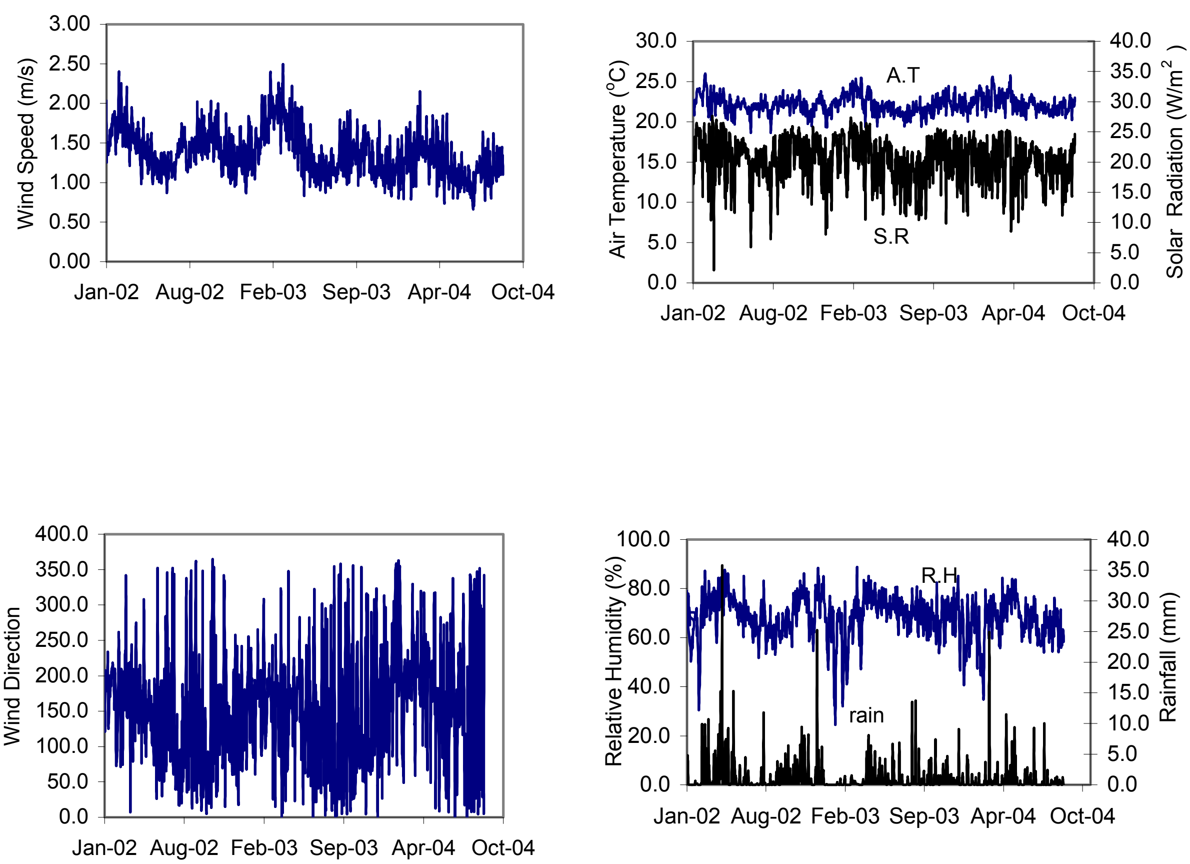


Fig. 5. Wind speed (top-left panel), wind direction (bottom-left panel), air temperature (A.T) and solar radiation (S.R) (top-right panel) and relative humidity (R.H) and rainfall (bottom-right panel) on 1-hour basis at Yala Swamp meteorological station from 2 July 2002 to 4 September 2004. Wind direction is the direction is the direction wind is coming from (not going to).

Air temperatures were highest in March-May and September-November, at the beginning and end of the wet season during the two equinoxes of March and September when solar radiation was maximum. There was a marked decrease in air temperature during the dry season when the sun was in the north in June-July and in the south November-December. Rainfall increased with relative humidity and was highest in March-May and September-November.

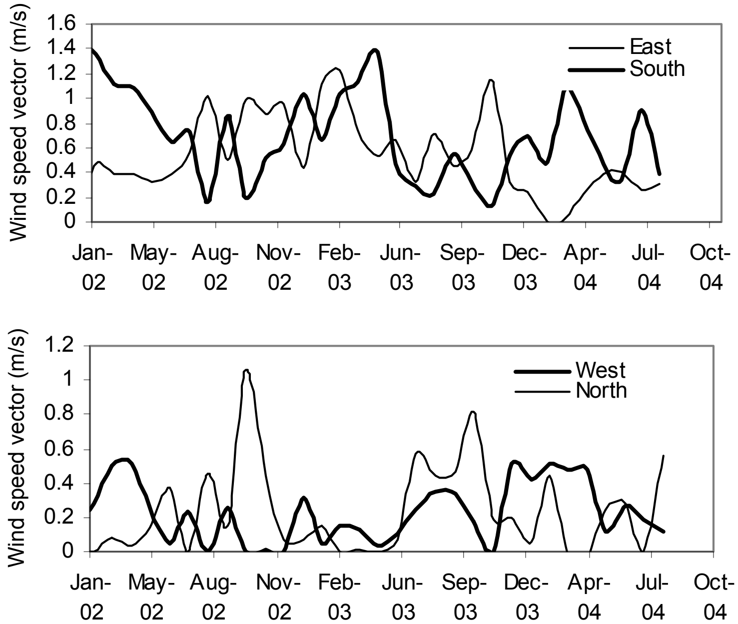


Fig. 6. Seven-day running averages of wind vector components at Yala station in the period January 2002-September 2004

The easterly and southerly wind vector components have the strongest signals throughout the year with the highest speeds of 1.4m/s experienced during the long and short rains (fig. 6). The westerly and northerly components peak during the dry months with moderate speeds of less than 1m/s.

Wind rose plots (fig. 7) show dominance of the lake breeze in the afternoons with strong signals at 4pm reaching 3m/s and above. The land breeze starts at 10 pm and lasts up to noon the following day. Calm conditions are marked from about 3 am to 8am.

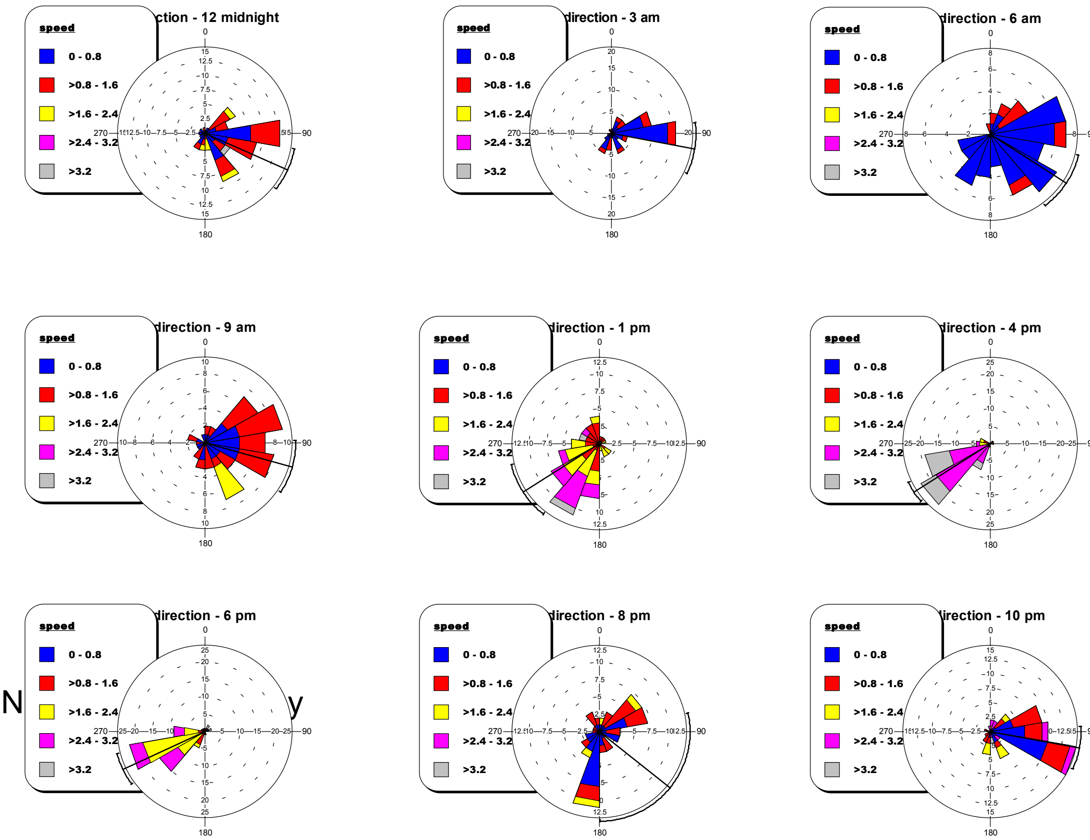


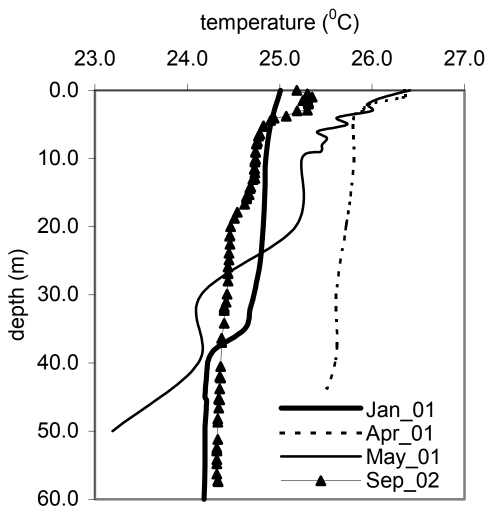
Fig. 7. Selected diurnal wind roses at Yala Swamp in the year 2002.

Stratification Cycle at Pelagic stations in national waters

The set of temperature profiles at pelagic stations KP2 and KP3 (fig. 8) show spatial and temporal variability in thermal stratification. Observations carried out at station KP2 at 1059hrs on 22 January 2001 showed slight warming in the morning of the upper 5m layer and a shoulder at 40m indicated the presence of a seasonal thermocline and calm wind conditions. The metalimnion and hypolimnion had near-isothermal conditions with the surface and bottom water temperatures of 25.^{0}10C and 24. 18^{0}C. The warming of the surface waters in the afternoon due to increased solar heating had created a strong, shallow thermocline at 4m, with bottom waters near-isothermal conditions as observed at 1315hrs on 6 April 2001. The hottest period of our measurements was made at 1250hrs on 11 May 2001 when the surface and bottom water temperatures were 26.41^{0}C and 23.19^{0}C. The water column was characterized by a complex step structure that indicated entrainment of the diurnal thermocline (10m), metalimnion (10-30m) and the hypolimnion. After seasonal mixing, the re-development of thermal stratification was observed at 1350hrs on 7 September, when the water column was divided into three layers. The temperature profile showed near-isothermal conditions with interruptions of a strong diurnal thermocline at 5m and a weak seasonal thermocline at 20m.

Observations made at station KP3 at 0833hrs on 23 January 2001 indicated cooler surface waters with temperatures of 25.01^{0}C and a shallower seasonal thermocline compared to measurements made at KP2 the previous day. Similarly, the water column was characterized by morning warming of cool surface waters at 25.51^{0}C and near-isothermal conditions in the bottom waters at 1015hrs on 7 April 2001, compared to the afternoon of the previous day at KP2. The complex step structure observed in the water column in the afternoon at KP2 was observed earlier at 0916hrs at KP3, with alternating regions of cool and warm waters and shallower diurnal and seasonal thermoclines. This indicated disruption of thermal stratification by the strong convective activity experienced during this time of the year.

KP2



KP3

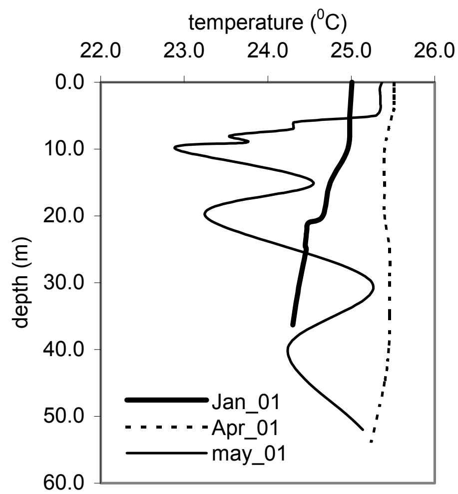


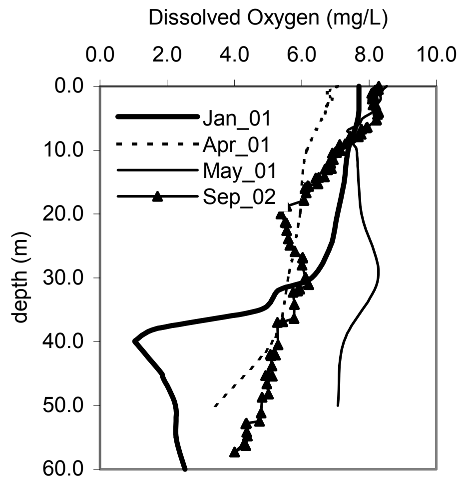
Fig. 8. Time series of temperature profiles observed at the pelagic stations KP2 and KP3 in the period 2001-2002. May data are very suspect or need explanation for high variability e.g, water warmer at 50 m than at 20 m.

We compared our results with the three phases of thermal stratification observed by Talling (1966). Our September 2002 measurements were similar with the first phase of Talling's thermal structure, where the diurnal and seasonal thermoclines were less pronounced. Diurnal and seasonal thermoclines were persistent in January 2001 as seen during the second phase of Talling's observations. The 20m seasonal thermocline observed at KP3 in January 2001 was shallower than the 30-60m variations measured in 1961. It is interesting that the expected strong thermal stratification during the wet months of April was not indicated by our measurements. The absence of a seasonal thermocline could be related to the presence of strong winds mixing the epilmnetic and hypolimnetic waters or strongly east sloping thermocline under strong winds. The third phase of thermal stratification was evident from our mid May 2001 measurements. The entrainment of the water column was possibly the beginning of the mixing period. We observed the lowest hypolimnetic temperature of 23.19^{0}C at 1250hrs on 11 May 2001, which was comparable to the coldest bottom waters (23.1 to 23.4^{0}C) measured in August and September in 1952-1954 (Fish 1957) and 1960-1961 (Talling 1966). We encountered higher surface water temperatures (25.01^{0}C-26.41^{0}C) at station KP2 in 2001-2002 than the 1960-6124.3^{0}C-24.7^{0}C observed near western Bukoba (Talling 1966).

Oxygen vertical distributions at national pelagic stations

Dissolved oxygen profiles were measured at the same time as temperature profiles (fig. 9). Changes in the depth of the diurnal and seasonal thermoclines were traceable in the depth of oxycline occurrence on most occasions as observed in 1952-954 by Fish (1957) and 1960-61 by Talling (1966) why not comparing temp and oxygen with Hecky et al for an additional period to establish whether trends are apparent. The concentration of oxygen below the 38m seasonal thermocline was depleted to below 2mg/L and 6.0mg/L in the upper 30m layer at 1059hrs on 22 Jan 2001 at station KP2. At 1315hrs on 6 April 2001, the oxygen distribution in the water column showed a gradual decrease from 7.07 mg/L to below 4mg/L at the 45m depth. The oxygen levels were highest and ranged from 8.53mg/L in the surface waters and 7.07mg/L in the bottom waters at 1250 hrs on 11 May 2001.

KP2 KP3



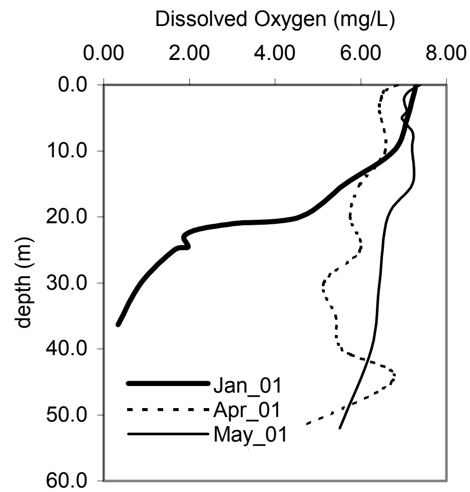


Fig. 9. Time series of dissolved oxygen distribution at pelagic stations KP2 and KP3 in the period 2001-2002.

Dissolved oxygen concentrations were strongly depleted to less than 4mg/L below the 20m 20m oxycline at 0833hrs on January 2001 at station KP3, which was shallower than the 38m oxycline observed the previous day at KP2. Oxygen levels dropped from 3.02mg/L at 21m depth to 0.34mg/L at the sediment-water interface. In contrast, the water column was well oxygenated (above 4mg/L) at 1015hrs on 7 April 2001 and at 0916hrs on 11 May 2001. A step structure was observed in April while oxygen levels ranged from 7.39mg/L in the surface to 5.51 in the bottom the May observations. How does this compare with Talling? Hecky et al

Stratification at littoral stations in national waters

Temperature profiles at stations KL1, KL3, KL4 and KL5 were plotted for the period December 2000 to May 2005 as shown in figure 10. Results show persistence of the diurnal thermocline during the day and the presence of a seasonal thermocline at the deeper Rusinga Channel station KL5.

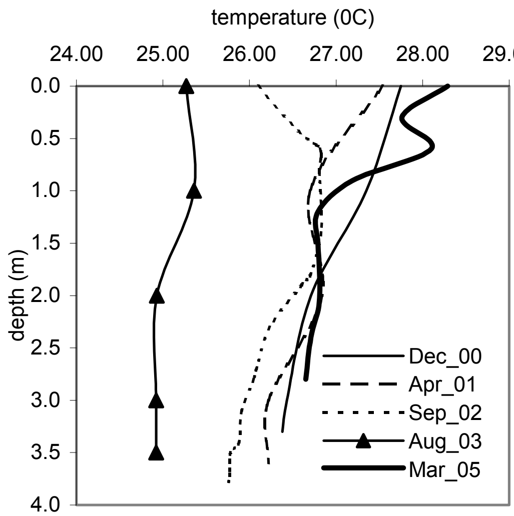
The water column was observed to gradually cool from 27.75^{0}C at the surface to 26.38^{0}C at 1200hrs on 5 December 2000 for station KL1. The upper 1m showed strong diurnal stratification at 1330hrs on 11 April 2001, but with lower surface temperatures of 27.54^{0}C. Observations made at 1557hrs on 8 September 2002 indicate strong cooling of the upper 0.7m layer, near-isothermal conditions from 0.7 to 1.5m followed by large vertical gradients. The lowest surface water temperature of 25.27^{0}C was observed at 1128hrs on 27 August 2003. A diurnal thermocline encountered at 1.5m and the upper and lower waters were isothermal. A step structure was observed in the diurnal surface layer (0-0.6m) and a strong diurnal thermocline was at 0.6-1.0m.

Observations for station KL3 at 1712hrs on 5 December 2000 reveal isothermal conditions, which indicated mixing in the water column. At 1025hrs on 18 January 2001, a diurnal surface layer was measured up to 1m depth and an entrained diurnal thermocline at 1.0-4.0m with isothermal temperatures below. The strongest stratification was observed at 1259hrs on 8 September 2002 with the diurnal surface layer at 1.5m and diurnal thermocline at 1.5m to 3m compared to the 2m depth of the diurnal thermocline encountered at 1032hrs on 16 May 2001. A 2m deep diurnal thermocline was also observed at 1044hrs on 24 March 2005.

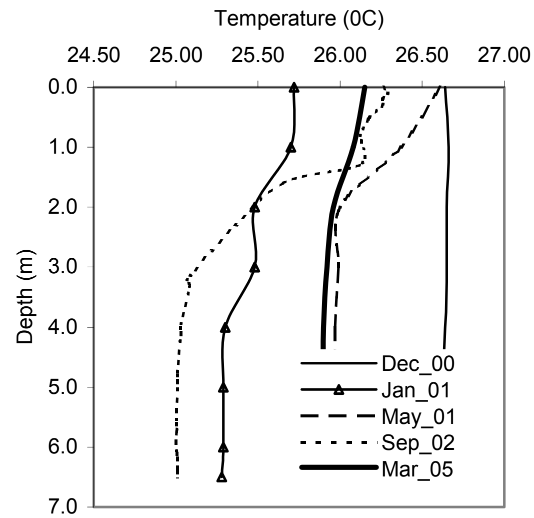
Persistent diurnal thermoclines were also recorded at station KL4. A diurnal surface layer was observed at 2m and a diurnal thermocline at 2-5m at 1200hrs on 6 December 2000. Isothermal conditions were experienced below the thermocline. The highest temperature gradients of 2^{0}C were observed at 1214hrs on 10 April 2001 and a diurnal thermocline occurred at 2m.

Results of the Rusinga Channel station KL5 show persistence of the diurnal and seasonal thermoclines on most observations. Experiments conducted at 1540hrs on 6 December 2000 reveal an epilimnion consisting of a 5m thick diurnal surface layer and a diurnal thermocline at 5-10m depth and surface temperatures of 26.47^{0}C. The hypolimnion shows near-isothermal conditions with mean temperatures of 25.8^{0}C. In contrast, thermal stratification was stronger in the water column at 1415hrs on 4 April 2001, and both diurnal and seasonal thermoclines were observed at 3m and 14m. The surface water temperature (24.9^{0}C) and bottom water temperature (24.65^{0}C) measured at 0815hrs on 8 September 2002 indicated gradual cooling and mixing of the water column. The water column characteristics observed at 1245hrs on 30 July 2003 were almost similar to those observed in April 2001, the diurnal thermocline was slightly deeper at 5m but the seasonal thermocline remained at 14m.

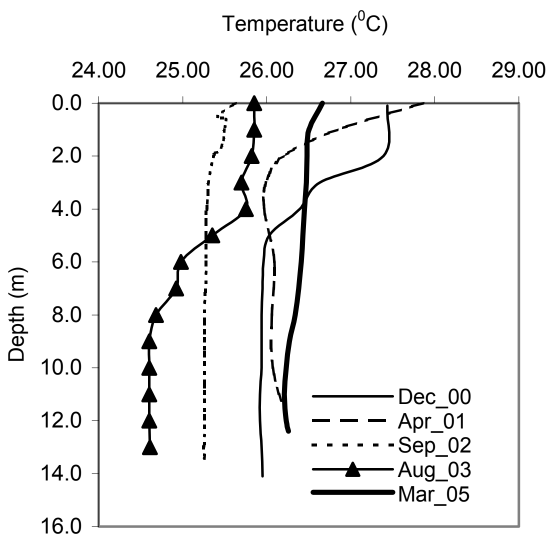
KL1



KL3



KL4



KL5

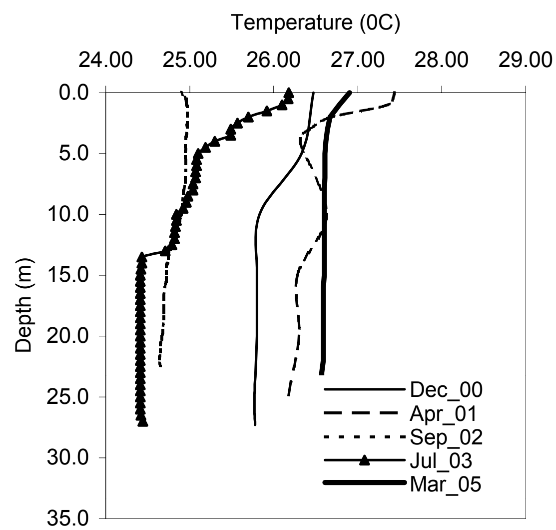


Fig. 10. Time series of temperature profiles observed at littoral stations KL1, KL3, KL4 and KL5 in the period 2000-2005.

The upper 3m showed gradual warming while hypolimnetic waters revealed mixing at 1045hrs on 24 March 2005. The lowest bottom water temperatures of 20.5^{0}C measured at Kisumu (Graham 1929) were not observed in our studies.

Overall the results show increase in water column temperatures over the years Not clear what is the basis of this statement—years since 1929 or since 2000?.

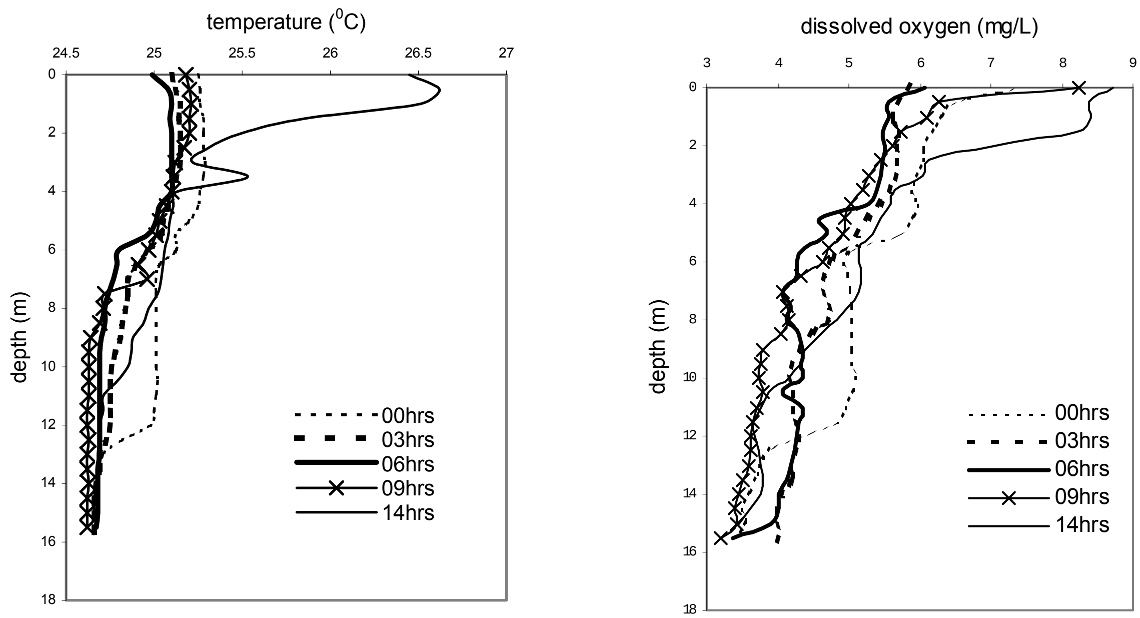


Fig. 11. Twenty-four hour time series of temperature (left panel) and oxygen (right panel) profiles observed at Rusinga Channel (station KL5) on 13 August 2003.

The diurnal cycle of thermal stratification at Rusinga Channel is presented in figure 11. Starting from midnight, the water column was still strongly stratified into three-layers with the presence of a diurnal thermocline at 6m and seasonal thermocline 12m (left panel). By 0300hrs, the water column had been eroded due to natural convective cooling as evidenced from changes in surface temperature from 25.25^0C to 25.1^0C and the two discontinuities had disappeared. The water column continued to cool by 06hrs when the surface temperatures were 24.99^0C. The water column had showed strong and increasing solar radiation that led to a two-layer structure with a diurnal thermocline at 7m depth and an increasing surface temperature of 25.18^0C, which indicated the warming of the Channel.

the diurnal thermocline (6m) being eroded due to natural convective cooling, while the metalimnion had near-isothermal conditions and the seasonal thermocline a shoulder with a temperature difference of 0.5^0C. The metalimnion and seasonal thermocline The night was characterized by calm conditions with a very weak land breeze. Incomplete paragraph. In general there is too much detail in the write-up for a national report—good though for a scientific MS. Try to simplify to primary message for each figure

Oxygen vertical distributions at littoral stations in national waters

Dissolved oxygen concentration profiles for the period 2000-2005 are presented in figure 11. Observations carried out at station KL1 at noon on 5 December 2000 show a gradual decrease of oxygen levels from 7.11 mg/L in the surface waters to 5.65 mg/L in the bottom waters. In contrast, an oxycline was present at the same 1 m depth as the diurnal thermocline at 1330 hrs on 11 April 2001. The epilimnion oxygen levels ranged from 7.2 mg/L to 6.15 mg/L and the hypolimnion levels from 6.18 mg/L to 4.56 mg/L. The water column was characterized by a step structure and high oxygen levels ranging from 8.5 mg/L to 7.4 mg/L at 1557hrs on 8 September 2002. The highest oxygen levels in the water were observed at 1128 hrs on 27 August 2003, ranging from 9.62 mg/L to 7.66 mg/L at 3m mark before dropping to 5.43 mg/L. The upper 0.5m surface waters showed high oxygen levels of 8.73 mg/L, which dropped to 8.61 mg/L to 7.0 mg/L at the 0.5 m to 1.5 m oxycline and above 6 mg/L in bottom waters. Again there is too much detail here for a national report—important message is that Gulf is well oxygenated to its bottom whereas deeper lake is not.

Observations at KL3 at 1712hrs on 5 December 2000 reveal near-uniform oxygen conditions of 7.39 mg/L to 7.24 mg/L up to the 5 m mark before reducing to 6.51 mg/L. The water column had an oxycline at 3 m and above oxygen levels range 7.86 mg/L to 7.50 mg/L and below oxygen levels of more than 5.0 mg/L, at 1025 hrs on 18 January 2001. There was a marked a steady decrease in oxygen levels from 8.69 to 7.47 above the 2m deep oxycline and a near- uniform range of 6.80 mg/L to 6.14 mg/L below, at 1032hrs on 16 May 2001. The oxygen profile at 1259hrs on 8 September was marked by a complex step structure that indicated the occurrence of an oxycline from 2. 5 m to 4.5 m. The oxygen levels in the surface layer were 7.96mg/L to 8.13mg/L and 6.4 mg/L to 5.2 mg/L in the hypolimnion. There was a gradual decrease in oxygen levels from 8.81 mg/L to 8.29 at 4m depth before dropping to 5.81 as observed 1026 hrs on 24 March 2005.

Experiments conducted at station KL4 at noon on 6 December 2000 reveal an oxycline at 4m to 6m depth with oxygen levels of 6.56 mg/L to 5.32 mg/L. The oxygen levels range from 6.67 mg/L to 6.58 mg/L above the oxycline and 5.22 mg/L to 4.49 mg/L below. The oxygen profile observed at 1214 hrs on 10 April 2001 had a complex step structure that comprised two oxyclines occurring at 1-4 m and 8-10 m depths. The oxygen levels fluctuated between 6.74 mg/L and 4.92 mg/L from top to bottom. A sudden decrease in oxygen levels in the upper 1m layer from 7.4 mg/L to 5.8 mg/L and a gradual decrease from 5.7 mg/L to 4.3 mg/L were measured at 1010hrs on 8 September 2002. At 1805hrs on 12 August 2003, a strong oxycline was observed at 4-9m depth with oxygen levels above 6mg/L in the surface waters and below 4mg/L in the hypolimnion. The highest surface oxygen levels of 8.07mg/L and bottom levels of 7.07mg/L with a weak oxycline at 6m depth were observed at 0831hrs on 24 March 2005. Again too much detail

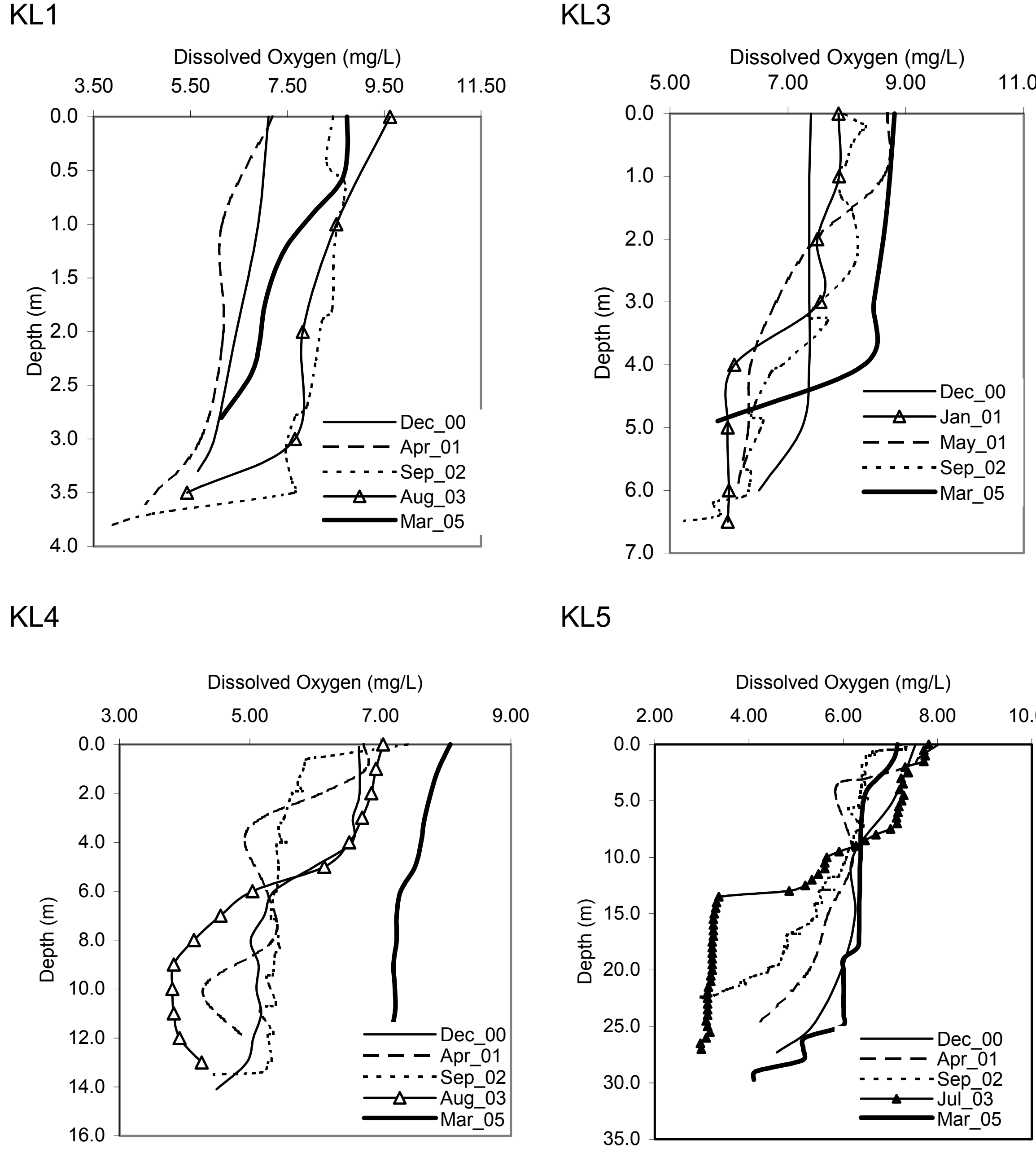


Fig. 11. Time series of dissolved oxygen profiles observed at littoral stations KL1, KL3, KL4 and KL5 in the period 2000-2005.

Observations at KL5 at 1540 hrs on 6 December 2000 show a weak oxycline at 5-10m with 7.53 mg/L in the upper mixed layer and 6.25 mg/L to 4.29 mg/L in the hypolimnion. Similarly, a shallower oxycline was present at 4 m depth with over 6 mg/L in the surface layer and 6.21 mg/L to 4.15 mg/L in the bottom waters were measured at 1415 hrs on 4 April 2005. The upper 1m showed gradual decrease in oxygen levels from 7.20 mg/L to 6.57 mg/L and a drop to less than 4.00 mg/L at 21 m depth, at 0812 hrs on 8 September 2002. The oxygen profile measured at 1245 hrs on 30 July 2003 had a weak oxycline at 2 m and a strong oxycline at 7-14 m. The oxygen levels were over 7.00 mg/L in the surface waters, below 4.00 mg/L in the bottom waters. Experiments carried out at 1027 hrs on 24 March 2005, show that the water column was characterized by a complex step structure with two oxyclines at 4m and 18 m depths. The oxygen levels ranged from 7.15 mg/L at the surface and 4.14 mg/L at the bottom. You present a figure so you do not have to describe it in this detail but do point out why you gave the figure.

Temperature and oxygen conditions in shallow gulfs

Water column temperature and oxygen levels during the study period (Table 1) show a peak in mean temperatures during the wet season months of March-April and December, and a minimum in the dry months of January and July-August. A maximum temperature of 28.38^{0}C and a minimum of 24.41^{0}C were recorded in the months of April and July. The highest mean dissolved oxygen concentrations of 6.98mg/L were observed in March, with maximum levels of 9.62mg/L in August at what depth and a minimum of 0.16mg/L observed in September at what depth.

Table 1. Mean monthly water column temperature and oxygen levels in Winam Gulf during sampling periods from 5 December 2000 to 24 March 2005.

Date	Mean temp (^{0}C)	Max temp (^{0}C)	Min Temp (^{0}C)	MeanDO (mg/L)	Max DO (mg/L)	Min DO (mg/L)
January	25.25	26.1	24.07	6.6	8.52	5.17
March	26.62	28.29	25.9	6.98	8.81	4.1
April	26.56	28.38	25.66	6.13	8.00	4.15
May	25.95	26.93	25.411	6.64	8.69	5.23
July	24.86	26.18	24.41	5.19	8.38	2.97
August	25.06	25.85	24.6	5.33	9.62	3.41
September	25.2	27.09	22.73	5.39	8.87	0.16
December	26.32	27.75	25.6	6.28	7.53	4.49

The spatial variability of epilmetic and hypolimnetic temperature and oxygen conditions at littoral and pelagic stations were compared (fig. 12 and table 2). Results show that the surface and bottom waters of Winam Gulf are generally warmer than the lake. Temperature and oxygen levels measured were different depending on time, depth and location of the station. The highest epilimnetic temperatures of 26.66^0C and hypolimnetic temperatures of 25.89^0C were measured at KL1, the shallowest station. Epilmnetic temperatures observed at littoral stations KL4 and KL5 at 1011hrs and 0815hrs on 8 Sep 2002 were lower than surface temperatures measured at pelagic stations KP1 the previous day at 1650hrs. The gulf was characterized by warmer and better oxygenated bottom waters.

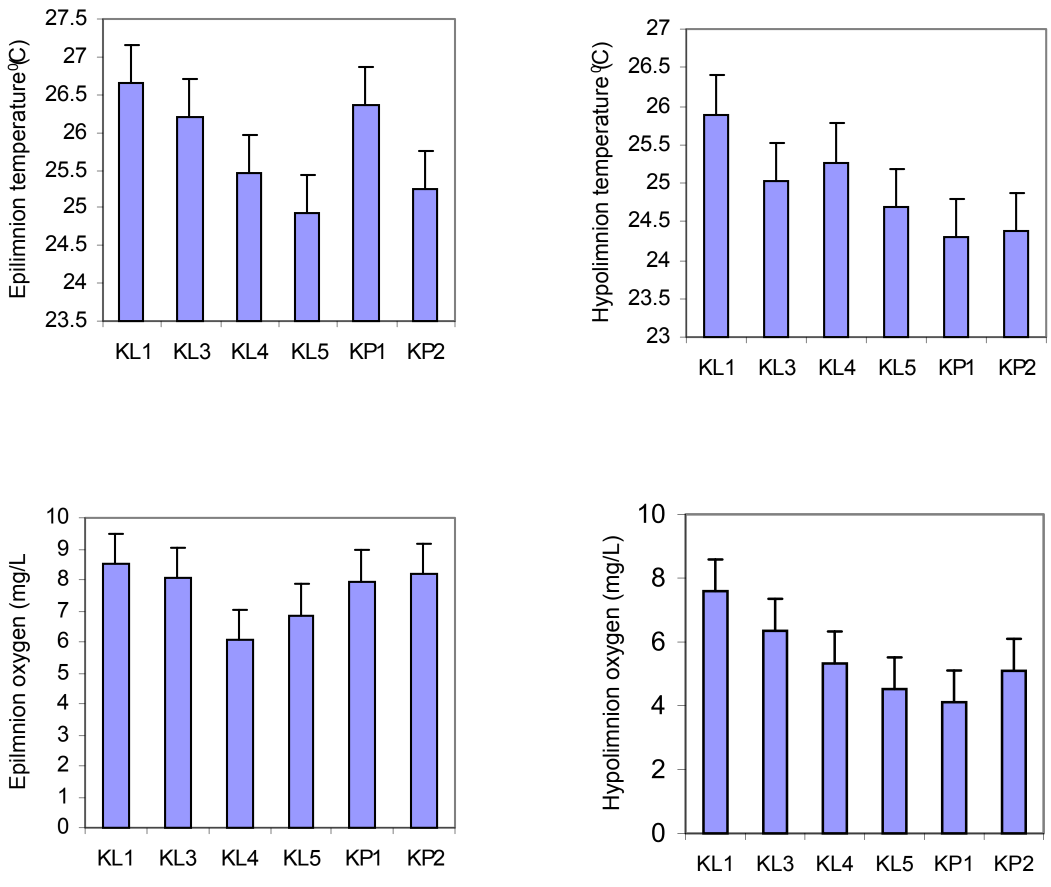


Figure 12. Spatial comparison of epilimnetic (surface waters) temperatures (top-left panel), hypolimnetic (bottom waters) temperatures (top-right panel), epilimnetic dissolved oxygen concentration (bottom-left panel and hypolimnetic

dissolved oxygen concentration (bottom-right panel) observations on 7-8 September 2002 at littoral and pelagic stations in Winam Gulf and Lake Victoria.

Dissolved oxygen concentrations in the surface waters of the gulf were similar to those measured offshore in the afternoons. The highest bottom water oxygen levels of 7.59 mg/L were measured at 1558hrs on 8 September 2002 at KL1. The bottom waters at the deeper littoral station KL5 were similar to those recorded at KP1 and KP2.

Table 2. Summary of epilimnetic (surface) amd hypolimnetic (bottom) water temperatures and dissolved oxygen in the period 2000-2005.

Station	Time (hours)	Epilimnetic Temp (^{0}C)	Hypolimnion Temp (^{0}C)	Epilimnetic DO (mg/L)	Hypolimnetic DO (mg/L)
KL1	1558	26.66	25.89	8.5	7.59
KL3	1259	26.2	25.02	8.06	6.35
KL4	1011	25.46	25.27	6.06	5.33
KL5	815	24.94	24.68	6.85	4.52
KP1	1650	26.37	24.3	7.94	4.11
KP2	1330	25.24	24.38	8.18	5.1

Interchange between gulfs and open lake

A picture of temperature and oxygen regimes is best captured by longitudinal and transverse transects conducted from the main Lake Victoria to Winam Gulf through a narrow constriction of Rusinga Channel at 0930hrs to 1300hrs on 15th August 2004 (fig. 13).

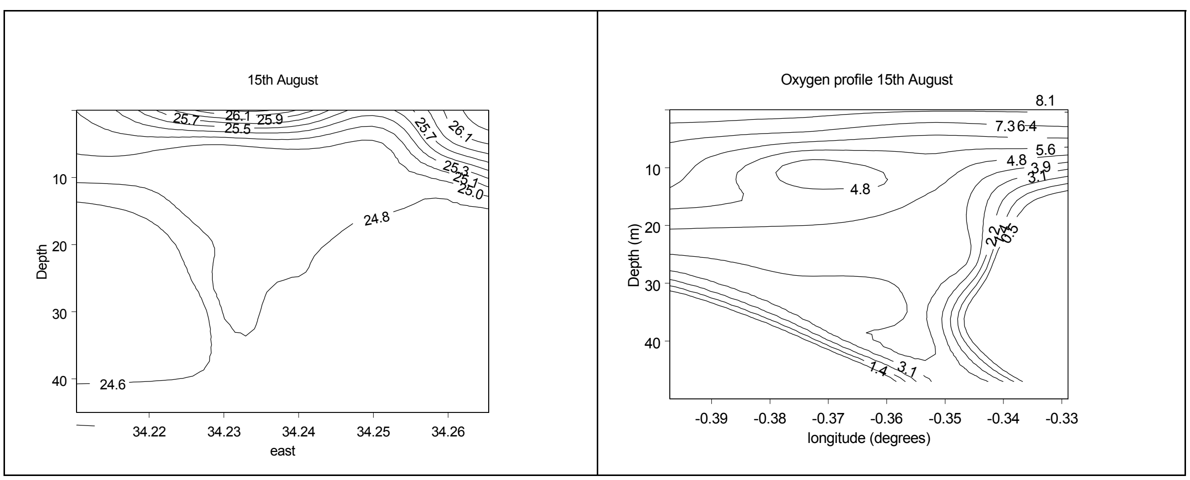


Fig. 13. Evidence of interchange between Winam Gulf and Open Lake Victoria from thermal (left panel) and oxygen regimes as observed on a longitudinal

transect along Rusinga Channel on 15 Aug. 2004. Locate stations where measurements made along this profile

The bunching of isotherms and isopleths in the surface waters indicated steep gradients while wide spacing in the bottom waters showed shallow gradients in time or space. The generally calm conditions, together with the strong and increasing solar insolation, led to a two-layer structure with a diurnal thermocline at 5 m depth (fig. 13). The presence of the diurnal thermocline shows that the gulf and lake were warming at the time of the transect. The generally horizontal gradients exhibited by isotherms 25.0^{0}C and 26.1^{0}C at Rusinga Channel is evidence of horizontal advection. The presence of sloping isotherms in the gulf indicated deepening of the surface mixed layer leading to exchange of cooler water masses from the main lake to the gulf.

The higher surface water temperature in the gulf as shown by isotherm 26.2^{0}C is due to differential heating by solar insolation from morning to afternoon hours. The inflow of water through Rusinga Channel builds up a pressure gradient during the day. The pressure gradient field is further strengthened by differential cooling at the perimeter of the gulf during the night. A likely water outflow is expected at this time.

The strong horizontal 5.8 to 8.1 mg/L isopleths of oxygen extending from the gulf to the lake show the horizontal mixing of gulf and lake surface waters at 5m. The anoxic conditions observed in the bottom waters (below 30m) offshore did not extend to the inshore waters.

DISCUSSION

Weather patterns over Winam Gulf and Lake Victoria play an important role in determining the introduction of nutrients to the photic zone. Upwelling of nutrients is considered to be of paramount importance to sustain food webs in lakes (Coulter 1991). The productivity of tropical lakes was linked to the intensity and direction of water movements, upwelling and horizontal currents, driven by wind speed and influenced by density based buoyancy differences (Verburg et al. 1998).

The process of mixing and upwelling occur at different timescales between Winam gulf and Lake Victoria. In the gulf, thermal stratification responds to daily land-lake breezes. During the day, the gulf is warmed up to a few metres deep by solar heating while cooling occurs at night. Mixing of epilimnetic and hypolimnetic waters and upwelling of pelagic regions occur during the dry season(June, July). In the dry season the Sudden stop here. In general there is a need to reduce detail in the text of this chapter and let figures present data, then highlight what reader should appreciate from the figure. Critical to communicate that the gulf has a different hydrodynamic regime than the lake and that interaction between the lake and the gulf is rather restricted. This section needs references.

CHAPTER 8

Lake Victoria monitoring of the pelagic, littoral, river mouths and near shore urban environments, Kenya

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INTRODUCTION

The Kenyan part of Lake Victoria covers an area of 3600 km^2 which is approximately 6 % of the area of the lake's 69,000 km^2. It has a catchment area of 49,000 Km^2, which is drained by several rivers and streams through which it contributes approximately 30% of total riverine inflow into the lake. The catchment falls in one of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centers, including the city of Kisumu, which contribute to the pollution of the lake with domestic and industrial wastes. The lake's basin is used as a repository for human, agricultural and human waste amongst other activities. Increased agricultural and municipal in-put into the lake has continued to endanger the environmental health of the lake and continues to raise concern. The lake is an important resource for the people living around it. It is used for various purposes, for example, provision of drinking water, fishing and transportation. The lake is home for several types of fish and other animals including the exotic invasive plant, Water Hyacinth), owing to the presence of high nutrients such as nitrates and phosphates.

The limnological and chemical status of the lake has been impacted by inputs of fertilizers into farms in the catchment, poor farming practices that lead to erosion of nutrient-bearing sediments, deforestation increasing runoff and nutrient yields,and biomass burning that release phosphorus and nitrogen into the air, and releases from municipal waste treatment. Major pollutants from these sources have been responsible for the limnological and water quality changes that have taken place in the lake. Loads of phosphorus, nitrogen, and silicon into the lake from municipal, industrial, non-point sources and from atmospheric deposition have been previously estimated using indirect methods, but this LVEMP has enabled the first comprehensive study of nutrient loading and the distribution of these nutrients within Kenya waters.

Concentrations of phosphorus have risen markedly, This has caused the lake to become eutrophic with frequent algal blooms occurring, with nitrogen fixing cyanobacteria and diatoms dominating in both pelagic and littoral waters (Hecky 1993, Mugidde 1993). Water turbidity has generally increased in the lake due to eutrophication and riverine inflow into the lake thus reducing water transparency. Dissolved oxygen concentration has also generally declined in deeper waters of the lake (Ochumba 1996, Hecky et al. 1994), with the deeper pelagic waters becoming increasingly anoxic. Temperature of water in the lake has generally risen over the years possibly due to global warming (Hecky et al. 1994).

Regular water quality measurements in Lake Victoria started before the turn of the last century when interest in the status of lake fishery started to rise. The first report on the water quality monitoring of the Kenyan part of Lake Victoria was by Worthington after his 1927 to 1928 surveys under Michael Graham (Worthington, 1930). Measurements were done in a station between Homa Bay (Ulambwi Bay) and Uyoma point within Nyanza (Winam) gulf. However, it is only in1950s and 1960s when more extensive measurements of nutrients and phytoplankton in the lake were undertaken by Talling. The results of his work are today used as references for assessing the water quality changes that have taken place in the lake in the past four decades. However, it was only from the mid-eighties that scientific publications appeared after several studies on the Kenyan part of the lake.

A group of local and international scientists undertook a baseline study on Kenyan Lake Victoria in 1984 and produced a report on a few aspects of the status of the lake (Foxal et al, 1984). Ochumba (1987) reported on periodic fish kills in the Kenyan part of Lake Victoria, which together with his work (Ochumba, 1990) on the hydrodynamics and eutrophication of Nyanza Gulf, have contributed to a heightened awareness on the serious threats to the lake water quality and the socio-economic implications. Ochumba & Kibaara (1989) reported on the observation of the blue-green algae (Cyanobacteria) and measured other related water quality aspects of the Kenyan Lake Victoria. Calamari et al (1995) carried out in-lake measurements of a limited number of physical-chemical water quality parameters and also assessed pollution input into Nyanza gulf. Other studies on phytoplankton (Lungaiya et al., 2000), and zooplankton (Mavuti & Litterick, 1992) have been carried out and have covered a few other water quality parameters. However, no geographically comprehensive and longer term monitoring on the water quality in the Kenyan part of Lake Victoria had been carried out before the start of Lake Victoria Environmental Management Programme.

Under Lake Victoria Environmental Management Project, extensive water quality studies have been undertaken in the Kenyan part of the lake. Data on temperature, dissolved oxygen, electrical conductivity, pH, nutrients (phosphorus, nitrogen, silica and carbon), water transparency (measured as secchi depth), suspended solids, turbidity, dissolved solids, phytoplankton, zooplankton, algal biomass (measured as chlorophyll a concentration), primary production, benthic macro invertebrates and bacteriology of the lake waters have been collected since 2000 and interpreted to give the current lake water quality status and to act as a reliable baseline for future lake monitoring.

Regular monitoring of the lake, therefore, coupled with application of appropriate pollution control measures in the lake basin is necessary for the purpose of safeguarding the lake against unwarranted pollution.

OBJECTIVES

The objectives of the Lake Victoria environment monitoring were to obtain data for:

- Determination of the present state of the lake water quality and ecosystem.
- Analysis of the relative importance of the biological processes and limiting factors in the eutrophication of the lake.
- Calibration of the Lake Victoria Water Quality Framework Model.
- Long -term monitoring of changes taking place in the lake.

To achieve these objectives a programme for monthly lake monitoring on the lake was established to gather data on the quality of the waters of the lake and the lake's limnology through in-situ measurements, and laboratory analysis of samples.

LAKE MONITORING

Pelagic Lake Monitoring

Three monitoring stations were established in the pelagic part of Lake Victoria (Kenya) namely, KP1, KP2 and KP3. The stations were established with the help of COWI consultants with (COWI-DHI, 2002) reference to stations established prior to LVEMP by the National Academy of Sciences so that they could lie as near as possible to transects along and across the lake (LVEMP, 2002).

Monitoring activities in the pelagic part of the lake were scheduled to be carried out on a monthly basis undertaking a 15 day cruise every month as recommended by LVEMP (2002). The measurements and samples taken at pelagic stations and the procedures used are indicated in section 4.0. Monthly monitoring, however, was not always possible due to logistical problems. Monitoring cruises activities were undertaken at least three times in a year.

Littoral Lake Monitoring

Six monitoring stations were established in the littoral part of the Kenyan side of Lake Victoria, namely, KL1, KL2, KL3, KL4, KL5 and KL6. The stations were established with the help of COWI consultants with reference to stations established prior to LVEMP by the National Academy of Sciences so that they could lie as near as possible to transects along and across Nyanza gulf (KL1-KL5) and the littoral part of the open lake. The measurements and samples taken at littoral stations and the procedures used are indicated in section 4.0. The frequency of monitoring was scheduled to take place monthly as in the case of monitoring of pelagic waters. average carried out three times in a year as for pelagic waters.

Near shore Urban Lake Monitoring

Four urban near shore lake stations, namely, Asembo Bay, Homa Bay, Mbita East and Mbita West were monitored along with littoral and pelagic stations. These stations were selected because they represent direct impacts of urbanization in the near shore areas. Municipal sewer discharges and industrial effluents are considered to be major sources of pollution of the lake. The bays are important sources of drinking water for people dwelling in the urban centers. The quality of water in these parts of the lake is suspect and from a public health point of view, the water is likely to contain water-borne carrying vectors and other contaminants. The pollution of water in these parts of the lake also poses a threat to aquatic life such as fish and other organisms. The ecosystem functions of the lake in these areas is likely to be affected by the pollutants that originate from the urban hot –spots. As in the case of pelagic and littoral stations, these stations were supposed to be monitored monthly but due to logistical problems this was not possible. They were sampled approximately three times in a year

River Mouth Station Monitoring

Rivers draining into Lake Victoria were monitored for limnological/water quality characteristics at their mouths. River mouths have been considered as potent pollution sources because of changes in their catchments, and as such it was deemed necessary to include them in this report. There are several rivers draining into the lake, four of which drain into the open lake and the rest into Winam gulf. The rivers include Nzoia, Yala, Sio, Gucha (these rivers drain into the open lake), Nyando, Sondu Miriu, Awach, Awach Kibuon, Oluch, Awach Seme, Awach Tende and Nyamasaria (these rivers drain into Winam gulf). These rivers are important as they transport large amounts of nutrients and nutrient-rich suspended sediments into the lake from the catchment. River mouths were also supposed to be monitored monthly but this was not possible due to logistical problems. They were monitored three times in a year on average.

MATERIALS AND METHODS

Study Area

The Kenyan part of Lake Victoria lies just south of the equator between 0^0 13' N/0^0 55'S and 33^0 56'E/ 34^0 45'E at an altitude of 1134 m above sea level.1400 Km^2 of the lake comprises Nyanza (Winam) gulf. Nyanza Gulf has a shoreline length of approximately 12,300 km and water depth at monitored stations varies from 3 m to 30 m with the deepest parts being found in Rusinga channel. The open lake has a surface area of approximately 2,200 km^2; a shoreline of approximately 3,440 km long and water depth in the pelagic zone varies from 30 m to 67 m.

The study area comprised both the pelagic and littoral parts of the lake. The pelagic part of the lake constitutes the area beyond 5 km from the shoreline and beyond 20 m deep. Stations established for monitoring in the pelagic zone include KP1; KP2 and KP3. The littoral part comprises Nyanza gulf and the inshore areas of the open lake. Stations established for monitoring in the littoral zone include KL1, KL2, KL3, KL4 (all in Nyanza Gulf,) KL5 (in Rusinga channel) and KL6 (in the open lake). The naming convention for the stations is as follows:

First letter: Country. K = Kenya, Second letter: L = Littoral (inshore). P = Pelagic (offshore).

The locations of the stations were chosen so that, as near as possible, they lay on transects along and across the lake. The study area and sampling locations are shown in (Fig 1). It was planned that a relatively limited number of key stations should be visited on monthly cruises and that all the required samples be collected on one cruise. LVEMP (2002) recommended that the plan of one cruise (15 days) per month be retained. The observed temporal variations in the state of the lake noted by LVEMP (2002) showed that monthly cruises are required to resolve the changes that occur. This was the programme that was adopted for lake monitoring.

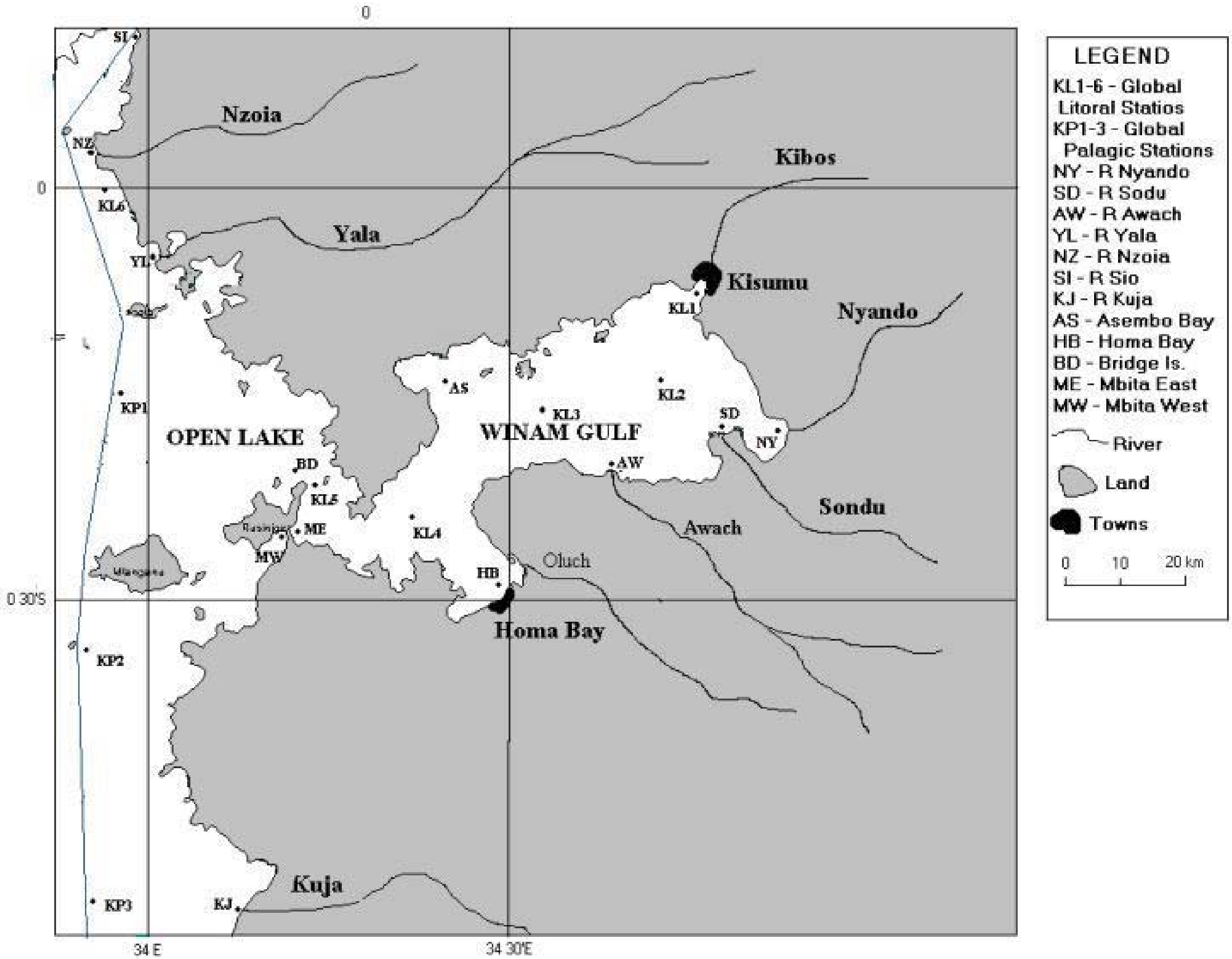


Figure1. Map of Lake Victoria showing sampling stations in the Kenyan part of the lake.

Field and laboratory methods

The methods described below apply to all the monitoring stations mentioned in this report.

Monitoring activities in the field involved *in-situ* measurement of limnological/water quality parameters, which included temperature, dissolved oxygen, electrical conductivity, pH, secchi depth, turbidity and total dissolved solids. The measurements were made with the Hydro lab Surveyor 4A Environmental Monitoring System. Primary production experiments and alkalinity measurements were also conducted in the fieldd. Primary production experiments were conducted by incubating for about two hours a set of light and dark bottles filled with lake water from the monitoring stations by immersing the bottles secured to a retrievable device into the same water column where the samples were collected and comparing dissolved oxygen concentrations in the incubated and unincubated samples. The difference in dissolved oxygen concentration was used to compute the photosynthetic rate as a measure of primary production.

At each station a Conductivity-Temperature-Depth (CTD) probe with additional sensors (Hydro lab Surveyor 4a) was used to measure temperature, dissolved oxygen (DO), pH, conductivity and turbidity at different depths down the water column. Light penetration was estimated with a 25 cm diameter white Secchi disc. GPS was used to locate the position of monitoring stations.

Secchi depth, temperature and dissolved oxygen (DO) profiles determined the depths for water samples and samples for phytoplankton and zooplankton.

- 0.5 m below surface
- 2.3 x secchi depth
- Start of DO- or temperature gradient
- 1 m below start of gradient
- 1 m above bottom
- 0.5 m above bottom

Water samples were taken in clean 1-litre capacity plastic containers. The samples were filtered on the boat through glass fibre filters (0.45μm) for determination of total, dissolved and particulate nutrients (nitrogen, phosphorus and carbon), loss on ignition (LOI) and chlorophyll *a*, and through membrane filters (0.2 μm) for particulate biogenic silica (PBSi). The filters and filtrate were frozen or kept below 4^0C to await analysis later in the laboratory.

In the laboratory, the samples were allowed to attain room temperature and divided into appropriate aliquots for use in the analysis of the nutrients using spectrophotometric methods as outlined in Wetzel & Likens (1991) and APHA (1995). Phosphate-phosphorus was analyzed as soluble reactive phosphate using the ascorbic acid method, nitrate-nitrogen using cadmium reduction and diazoic complex method and silica (DRSi) using the heteropoly blue method. Samples for analysis of total and dissolved organic nutrients were digested and analyzed as outlined in APHA (1995). Total phosphorus (TP) and dissolved organic phosphorus (DOP) were analyzed as PO_4-P whereas total nitrogen (TN), and dissolved organic nitrogen (DON) were analyzed as NO_3-N. For the analysis of particulate biogenic silica (PBSi) the filtered content was digested using wet alkaline method (2ml of 0.5M NaOH added and heated in the oven for 15 minutes at 85^{o}C) to release the bound silica. The digest was then analyzed as silica (SiO_2-Si). Chlorophyll-*a* pigment was extracted, in the laboratory, using 90% ethanol and analyzed using spectrophotometric methods as recommended in Wetzel & Likens (1991). For the analysis of total suspended solids (TSS) appropriate sample volume was filtered through a preweighed glass fiber filter paper (0.45μm), the filter paper with the content dried in an oven for 24h at 105 ^{o}C and weighed to calculate the TSS.

Phytoplankton samples for determination of abundance were collected with a 5 litre Schindler sampler at the surface (0.5m) Secchi depth, 2.3x Secchi depth and 5m intervals up to 1 m above the bottom in deep waters. These sampling depths effectively covered the euphotic zone. On lifting the sampler from the water column 100 ml of water sample from each depth was removed without being filtered and transferred to 125 ml dark glass bottles. Immediately, the samples were fixed with 1% acid Lugol's iodine solution (APHA, 1995). Few drops of formalin (4%) were added to the samples to keep them longer in case of delay in analysis or if samples were desired for archiving. The samples were kept in the darkened containers to avoid damage by iodine. For algal species composition (taxonomic survey) water samples were taken from the same depths with the same sampler. Samples collected from various depths were mixed and a sub-sample (100ml) was taken and drained into 125 ml amber glass bottles. Sugared formalin was used to fix the sample. However, it is recommended that integrated samples for species composition should be collected using plankton net of 10-20mm mesh size. During the cruises we did not have such a net. Abundance of phytoplankton was estimated using the formula given by APHA (1995). It is best to sample phytoplankton at a particular time each day. Between 8.30 a.m and 10.00 a.m is the preferred time. This is because the algae move up in the water to the surface, towards the sunlight, in the morning. In the afternoon the algae particularly the blue green algae tend to sink to lower regions. By sampling at roughly the same time on each sampling occasion one can directly compare the algal results from different days.

In the laboratory, samples were shaken and sub-samples of 1-2 ml were introduced in Utermol sedimentation/counting chambers (Utermol, H., 1958) and phytoplankton was allowed to settle for at least three hours. Phytoplankton cells were identified to the species level wherever possible, and counted by the Utermohl method using LEICA DMIL inverted microscope equipped with phase contrast and bright field illumination as needed. Standard literatures, including algal taxonomy keys, were used for identification of species.

Vertical hauls of Zooplankton were collected from each station using 100 mm mesh size zooplankton net with a mouth diameter of 30 cm. Samples were collected at different depths and sieved through 60 mm mesh. The samples were preserved in 5% formalin for later examination in the laboratory. In the laboratory, triplicate counts were made and the zooplankton identified to possible taxonomic levels.

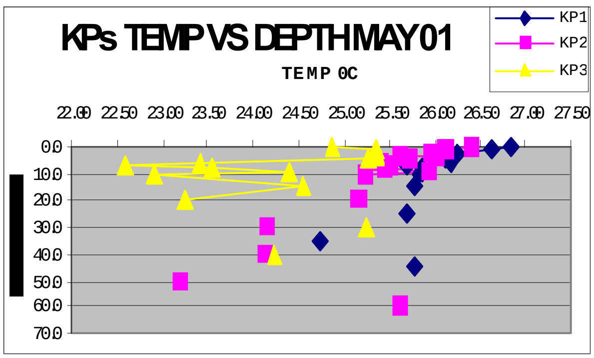
Zooplankton average densities were derived from the triplicate counts taking into consideration the sample volume (S), sub-sample volume (s) and the volume of water filtered along the water column. The densities were expressed in numbers per litre.

Samples for benthos were taken with an Ekman grab sampler. Benthos were separated from the sediments using suitable sieves and preserved in containers with 4% formalin.

RESULTS

Temperature and Stratification

Surface water temperatures in both pelagic and littoral waters were usually higher than deeper water temperatures. In general, temperature in littoral waters was higher than that in pelagic waters at similar depths. Temperature in pelagic waters ranged from 20.88^{o}C to 27.74^{o}C with mean temperature of 25.48^{o}C while in littoral waters temperature ranged from 21.8 ^{o}C to 28.8 ^{o}C with mean temperature of 26.06^{o}C. Littoral waters were most of the time well mixed and were only weakly stratified at certain times of the year (September –March). Mixing of water in pelagic waters was observed to occur up to certain depths at which stratification was notable. Stratification was evident and persistent from September to March in pelagic stations each year and the thermocline generally occurred between 20 m and 40 m (Figures 2 – 7). Water temperature in the urban lake stations and at river mouths was generally in the same range as that observed in pelagic and littoral waters. Most times the entire water column was well mixed as evidenced by silmilar high temperatures observed from the surface to the bottom. The results are shown in appendices E, F, G and H.



Figures 2 -7 showing temperature profiles (stratification and mixing phenomena) in pelagic and littoral waters

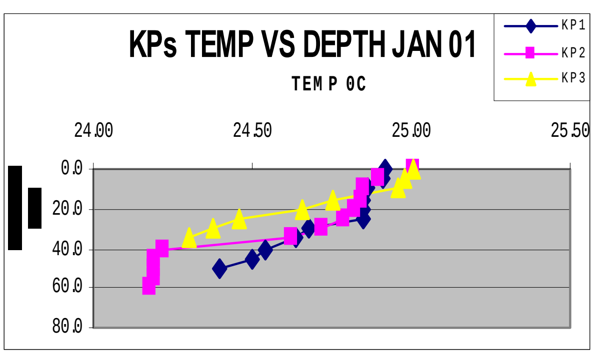
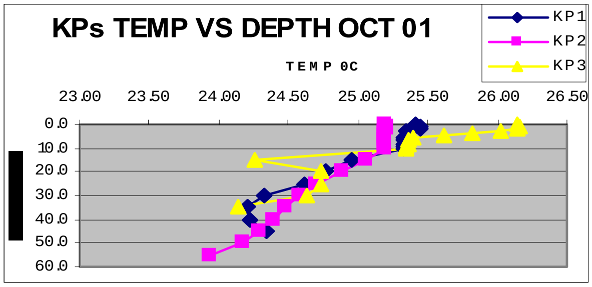


Fig. 2 Fig. 3



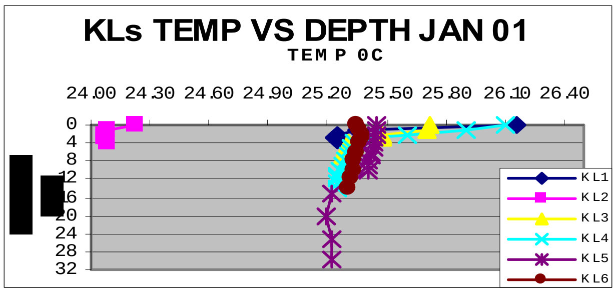
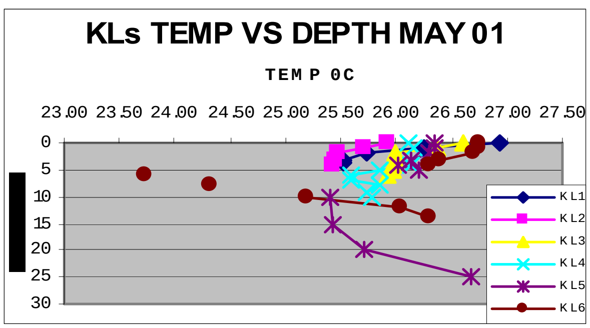


Fig.4 Fig. 5



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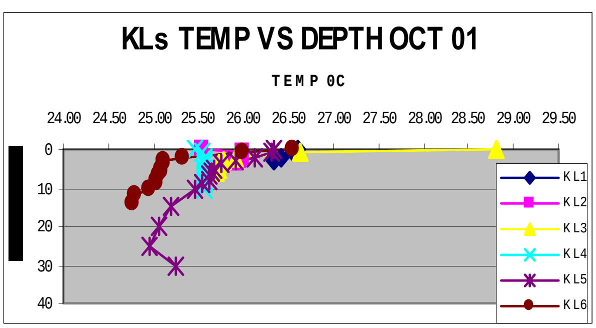
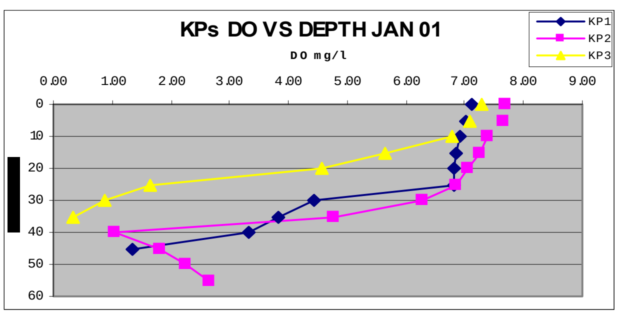


Fig. 6 Fig.7

Dissolved Oxygen

Dissolved oxygen in both pelagic and littoral waters was highest in the euphotic zone (7-12mg/l) of the water column. It was observed that when the water was well mixed in both pelagic and littoral waters only slight differences occurred in dissolved oxygen concentration between the upper and deeper waters. In pelagic waters, large differences in dissolved oxygen concentration were observed during periods of stratification. The waters above the thermocline had higher dissolved oxygen concentration (7.0 – 11.7mg/l) than waters below the thermocline. During periods of stratification bottom waters in both pelagic and littoral waters exhibited anoxic conditions (DO<5mg/l) (Figures 8 – 13). As in pelagic and littoral waters, dissolved oxygen concentration in urban lake waters and at river mouths was observed to be generally higher in the upper parts of the water column and lowest in the lower parts of the water column. The results are shown in appendices E, F, G and H.

Figures 8 – 13 showing dissolved oxygen profiles in pelagic and littoral waters



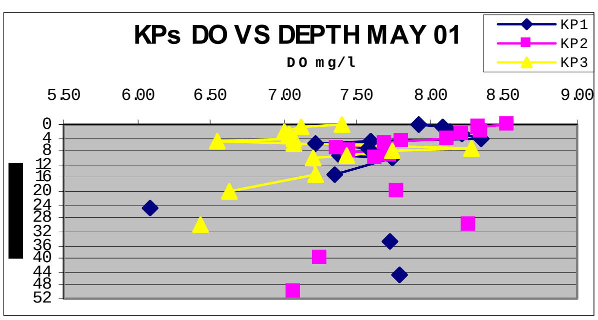
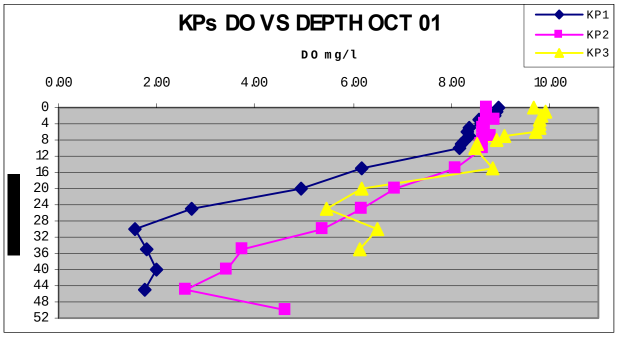


Fig. 8

Fig. 9



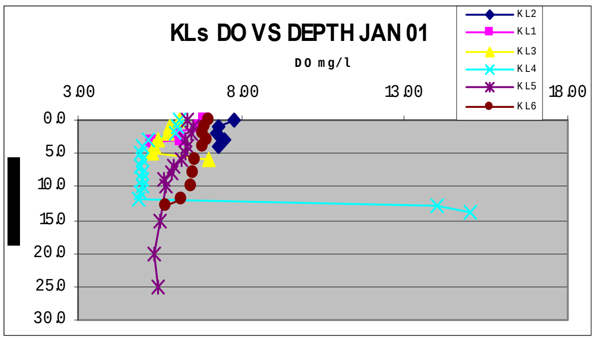
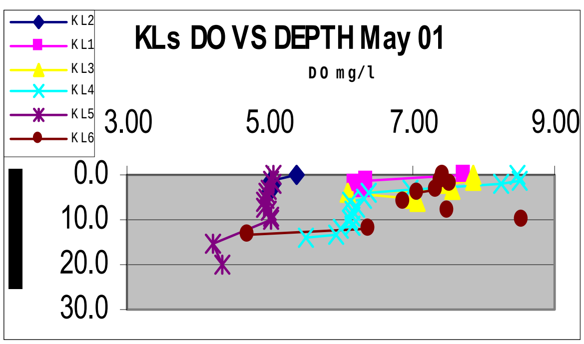


Fig. 10

Fig. 11



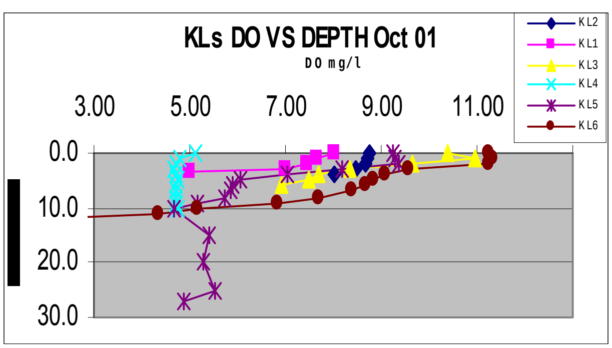


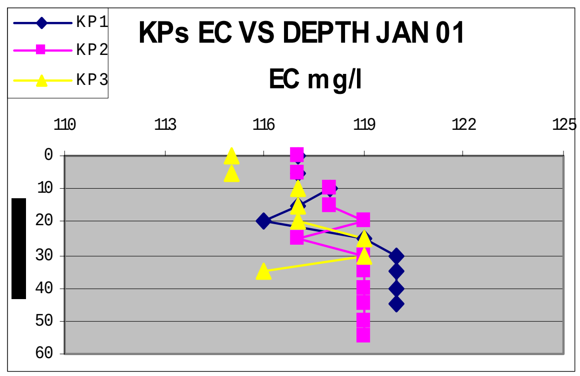
Fig. 12

Fig. 13

Conductivity

Generally conductivity was higher in littoral waters (105-161 μS/cm) than in pelagic waters (98-134 μS/cm) and a general decrease along Nyanza (Winam) gulf towards the main lake (181 μS/cm to 96 μS/cm) was apparent (Figures 14 -17). In urban lake stations and at river mouths electrical conductivity ranged from 94-174.9μS/cm. On average urban waters had higher electrical conductivity (138.13μS/cm) than littoral (135.64μS/cm) and pelagic (99.02μS/cm) waters. The results are shown in appendices E, F, G and H

Figures 14-17 showing conductivity profiles in pelagic and littoral waters



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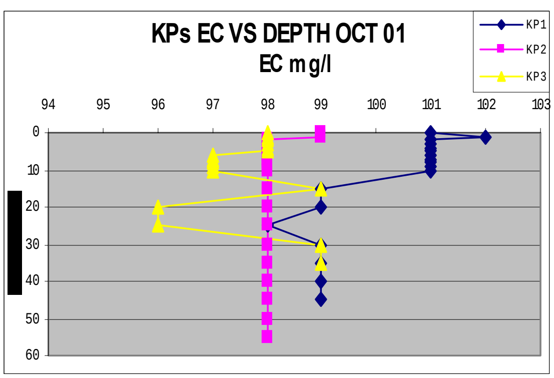


Fig. 14

Fig. 15

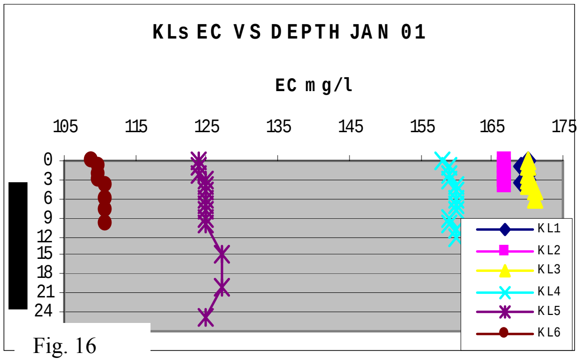


Fig. 16

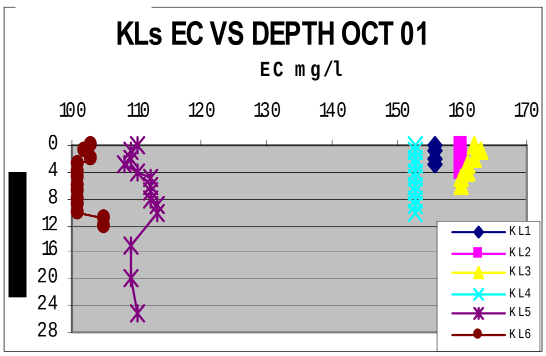


Fig. 16

Fig. 17

pH

pH generally was higher in the surface waters (7- 10) and gradually decreased down the water column in both pelagic and littoral waters (Figures 18 -23). The pH of water in urban lake stations and at river mouths was generally in the same range as that observed in pelagic and littoral lake stations. The results are shown in appendices E, F, G and H.

Figures 18-23 showing pH profiles – pelagic and littoral stations

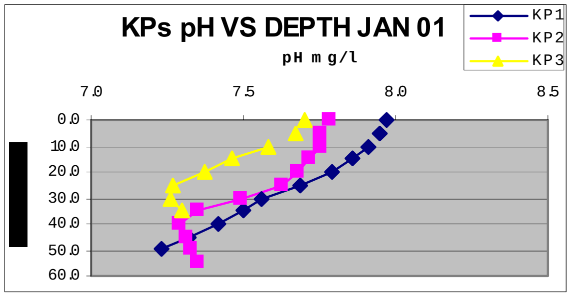


Fig. 19

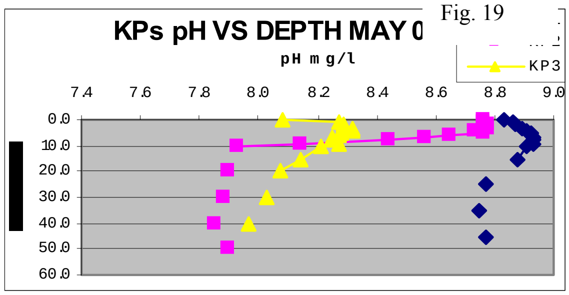


Fig. 18

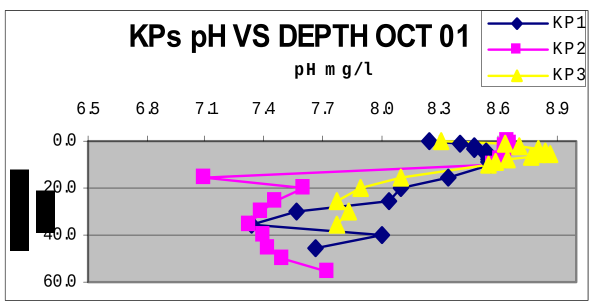


Fig. 20

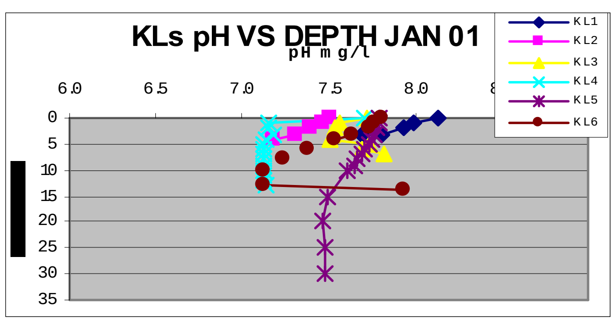
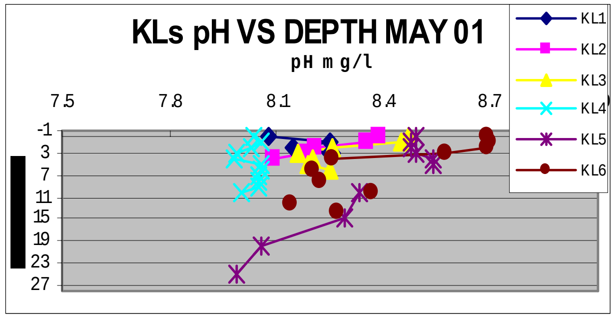


Fig. 21



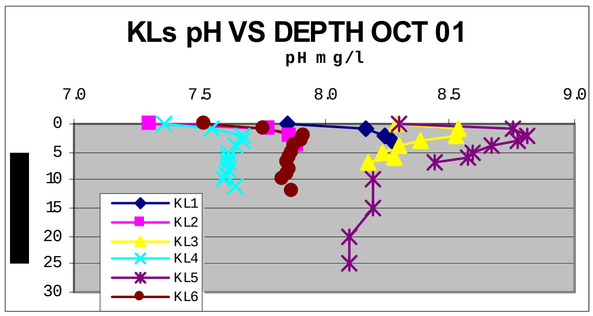


Fig. 22 Fig23

Total and dissolved nitrogen

Some differences in total nitrogen concentration were observed between stations and between different depths both in littoral and pelagic waters. Differences in total nitrogen concentration were also observed between littoral and pelagic waters with littoral waters having much higher concentrations (mean TN 1.12 mg/l) than pelagic waters (mean TN 0.48mg/l). Total particulate nitrogen and dissolved organic nitrogen were both observed to be higher in littoral waters (mean TPN, 0.32mg/l; DON, 0.52mg/l) than in pelagic waters (mean TPN, 0.14mg/l; DON, 0.45mg/l). Nitrite levels were higher in littoral waters (mean $N0_2$, 0.05mg/l) than the levels in pelagic waters (mean NO_2, 0.04mg/l) while nitrate levels were slightly higher in pelagic waters (mean $N0_3$, 0.08mg/l) than in littoral waters (mean NO_3, 0.06mg/l). Ammonium levels were also slightly higher in pelagic waters (mean, NH_4 0.07 mg/l) littoral waters ($NH_{4,}$ 0.06mg/l). There was no difference observed in inorganic nitrogen levels between pelagic waters (mean 0.13mg/l) and littoral waters (mean 0.13mg/l). Littoral waters had higher total nitrogen levels than the urban centers Asembo Bay (mean TN, 0.84 mg/l) and Homa Bay (mean TN, 0.79 mg/l). Kuja and Sio river mouths were observed to have the highest total nitrogen levels (mean TN, 3.12 and 1.08 mg/l respectively) among the rivers. Nzoia, Yala and Awach Kibuon had mean TN concentrations of 0.83mg/l, 0.75mg/l and 0.8mg/l respectively. Differences were observed in total nitrogen levels between the urban centers Asembo Bay and Homa Bay, and Mbita East (mean TN,0.68 mg/l), Mbita West (mean TN, 0.58 mg/l). Total particulate nitrogen was observed to be higher in the urban centers Asembo Bay and Homa Bay than in littoral and pelagic waters including Mbita East and Mbita West. The results are shown in appendices E, F, G and H.

Total phosphorus and dissolved phosphorus

Pelagic waters had marginally higher total phosphorus concentration (mean TP, 0.2mg/l) than littoral waters (mean TP, 0.19mg/l). Total particulate phosphorus concentrations were higher in littoral waters (mean 0.04mg/l) than in pelagic waters (0.02mg/l). Differences in dissolved organic phosphorus and phosphate phosphorus concentrations were observed between pelagic and littoral waters with pelagic waters having higher concentrations (mean DOP, 0.04mg/l; PO_4-P, 0.16mg/l) than littoral waters (mean DOP, 0.02mg/l; PO_4-P, 0.09mg/l). Total phosphorus concentrations in urban lake stations and river mouths were also surprisingly lower than those observed in pelagic stations. The results are shown in appendices E, F, G and H.

Silicate

Silicate concentrations in pelagic waters were observed to be lower (mean $Si0_2$, 0.84mg/l) than the levels in littoral waters (mean SiO_2 3.49mg/l) of Kenya. Similarly particulate biogenic silica concentration was lower in pelagic waters (PBSi mean 1.05mg/l) than in littoral waters (PBSi 4.34mg/l). Generally silica concentrations in urban lake stations were observed to be high (mean PBSi 3.03-10.67mg/l) while silica concentrations at river mouths were generally lower (mean PBSi 0.67-3.14mg/l) excepting at Awach Kibuon river mouth where concentrations were observed to be quite high (mean 7.62mg/l). Particulate biogenic silica concentration in urban lake stations was generally lower (mean PBSi 0.69- 4.9mg/l) than that observed in littoral stations but higher than the concentration observed in pelagic stations. The results are shown in appendices E, F, G and H.

Total suspended solids

Littoral stations were observed to have higher total suspended solids concentration (mean TSS 10.3mg/l) than pelagic stations (mean TSS 2.47mg/l). Urban lake stations had the highest total suspended solids concentration (mean TSS11.36-65.3mg/l). Total suspended solids concentration at river mouths varied from river to river with mean concentrations ranging from 3.52-32.93mg/l. The results are shown in appendices E, F, G and H.

Alkalinity

Alkalinity in pelagic waters ranged from 22.0 to 59.0 mg/l CaCO3. In littoral waters alkalinity varied from 27.0 to 92.0 mg/l CaCO3. In urban lake stations and at river mouths alkalinity of water was observed to be within the range observed in littoral waters E, F, G and H.

Chlorophyll *a*

Chlorophyll *a* concentration was higher in littoral waters (mean 0.21 mg/l this seems very high; is it 0.021??) than in pelagic waters (0.01mg/l). Chlorophyll *a* concentration in urban lake stations was higher (mean 0.66-1.27mg/l these also are very high) than that observed in pelagic and littoral stations. River mouths were observed to have much higher chlorophyll *a* concentration (mean 1.31-3.32mg/l). The results are shown in appendices E, F, G and H. I did not see data on chlorophyll by station in these appendices

Water transparency

Water transparency measured as Secchi depth in pelagic waters was higher (2.6m) than that in littoral waters (1.2m). Secchi depth was much lower in the urban lake waters, Asembo Bay (1.0m) and Homa Bay (0.7m) and in the urban lake stations Mbita East and Mbita West mean secchi depths were 1.27m and 1.24m respectively. Secchi depth at Yala river mouth was similar to that observed in littoral waters (mean 1.4m) while the rest of the river mouths had very low secchi depth (mean 0.06-0.87m.) The results are shown in appendices E, F, G and H.

Turbidity

Turbidity of water in pelagic stations was much lower (mean 7.83 NTU) than that in littoral stations (mean 21.27 NTU). Turbidity of water in the urban lake stations Asembo Bay and Homa Bay was quite high (mean 14.76 NTU and 33.52 NTU respectively). Turbidity of water in the urban lake stations Mbita East and Mbita West was much lower (1.27 NTU and 4.42 NTU respectively). Turbidity of water at river mouths excepting Yala river mouth (mean turbidity 7.07 NTU) was quite high (mean 11.78- 78.74 NTU). The results are shown in appendices E, F, G and H.

Total particulate carbon and total organic carbon

Total particulate carbon and total organic carbon concentrations were higher in littoral waters (mean TPC, 2.51 mg/l and TOC, 28.92 mg/l) than in pelagic waters (TPC, 0.97 mg/l and TOC, 23.52 mg/l). Total particulate carbon concentration in the urban lake stations Asembo Bay and Homa Bay was higher (4.45 and 2.77 mg/l respectively) than that in pelagic and littoral waters. Total particulate carbon concentration in Mbita East and Mbita West stations was low (mean 1.45 and 1.27 mg/l respectively). The results are shown in appendices E, F, G and H.

Phytoplankton

The phytoplankton community (at all stations?) was composed of Cyanobacteria (blue-green algae), Bacillariophyta (diatoms), Chlorophyta (green algae), Euglenophyta (euglenoids) and Pyrrophyta (unicellular flagellates). There was spatial and temporal variation in abundance, distribution and diversity. Both Cyanobacteria and diatoms were the more abundant and more widely distributed taxa in both littoral and pelagic waters. Cyanobacteria dominated other algal species in both littoral and pelagic waters This is not the case in the figure below where pelagic has diatoms as most abundant. Several species of algae from the two groups were common in both pelagic and littoral waters. These included *Microcystis aeruginosa*, *Nitzschia* species, *Synedra* species, *Navicula* species, *Anabaena spiroides*, *Planktolyngbya* species, *Anabaenopsis* species, *Merispodia* species, *Cylindrospermopsis* species, *Cymbella* species, *Anabaena circinalis*, *Spirulina platensis*, *Aphanocapsa* species, *Aulacoseira* species, Coelomoron species, *Chrooccoccus* species, *Ankistrodesmus* species, and *Euglena* species. *Microcystis aeruginosa* generally dominated over other cyanobacterial species.

The composition of algae in pelagic and littoral waters in the Kenyan side of Lake Victoria is shown in Figures 24 and 25 and Appendix K.

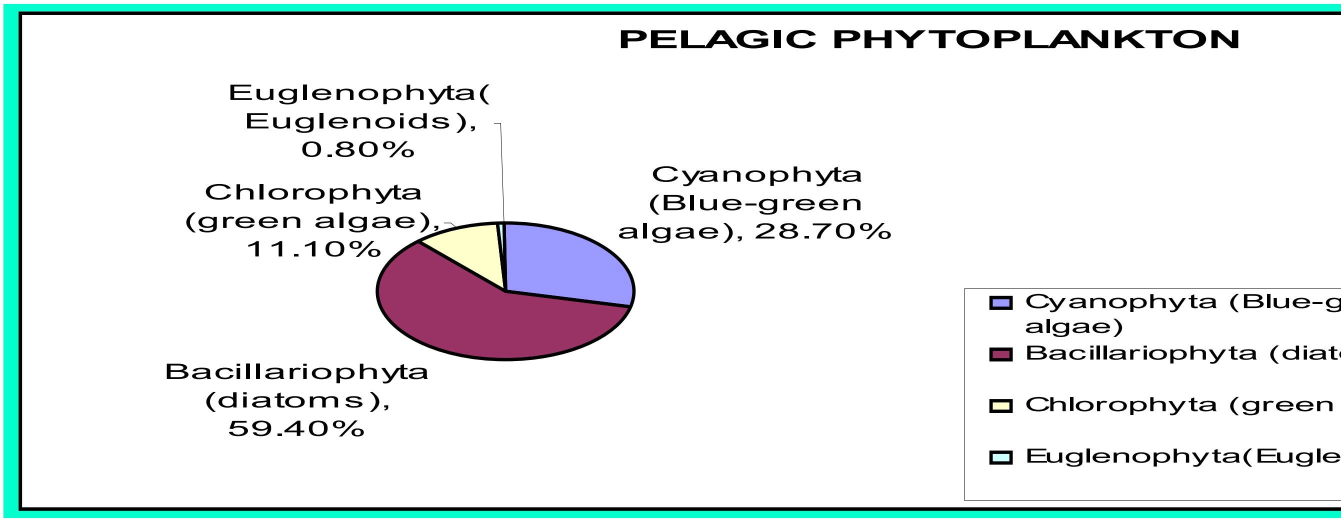


Fig.24

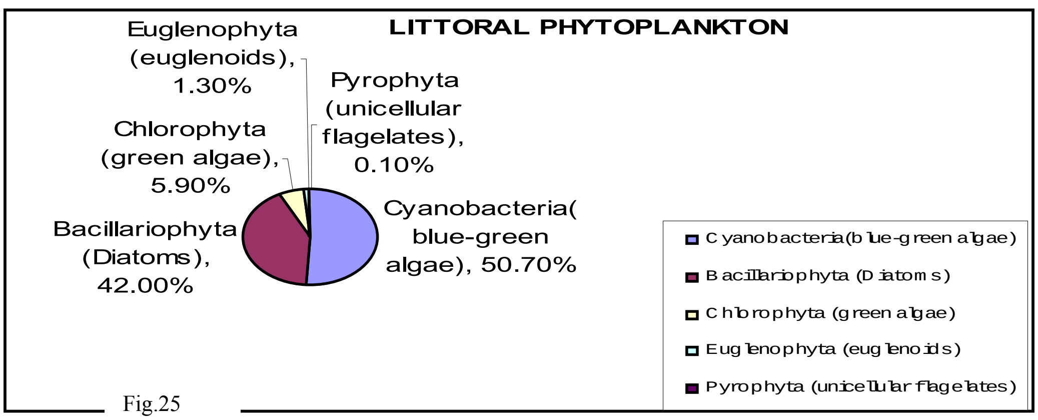


Fig.25

A general pattern of increasing dominance of N-fixing types (Anabaena and Cylindrospermopsis) in inshore and non-N-fixing types (viz. Microcystis) in offshore waters was apparent in qualitative algal examination. Overall 63 species from approximately 38 Taxa (Genera) were identified during this study.

The phytoplankton community observed in river mouths (Nzoia, Sio, Nyando, Sondu, and Awach Tende) included Cyanobacteria, Diatoms and Green algae. Cyanobacteria dominated followed by Diatoms. Green algae were very few. *Microcystis aeruginosa* dominated other cyanobacterial species and *Nitzschia* species dominated other diatoms. Other common species were Spirulina This ID seems suspect I have not heard Spirulina reported in Victoria before—this should be checked, *Anabaena circinalis*, *Anabaenopsis circularis*, *Nitzschia*, and *Synedra* species.

Cyanobacteria and Diatoms were observed in urban lake stations with *Microcystis aeruginosa* and *Nitzschia* species dominating. Other common species included *Microcystis aeruginosa, Anabaena circinalis, Anabaenopsis* species, *Synedra* and *Navicula* species.

Primary productivity

Photosynthetic rate experiments carried out in pelagic and littoral stations to determine primary production showed that littoral waters were more productive than pelagic waters. Fig. 26 shows the optimum rates of photosynthesis for gulf and lake waters on various dates. No methods are given for these results was an oxygen method used then report as oxygen produced

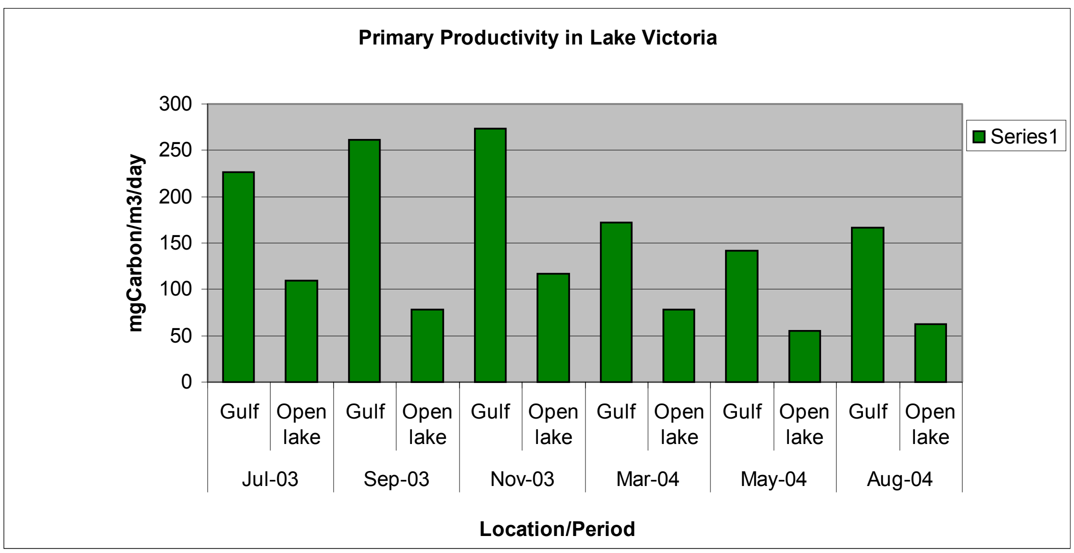


Fig. 26 showing primary Productivity in Lake Victoria

Zooplankton

The zooplankton community was composed of Copepods, Cladocera and Rotifers (Fig.27). Copepoda dominated the zooplankton community in all the stations with percentages ranging from 73-97.5%. Rotifers were the most diverse group. Twenty-four species were identified. The shallow gulf stations and the river mouths had higherst densities of zooplankton while the open lake densities were lower in the deeper water columns.

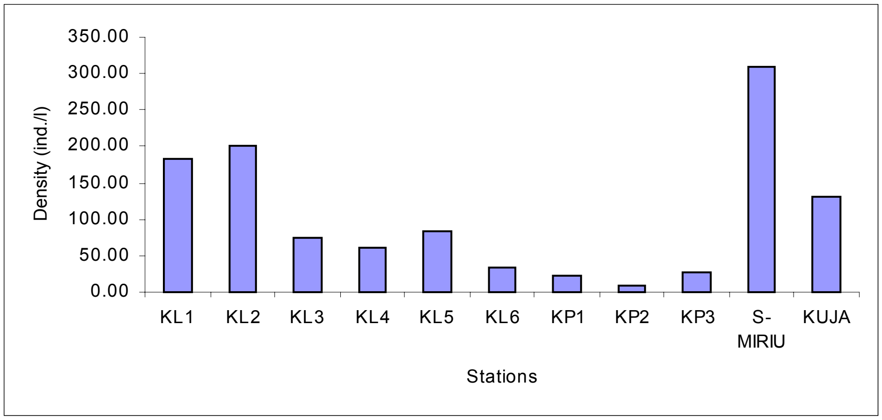


Fig. 27 Spatial variation in zooplankton density in Lake Victoria

Benthic invertebrates

Three major benthic macroinvertebrate groups namely snails (Gastropods), bivalves (Pelecypoda) and worms (Nematodes) were monitored during the study period. Snails and many bivalve species occurred primarily in the littoral zones of the lake, urban lake stations and at river mouths while nematodes occurred mostly at river mouths and urban lake stations. There was spatial and temporal variation in abundance and diversity. The macroinvertebrates observed in the Kenyan side of the lake are shown in appendix N.

Lake water microbiology

The microbiology of pelagic, littoral, urban lake waters and river mouths was determined with respect to coliform organisms. It was observed that pelagic waters had much less contamination bacteriologically than littoral and urban lake waters and river mouths where coliform counts were always greater than 2400 organisms per 100 milliliter of water examined. It was also observed that in undisturbed areas of littoral waters coliform counts were much less than in disturbed areas such as water abstraction points and fish landing beaches.

Discussion

The Water quality of Lake Victoria can best be understood by separately considering the deep offshore areas and the shallow inshore areas which include Nyanza (Winam) gulf. Data obtained between 2000 and 2005 show that the water quality of these two parts is distinctively different. Similar observations were made by Worthington (1930). He differentiated two types of environments within the lake, the shallow semi-isolated gulfs such as Nyanza and Mwanza gulfs and Murchison Bay which he compared to temperate eutrophic lakes that are not deep enough to be persistently stratified and the deep offshore lake waters which he compared to a deeper eutrophic lake in temperate zones. Results from the present study support this observation for Nyanza (Winam) gulf and other littoral parts whose waters have been observed to have different physico-chemical characteristics from those in the pelagic part of the lake.

The inshore areas are directly influenced by land-based inflows and due to their relatively shallow depth they are continuously mixed by wind action especially during late afternoon and early morning hours when winds are strongest (Worthington, 1930, Water Quality Component, LVEMP, 2000-2005, unpublished)). On the other hand, the offshore areas are not directly influenced by land-based inflows except through mixing with the inshore waters and due to increased depth they do experience annual stratification during some parts of the year which hinders complete mixing therefore influencing the water quality status especially at deeper depths.

The quality of water in the lake has considerably deteriorated over the years as a result of high annual inflow of nutrients into the lake from both the land and the atmosphere, which have accelerated the process of eutrophication in the lake with massive algal blooms and increased chlorophyll 'a' levels in pelagic waters from 1.2 - 4.0μg/l (Talling,1960s) and 15.8μg/l (Mavuti and Litterick, 1991) to levels of up to 10μg/l in pelagic waters (Water Quality Component, 2001 -2005, unpublished), and in littoral waters from 10 – 67.1μg/l (Talling 1960s) and 60.6μg/l (Mavuti and Litterick, 1991) to levels of up to 1560 mg/l (Water Quality Component, 2001 -2005, unpublished). These data show that the lake has been undergoing eutrophication over the years with the inshore waters being more eutrophic and more productive (Fig.26 and 27) than pelagic waters.

The mixing of water in littoral areas (shallow inshore waters) leads to the re-suspension of bottom sediments, which contributes to the low water transparency owing to increased turbidity in the water. The higher conductivity in littoral waters (105-181μS/cm) compared to that in pelagic waters (96-134μS/cm) can be attributed to the influence of land inflow through rivers and surface run-off and the limited exchange of waters between Nyanza (Winam) gulf and the open lake (Calamari et al, 1995).

Phosphorus and nitrogen levels were high in both pelagic and littoral waters with phosphorus levels being higher in pelagic waters and nitrogen levels being higher in littoral waters. Past studies have shown differences in some nutrient concentrations between stations within littoral waters particularly in Nyanza (Winam) gulf and those in pelagic waters. Mavuti &Litterick (1992), measured higher levels of PO4-P (soluble reactive phosphorus (SRP) in pelagic waters (16μg/l) than in Nyanza gulf (7 μg/l) which is a part of the littoral waters, which has been confirmed by the results of LVEMP (pelagic waters, 156 μg/l (This seems too high even for Total P unless it is a maximum observation) and littoral waters, 90 μg/l). Since littoral waters are recipients of land inflows directly that convey polluting materials such as industrial and municipal effluents and agricultural based fertilizers, it might be expected that phosphorus levels would be higher in littoral waters than in pelagic waters. The reason that could be advanced to explain this scenario is that the well oxygenated conditions in littoral waters keep PO_4-P strongly bound in suspended mineral particles (mainly iron oxides) whereas in pelagic waters where anoxic conditions occur due to increased depth, soluble reactive phosphorus is released into the water column leading to higher concentrations (Gikuma –Njuru &Hecky, 2005). Dissolved organic phosphorus levels were also higher in pelagic waters. The same reason given in respect of PO_4-P levels in pelagic waters also applies in respect of dissolved organic phosphorus. The relatively high levels of phosphorus in urban lake stations might be due to discharge of sewage e.g. Homa Bay, and agricultural activities near the shore e.g. Asembo Bay. The high levels observed at Mbita East might be due to influence from Nyanza (Winam) gulf through Rusinga Channel while the high levels observed at Mbita West might be due to influence from the open lake.

Total nitrogen, total particulate nitrogen and dissolved organic nitrogen concentrations were much higher in littoral waters than in pelagic waters. The higher concentrations of these materials might arise from riverine inputs and resuspension of bottom sediments. Riverine inflow might also be the cause of the high levels observed at river mouths while in urban lake stations such as Asembo Bay, Homa Bay and Mbita East water exchange with the gulf waters and resuspension might be the cause, and at Mbita West agricultural activities on Rusinga Island and exchange with the open lake might be the cause.

The TN: TP ratio in pelagic waters was calculated as 3.35 and the TN: TP ratio in littoral waters was calculated as 5.89 (on a weight basis). These ratios are far below the Redfield ratio of 16.1 (the ratio of a balanced aquatic system) which favours optimal algal growth in an aquatic system. According to Guildford & Hecky (2000), TN: TP <20 (molar) can result in nitrogen fixing cyanobacterial species. The above ratios show that nitrogen could be a limiting factor in the growth of algae both in pelagic and littoral waters but with more nitrogen limitation in pelagic waters. The low TN: TP ratios could be responsible for the dominance of Cyanobacteria and particularly N fixing Cyanobacteria in both pelagic and littoral waters.

Unlike phosphorus and nitrogen which have been rising, silicon levels have decreased in Lake Victoria (Hecky & Bugenyi, 1992; Hecky, 1993; Vershuren et al; 1998). This decrease was observed during the 2000-2005 study by LVEMP for both pelagic and littoral waters where levels were found to be lower (mean 0.84 and 3.46 mg/l respectively) than those reported by Talling (1965) (1.2 -5.5mg/l SiO_2). This is a substantial reduction relative to Talling's values. Silica concentrations were higher in littoral waters than in pelagic waters. The decrease in silica concentration can be attributed to higher demand by diatoms relative to supply from rivers because of increased availability of N and P. Silica depletion was widespread during the eutrophication of the Laurentian Great Lakes in North America during their eutrophication and silica concentrations have risen in those lakes since the imposition of successful phosphorus reduction strategies (Barbiero et al.2002). Since diatoms require silica for cell wall formation (Wetzel, 1985), the lower concentration of silica in pelagic waters compared to that in the gulf could be partly be as a result of diatom uptake and burial in the pelagic sediments and decreased regeneration owing to reduced mixing conditions in pelagic waters. The higher concentrations of particulate biogenic silica within littoral waters might be as a result of resuspension and silica containing plant debris brought in by the rivers (Bootsma et al; 2003) while in offshore waters particulate biogenic silica may be more representative of diatom concentrations.

Total particulate carbon and total organic carbon concentrations were on average higher in littoral waters than in pelagic waters. This could be explained in terms of much higher productivity of littoral waters compared to pelagic waters.

Turbidity resulting from land inflows and biological activity (eutrophication) within the lake has continued to increase impacting negatively on the quality of water as well as reducing water transparency as shown by Secchi depth measurements in pelagic waters, 0.0 – 4.2m, and in littoral waters, 0.2 – 2.4m (Water Quality Component, LVEMP, unpublished) and reducing the amount of light necessary for algal photosynthesis. High turbidity in water is undesirable from the point of view of using the lake water for drinking and industrial purposes and places a big cost on water treatment. Turbidity will also affect fish and other pollution prone aquatic organisms thus reducing their populations as it reduces dissolved oxygen concentration in the water through uptake by materials responsible for it. Comparison of data gathered during LVEMP (up to 107.7 NTU in pelagic waters and 200.3 NTU in littoral waters and data gathered prior to LVEMP (up to 16.0NTU in pelagic waters and 25.0 NTU in littoral waters, Ochumba and Kibaara, 1989 ;) show that turbidity in the lake has been increasing.

Temperature profiles showed that water temperatures in littoral areas are about 1^{o}C higher than in pelagic waters. The temperatures varied in an irregular manner from KL1 out to Rusinga Channel (KL5). This could perhaps be explained by the discharges from the rivers and streams into the Nyanza (Winam) gulf. Nyando and Sondu Rivers have significant flows all year round and there are many additional small discharges from the streams in the north and south of the gulf. The temperatures of the discharges will be different from each other and different from the lake, and could cause the irregular variations of the water temperatures that are observed. This hypothesis should be investigated further.

There is frequently a strong thermocline close to the surface in littoral waters**.** The thermocline could be the result of solar heating during day-light. This could be verified by making paired measurements at night or very early in the morning.

It has been hypothesized that the thermal stratification would result in outflow of warmer Gulf water through Rusinga to be replaced by cold water inflows could be an important factor as a flushing mechanism for Nyanza (Winam) Gulf. This hypothesis should be investigated. On the other hand, the discharges from the rivers will definitely give a net outflow and thereby a flushing of the gulf. Also, it is known that there are strong currents in Rusinga Channel both into and out of the gulf, probably correlated to the diurnal onshore –offshore wind pattern. These wind driven currents will also contribute to the flushing of the gulf. Greater understanding of the physical circulation is needed to fully understand the differences between Gulf and Lake waters.

The levels of dissolved oxygen below the surface layers over most of the lake are low. This could be attributed to the presence of pollutants that take up a lot of the oxygen. This has increased the demand for oxygen in the lake therefore affecting the quality of water and interfering with the lake's ecology. Water surface dissolved oxygen concentrations are 7-12mg/l in both pelagic and littoral waters. Excessive pollution of the lake will undoubtedly seriously affect the current levels making them drop thus jeopardizing the lake further. The hypolimnetic waters in the open lake are often anoxic and few organisms can tolerate such conditions. A good example of the seriousness of anoxic conditions in the bottom pelagic waters is the virtual absence of macro invertebrates. This observation was made on the many occasions the waters were sampled for these organisms. Levels of dissolved oxygen below 5mg/l can be disastrous to fish survival in freshwaters. Tilapia and Nile Perch have been known to be seriously affected by dissolved oxygen concentration below 5 mg/l.

Electrical conductivity in pelagic waters was observed to be lower than that in littoral waters. The high electrical conductivity observed in littoral waters particularly in Nyanza (Winam) gulf is most likely due to soluble salts (dissolved solids) that are deposited therein by the many rivers coming in from the catchment, which has diverse geological structure. The pelagic waters are dominated by direct and dilute rainfall on the surface and are weakly influenced by riverine flow into the lake hence the low electrical conductivity observed. Open lake conductivity is determined by the balance of inflowing dissolved salts and the loss of those salts at the outflow or to sedimentation as precipitates. Comparison with data gathered before LVEMP show that electrical conductivity of water in pelagic and littoral waters tended to rise over the years (Appendices I and J).
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Water in the euphotic zone both in pelagic and littoral waters was observed to be alkaline (pH 9.8 – 10.0). This could be explained in the light of high photosynthetic capacity of the waters in this zone. During photosynthesis carbon dioxide in the water is utilized resulting in pH rise. Comparison with data gathered before LVEMP show that the pH of water in the lake has risen over the years (Appendices I and J).

Total suspended solids in pelagic waters was significantly low (2.47mg/l on average)) compared to that in littoral waters (10.29mg/l on average). Littoral waters receive an assortment of materials from the catchment through the many rivers that drain into it coupled with the undesirable effects of eutrophication compared to pelagic waters that are less effected by riverine inflows. Also higher algal productivity in shallower waters will lead to higher suspended solids. This explains why littoral waters have higher total suspended solids concentration than pelagic waters.

Cyanobacteria and Diatoms were observed to be prominent in the phytoplankton communities both in pelagic and littoral waters with cyanobacteria dominating. This compares well with work done by other researchers prior to LVEMP (Hecky, 1993, Lungaiya et al., 2000). The overall increase in algal abundance and dominance of blue-green algae observed in this study could be attributed to the logical consequence of excess nutrient loading (N and P) that results from biomass burning, municipal and industrial pollution, deforestation and greatly intensified agriculture throughout the drainage basin of Lake Victoria, which comprises Tanzania, Uganda, Kenya, Burundi and Rwanda (Hecky and Bugenyi, 1992; Hecky, 1993; Mugidde, 1993; 2000, 2001; Kling *et al.,* 2001; Verschuren *et al.,* 2002). Generally, increase of Nitrogen and Phosphorus would cause a shift in the composition of algal primary producers, from diatoms to blue green algae. This is the situation in Lake Victoria today. This phenomenon is an indication of high level of eutrophication which is one of the most serious potential dangers to the Lake Victoria waters. The dangers include reduced dissolved oxygen, increased turbidity, reduced water transparency, fish kills and deterioration of

water quality. Specifically, increased nutrient levels cause increased total primary production, especially by bloom-forming Cyanobacteria.
The increased population of Cyanobacteria in the lake (especially in inshore areas) will negatively impact on the water quality, as this group of algae is known to produce toxins, which can both cause fish kills and compromise drinking water quality (Ochumba 1984; Ochumba 1987; Ochumba & Kibaara, 1989; Ochumba, 1990; Bugenyi & Magumba, 1996; Lungaiya et al., 2000; Kling et al 2001; Hummert et al., 2001; Orient et al., 2001). The dominance of Cyanobacteria in littoral waters, bays and river mouths may pose both direct and indirect other risks for the health and economic well being of people living in the coastal communities. *Microcystis* for example, which dominated the plankton samples in all near-shore stations, is associated with liver poisoning (Svonen, 1996). Species of genera *Anabaena* and *Microcystis* are among the most distributed toxin producers in eutrophicated fresh waters (Tartined *et al*, 2000).

Some species of Cyanobacteria such as the *Anabaena* and *Cylindrospemopsis*, which dominated in this study, are known to have ability of fixing atmospheric nitrogen and hence can influence the nitrogen budget of Lake Victoria through nitrogen fixation. Indeed, Mugidde (2001) reported that biological fixation of nitrogen is the largest single source of N (480 kilo tones per year). This atmospheric source may account for over 80% of total N loading to the lake.

Littoral waters were observed to be more productive than pelagic waters. This arises from the much higher population of primary producers (phytoplankton) in the gulf particularly the Cyanobacteria. Primary productivity in the lake has increased several fold since Talling's observations in 1950s.

Zooplankton density was observed to be higher in littoral waters and river mouths than in pelagic waters and the same was true for benthic macoinvertebrates. Since zooplankton is an important food source for several fish species, it is possible that the inshore lake areas have more productive fishery than the open areas. Species of dominant microfauna observed in the lake belong to the groups Copepoda, Cladocera and Rotifera with higher numbers occurring in Nyanza (Winam) gulf (Mavuti & Litterick, 1991, Water Quality Component, LVEMP, 2001-2005). Species of benthic biota particularly macro invertebrates (Gastropods, Bivalves, and Nematodes) were concentrated in bays and river mouths. The occurrence/relative abundance of the organisms in littoral, urban lake waters, bays and at river mouths was due to a good supply of oxygen (because of the shallowness of these areas) arising from well-oxygenated river water and the oxygen supplied through photosynthetic activity of phytoplankton, and the plentiful food supply associated with the sediments in these areas. These organisms affect nutrient flux between the sediments and the water column as they feed and move about. The movement of water, which is dependent on water currents, wave action and water depth, at river mouths and the inshore areas of the lake, play a crucial role in the supply of food and other essential factors such as dissolved oxygen, which are essential for the survival of benthic organisms.

Biodiversity in the Kenyan side of the lake has been affected by high pollution input into the lake. Some species of fish as well as species of other biota have been decimated. The introduction of the Nile Perch into the lake in the 1960s took a huge toll on the native algivorous Tilapia and haplochromines (Kilham & Kilham 1990) and this may have contributed to the increased algal abundance in the Gulf and lake.

Conclusions

- The environment in the pelagic area of the lake is distinctively different from that in the littoral area.
- Pelagic waters are persistently stratified for much of the year (September to April) as opposed to littoral waters which are weakly stratified as shown by spatial and temporal variations of water temperature.
- Dissolved oxygen concentrations in the euphotic zone of pelagic and littoral waters was found to vary from 7 -12 mg/l but in the deeper waters of pelagic waters anoxic conditions (DO<2mg/l) persist.
- Pelagic waters are less productive than littoral waters as evidenced by less algal blooms, less biomass in terms of chlorophyll *a,* less primary production, less plankton biomass, and less biodiversity observed therein.
- The level of nutrients in the lake particularly phosphorus and nitrogen is high and far exceeds levels (about 3 fold) observed four decades ago with phosphorus levels being higher in pelagic waters and nitrogen levels being higher in littoral waters. This has caused the lake to become eutrophic (signs of massive algal blooms and increased chlorophyll *a* levels) resulting in several undesirable effects, for example, general deterioration of water quality in the lake, increased water turbidity, reduced water transparency, reduced dissolved oxygen, reduced euphotic zone, interference with the food web and reduced biodiversity.
- Surface water temperatures have increased over the years (25.2^{o}C in 1960s compared to the present levels of 28.8^{o}C) in the gulf and to a lesser extent in the open lake.
- Diatoms and Cyanobacteria are prominent in the phytoplankton communities in the lake with cyanobacteria dominating in both areas.
- The high population of the zooplankton communities Copepoda and Rotifera particularly in inshore areas of the lake as much as cyanobacteria signify the deterioration of the environment of the lake.

- The data/information generated from the lake by LVEMP in respect of the lake's limnology (water quality characteristics, pollution status in terms of nutrient chemistry, primary productivity, and biota structure) is essential to formulate appropriate policy and regulations for proper management of pollutants particularly from land-based sources to safeguard the lake against pollution.
- The information will also serve as reliable baseline for future monitoring and studies in the lake.
- The data will also serve as input into the proposed Lake Victoria Water Quality Framework Model for the purpose of predicting the short and long-term changes that might affect the lake and enable appropriate environmental management strategies to be instituted in the lake basin and the lake's catchment to protect the lake from undue pollution.

Worthington and every scientist since then has recognized the inhomogeneity of the lake environment.

Pollution Hot Spots

From the results generated during the project, it was possible to identify certain areas in the lake which could be classified as hot spots owing to the phenomena taking place there such as high inflows from the land (non-point and point pollution sources), persistent algal blooms, and high algal biomass that mark out these areas as pollution reservoirs. These areas are:

- The Eastern Nyanza Gulf near Kisumu,
- Nyando and Sondu river mouths.
- Awach Kibuon river mouth at Kendu Bay.
- Nzoia, Sio and Kuja river mouths.

Recommendations

- The data/information from lake monitoring should be used in conjunction with data generated from the catchment to formulate appropriate policy and strategies for proper management of Lake Victoria ecosystem to ensure its sustainability for the benefit of the riparian communities.
- The data/information should be harmonized with the data/information generated in the Ugandan and Tanzanian sides of Lake Victoria to produce a common document on limnological changes that have taken place in the lake over the years and the status of the water quality in the lake where appropriate strategies that ought to be taken by the governments of Lake Victoria riparian states to improve the current undesirable state of the lake should be clearly indicated.
- The monitoring of the lake should be a continuous process and should not just be seen as a LVEMP activity that ceases when LVEMP ceases. Considering the importance of the lake, the government should

institute a framework for long-term monitoring of the lake agreeable by all environmentally oriented ministries under the auspices of the Ministry of Environment and natural Resources.

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Appendix A

Abbreviations

Alk.	=	Alkalinity
APHA	=	American Public Health Association
AS.B	=	Asembo Bay
AW. K.R.	=	Awach Kibuon River
AW.R	=	Awach River
AV	=	Average
$CaCo_3$	=	Calcium carbonate
CH	=	Chlorophyll
cm	=	Centimetre
DO	=	Dissolved Oxygen
DON	=	Dissolved Organic Nitrogen
DOP	=	Dissolved Organic Phosphate
DRSI	=	Dissolved Organic Silica
E	=	East
EC	=	Electrical Conductivity
h	=	Hour
HM	=	Homa Bay
IN	=	Inorganic Nitrogen
KL	=	Kenya Littoral
km^2	=	Kilometre squared
KP	=	Kenya Pelagic
LOI	=	Loss on Ignition
LVEMP	=	Lake Victoria Environmental Management Project
M	=	Metre/Molar where appropriate
Max	=	Maximum
ME	=	Mbita East
Min.	=	Minimum
Mg/l	=	Milligrame per litre
ml	=	Millilitre
Mw	=	Mbita West
N	=	Nitrogen
NH_4	=	Ammonia/Ammonium
NO_2	=	Nitrite
$NO_{3-}N$	=	Nitrate – Nitrogen
NO_3	=	Nitrate
NTU	=	Nephelometric Turbidity Units
Nz. R	=	Nzoia River
ºC	=	Degrees Centigrade
PBSi	=	Particullate Biogenic Silica
pH	=	Logarithm of hydrogen ion concentration
S	=	South
SiO_2	=	Silicon dioxide (Silicate)
Sp	=	Species
Temp.	=	Temperature
TN	=	Total Nitrogen
TOC	=	Total Organic Carbon
TPC	=	Total Particulate carbon
TPN	=	Total Particulate Nitrogen
TP	=	Total Phosphorus
TPP	=	Total Particulate Phosphorus
TURB.	=	Turbidity
TSS	=	Total Suspended Solids
µg/L	=	Microgrammes per litre
Viz	=	For instance
µm	=	Micrometre
µS/cm	=	Microsiemens per centimetre

Appendix B

Lake Monitoring stations- coordinates and maximum depth

STATIONS	COORDINATES.	MAXIMUM DEPTH (m)
KP 1	33' 59. 670' E 00'18, 808' S	57
KP 2	33' 57, 051' E 00' 36, 931' S	65
KP 3	34' 03, 828' E 00' 54, 296' S	57
KL 1	34' 43, 248' E 00' 07, 255' S	3.5
KL 2	34' 39, 767' E 00' 13, 410' S	5.0
KL 3	34' 31, 183' E 00' 15, 346' S	6.0
KL 4	34' 22, 894' E 00'22, 807' S	15.0
KL 5	34' 14, 282' E 00' 20, 973' S	28.0
KL 6	33' 58, 386' E 00' 00 669' S	16.0

Appendix C

Urban Lake Monitoring Stations- coordinates and maximum depth

STATIONS	COORDINATES	MAXIMUM DEPTH (m)
Asembo Bay	34^0 23.961'E 0^0 12.296'S	4
Homa Bay	34^0 27.588'E 0^0 31.022'S	3.5
Mbita East	34^0 12.651'E 0^0 25.001'S	11
Mbita West	34^0 11.767'E 0^0 25.893'S	13

Appendix D

River Mouth Monitoring Stations- coordinates and maximum depth

STATIONS	COORDINATES	MAXIMUM DEPTH (m)
Nzoia River. Mouth	$33^0$56.819'E 0^0 03.222'S	3
Sio River	$34^0$00.006'E 0^0 13.357'S	4.5
Yala River	$34^0$02.70'E 0^0 03.712'S	4.5
Kuja River	$34^0$037.912E 0^0 55.046'S	7
Awach Kibuon	$34^0$39.003E 0^0 20.099'S	2

Appendix E: Results of pelagic lake monitoring: maximum, minimum and average values.

ST.		Temp ^oC	DO Mg/l	EC µS/cm	pH	TN Mg/l	TPN Mg/l	DON Mg/l	NO_2 Mg/l	NO_3 Mg/l	NH_4 Mg/l	IN Mg/l	TP Mg/l	TPP Mg/l	DOP Mg/l	PO_4P Mg/l	PBSi Mg/l	Si Mg/l	T Mg/l	ALK Mg/l$CaCO_3$	LOI Mg/l	CH Mg/l	SECCHI	TURB NTU	TPC Mg/l	TOC Mg/l
KP1	Max	26.84	1O.07	120	9.6	1.338	0.333	1.368	0.017	0.567	0.315	0.609	3.78	0.128	0.15	2.29	22.50	3.041	25.0	56.0	3.4	0.02	3.8	107.7	1.3	30.55
	Min	21.05	0.15	86	6.2	O.301	0.010	0.077	0.001	0.001	0.007	0.017	0.025	0.002	0.00	0.003	0.003	0.040	0.20	22.0	0.5	0.001	1.6	0.0	0.20	15.09
	Av	25.97	6.27	98.86	8.0	0.093	0.12	0.45	0.004	O.O8	0.08	0.15	0.O29	0.022	0.05	0.157	1.65	1.020	4.32	43.23	2.58	0.007	2.4	6.18	0.98	23.71
KP2	Max	27.20	11.77	134.0	9.6	1.46	0.71	1.21	0.014	0.57	0.28	0.44	3.4	0.03	0.18	1.4	5.89	3.95	11.0	59	4.0	0.02	4.0	106.3	1.40	32.14
	Min	20.88	0.10	85.0	6.10	0.31	0.01	0.10	0.001	0.001	0.002	0.004	0.02	0.002	0.02	0.004	0.003	0.12	0.0	27	0.25	0.0	2.1	0.0	0.10	18.91
	Av	25.23	5.98	100.25	7.86	0.65	0.18	0.47	0.003	0.08	0.05	0.11	0.32	0.01	0.04	0.13	0.55	0.71	1.5	43.58	2.67	0.01	3.0	8.4	0.89	25.42
KP3	Max	27.74	10.90	119	9.8	1.41	0.36	1.23	0.025	0.39	0.27	0.47	2.06	0.06	0.09	1.75	12,5	2.35	4.5	54	4.2	0.02	4.2	55.0	1.30	24.07
	Min	22.59	0.34	85	6.4	0.37	0.01	0.13	0.001	0.002	0.002	0.01	0.05	0.002	0.03	0.01	0.001	0.12	0.0	25	2.0	0.0	0.0	0.0	0.80	17.07
	Av	25.26	6.16	97.95	8.03	0.69	0.13	0.43	0.004	0.07	0.06	0.13	0.25	0.02	0.03	0.18	0.95	0.78	1.58	42.83	2.98	0.01	2.4	8.9	1.05	21.44

Appendix F showing the results of littoral lake monitoring: maximum, minimum, average values

ST.		Temp ^0C	DO Mg/l	EC µS/cm	PH	TN Mg/l	TPN Mg/l	DON Mg/l	NO_2 Mg/l	NO_3 Mg/l	NH_4 Mg/l	IN Mg/l	TP Mg/l	TPP Mg/l	DOP Mg/l	PO4P Mg/l	PBSi Mg/l	Si Mg/l	TSS Mg/l	ALK Mg/l$CaCo_3$	LOI Mg/l	CH Mg/l	SECCHI (m)	TURB NTU	TPC Mg/l	TOC Mg/l
KL1	Max	28.54	8.64	181	9.49	2.56	0.48	0.87	0.017	0.39	0.13	0.50	1.21	0.08	0.04	0.76	30.83	9.9	18.5	86	12.0	1.56	1.0	129.0	5.2	40.72
	Min	24.07	3.7	1072	7.3	0.68	0.01	0.22	o.001	0.003	0.004	0.03	0.03	0.02	0.01	0.003	0.003	0.73	9.0	64	6.0	0.007	0.2	12.5	2.4	23.06
	Av	26.5	6.4	135.85	9.04	1.29	0.25	0.6	0.006	0.05	0.06	0.12	0.16	0.07	0.03	0.1	3.54	4.2	12.59	74.33	9.39	0.75	0.7	33.3	3.75	33.97
KL2	Max	28.38	8.76	172	9.5	5.15	0.55	1.00	0.023	0.08	0.20	0.21	1.27	0.09	0.07	1.2	9.17	8.74	25.0	90	11.0	0.06	1.2	200.3	5.0	35.32
	Min	23.39	4.98	100	7.2	0.54	0.29	0.06	0.001	0.003	0.001	0.03	0.03	0.002	0.001	0.001	0.01	0.73	8.0	37	4.75	0.004	0.3	6.9	1.90	19.23
	Av	25.4	6.75	152.11	8.32	1.22	0.38	0.38	0.005	0.03	0.05	0.08	0.15	0.04	0.02	0.1	7.72	4.2	13.56	69.59	8.0	0.02	0.8	40.0	3.24	28.71
KL3	Max	28.81	10.94	174	10.0	3.09	1.26	2.43	0.06	0.096	0.41	0.44	1.36	0.09	0.06	0.65	11.82	11.5	197	92	12.0	0.06	1.2	54.7	14.4	-
	Min	24.03	4.15	107	7.0	0.19	0.01	0.17	0.001	0.001	0.001	0.004	0.02	0.004	0.00	0.002	0.003	0.531	4.67	37	4.25	0.003	0.8	5.2	1.7	-
	Av	25.85	6.60	157.46	8.46	1.35	o.42	0.72	0.001	0.03	0.06	0.09	0.14	0.05	0.01	0.06	1.81	5.06	18.27	71.88	7.74	0.02	1.0	18.1	4.08	-
KL4	Max	27.86	8.52	168	9.4	2.17	1.33	1.23	0.016	0.55	1.44	0.75	1.48	0.20	0.34	0.51	9.2	9.05	59.5	89	6.0	0.01	1.6	6.7	7.89	37.55

	Min	23.22	2.19	105	6.8	0.33	0.01	0.06	0.001	0.004	0.001	0.02	0.006	0.002	0.00	0.0	0.01	0.43	2.6	36	1.75	0.0	1.0	0.0	0.7	21.97
	Av	25.73	5.55	154.97	7.98	1.10	0.39	0.54	0.005	0.08	0.10	0.15	0.15	0.04	0.03	0.05	9.12	4.69	9.67	66	4.62	0.02	1.4	15.3	2.28	31.65
KL5	Max	27.44	9.47	151	9.2	2.60	1.74	0.99	0.031	3.5	0.56	3.9	2.23	0.04	0.19	1.50	16.27	5.99	7.0	63	4.6	0.03	2.2	24.4	1.92	28.98
	Min	23.71	2.30	110	6.7	0.49	0.01	0.06	0.001	0.002	0.007	0.02	0.05	0.002	0.001	0.002	0.002	0.06	0.6	28	2.25	0.0	1.2	1.4	0.9	17.86
	Av	25.76	5.74	114.21	7.91	0.94	0.03	0.43	0.006	0.16	0.08	0.27	0.23	0.03	0.02	0.14	2.53	1.43	3.25	49.76	3.14	0.01	1.9	8.3	1.19	24.01
KL6	Max	28.01	11.99	112.13	9.9	1.50	0.87	1.37	0.009	0.17	0.14	0.24	3.4	0.09	0.87	1.81	15.83	8.95	10.8	58	7.0	0.07	2.4	77.5	2.8	29.05
	Min	21.84	1.65	96	7.1	0.39	0.003	0.08	0.001	0.001	0.004	0.004	0.02	0.002	0.01	0.001	0.003	0.02	0.0.0	27	1.4	0.04	0.8	0.0	0.96	23.52
	Av	27.12	6.7	99.21	8.35	0.82	0.32	0.45	0.004	0.02	0.06	0.06	0.32	0.01	0.02	0.09	1.31	1.18	4.44	47	3.97	0.02	1.5	12.6	0.53	26.24

Appendix G showing the results of urban lake monitoring: maximum, minimum and average values.

ST.		Temp°C	DO Mg/l	EC μS/cm	pH	TN Mg/l	TPN Mg/l	DON Mg/l	NO_2 Mg/l	NO_3 Mg/l	NH_4 Mg/l	IN Mg/l	TP Mg/l	TPP Mg/l	DOP Mg/l	PO_4P Mg/ll	PBSi Mg/l	Si Mg/l	TSS Mg/l	ALk Mg/l $CaCo_3$	LOI Mg/l	CH Mg/l	SECCHI (m)	TURB NTU	TPC Mg/l
AS.B	Max	28.25	9.85	174.9	10.55	0.914	0.40	0.52	0.004	0.032	0.049	0.033	0.080	0.039	0.04	0.056	3.437	12.21	19.00	91.00	1 4.75	0.011	0.6	30.80	5.60
	Min	24.12	5.36	151.2	7.6	0.728	0.40	0.39	0.00	0.002	0.003	0.009	0.028	0.039	-0.02	0.001	0.031	0.684	6.50	35.00	7.50	1.79	1.1	4.00	3.00
	Av	26.34	7.21	162.35	8.92	0.837	0.40	0.45	0.002	0.011	0.022	0.023	0.044	0.039	0.011	0.019	0.977	5.477	11.36	73.00	11.13	0.76	1.0	14.76	4.45
HB	Max	28.51	9.13	172.0	10.8	0.9	-	0.63	0.017	0.081	0.053	0.151	0.094	0.035	0.037	0.036	2.367	6.345	14.33	72.0	7.50	1.48	1.10	40.10	3.0
	Min	24.71	2.84	144.0	7.3	0.63	-	0.35	0.004	0.003	0.026	0.05	0.037	-	0.012	0.029	0.593	4.205	8.0	36.0	6.33	0.015	0.014	18.40	2.5
	Av	27.19	6.34	158.24	8.54	0.79	-	0.48	0.009	0.041	0.038	0.1	0.067	-	0.022	0.033	1.103	4.895	10.67	65.3	6.92	0.84	0.66	33.52	2.77
ME	Max	28.05	9.49	164.0	9.1	0.84	0.19	0.55	0.016	0.26	0.169	0.138	0.117	0.031	0.067	0.047	0.808	3.070	4.60	72.0	4.25	3.25	2.20	9.20	1.7
	Min	24.04	5.02	111.0	7.0	0.49	0.15	0.19	0.001	0.003	0.005	0.024	0.043	0.017	0.001	0.020	0.046	0.033	1.00	47.0	3.00	0.005	0.008	1.7	1.2
	Av	27.21	7.23	130.58	8.6	0.68	0.16	0.29	0.005	0.07	0.07	0.08	0.06	0.02	0.03	0.03	0.28	1.46	3.13	54.08	3.66	2.10	1.27	2.63	1.45
MW	Max	27.17	11.69	107.0	9.9	0.98	0.08	0.43	0.004	0.17	0.075	0.096	0.152	0.024	0.117	0.117	0.685	2.48	7.60	52.0	4.4	6.024	2.6	16.0	1.30
	Min	24.57	0.81	94.0	7.13	0.27	0.06	0.20	0.001	0.003	0.017	0.031	0.061	0.011	0.009	0.040	0.018	0.146	1.80	45.0	2.4	0.002	0.004	0.40	1.20
	Av	26.19	6.15	101.34	8.8	0.58	0.07	0.31	0.002	0.04	0.050	0.06	0.09	0.018	0.05	0.067	0.199	0.69	3.025	45.38	3.26	2.212	1.24	4.42	1.27

Appendix H showing the results of river mouths monitoring: maximum, minimum and average values.

ST.		Temp °C	DO Mg/l	EC µS/cm	pH	TN Mg/l	TPN Mg/l	DON Mg/l	NO_2 Mg/l	NO_3 Mg/l	NH_4 Mg/l	IN Mg/l	TP Mg/l	TPP Mg/l	DOP Mg/l	PO_4P Mg/l	PBSi Mg/l	Si Mg/l	TSS Mg/l	ALk Mg/l $CaCo_3$	LOI Mg/l	CH Mg/l	SECCHI (m)	TURB NTU	TPC Mg/l
NZ.R.	Max	28.62	10.50	134.0	9.73	1.06	0.012	0.69	0.023	0.13	0.40	0.77	0.16	0.12	0.06	0.09	0.66	5.50	83.0	58.0	13.33	7.83	1.20	234.7	5.33
	Min	21.32	5.33	95.3	6.99	0.66	0.012	0.15	0.00	0.03	0.03	0.06	0.04	0.12	0.021	0.02	0.02	0.70	5.20	27.0	8.20	0.00	0.008	7.60	5.33
	Av	25.81	7.74	107.78	8.16	0.83	0.012	0.35	0.08	0.11	0.12	0.31	0.11	0.12	0.03	0.04	0.24	3.14	32.93	48.6	10.77	1.31	0.69	78.74	5.33
SIO	Max	28.31	11.82	116.5	10.21	1.25	-	0.50	0.002	0.013	0.10	0.045	0.12	0.031	0.025	0.047	0.59	3.97	12.6	69.0	8.67	10.84	1.40	39.8	3.47
	Min	24.17	2.70	98.00	7.55	0.90	-	0.08	0.00	0.03	0.00	0.011	0.03	0.031		0.002	0.043	0.26	6.5	26.0	7.6	0.016	0.011	5.40	3.47
	Av	26.38	7.83	109.65	8.88	1.08	-	0.33	0.001	0.08	0.04	0.03	0.06	0.031	0.011	0.02	0.26	1.98	9.53	52.29	8.13	2.72	0.87	14.78	3.47
YALA	Max	27.64	9.08	125.7	9.58	0.86	0.011	0.57	0.002	0.08	0.231	0.079	0.17	0.03	0.09	0.111	0.23	1.45	6.60	58.0	5.67	13.25	2.10	17.70	2.27
	Min	24.67	3.02	92.0	7.11	0.66	0.011	0.33	0.00	0.008	0.003	0.028	0.054	0.03	0.001	0.006	0.08	0.39	0.20	41.0	5.60	0.005	0.013	1.40	2.27
	Av	26.35	6.63	101.42	8.19	0.75	0.01	0.42	0.01	0.03	0.08	0.05	0.10	0.03	0.06	0.06	0.16	0.88	3.52	50.44	5.63	3.32	1.41	7.07	2.27
KUJA	Max	27.18	9.05	105.0	9.36	8.22		0.55	0.017	0.038	0.26	0.091	0.12	0.05	0.06	0.06	0.71	0.88	7.60	60.0	4.00	14.46	1.50	127.6	1.6
	Min	21.15	4.62	92.6	6.56	0.413		0.28	0.00	0.005	0.04	0.041	0.07	0.05	0.011	0.011	0.014	0.50	3.60	24.0	3.20	0.008	0.014	6.60	1.6
	Ave	25.39	7.18	100.18	7.88	3.12		0.41	0.01	0.02	0.09	0.06	0.09	0.05	0.04	0.04	0.39	0.67	5.05	42.14	3.6	2.90	0.99	18.78	1.6
AW. K. R	Max	27.69	7.54	168.0	7.87	0.88	-	0.33	0.00	0.05	0.05	-	0.06	-	0.02	0.007	0.012	7.62	13.75	81.0	5.00	0.008	0.006	23.80	-
	Min	26.20	5.81	166.0	7.67	0.88	-	0.33	0.00	0.05	0.05	-	0.06	-	0.02	0.007	0.012	7.62	13.75	81.0	5.00	0.008	0.006	17.50	-
AW. R.	Max	27.90	8.81	170.8	9.41	1.80	1.29	0.65	0.65	0.13	0.12	0.24	0.12	0.08	0.062	0.04	0.96	7.50	15.6	96.0	11.50	39.16	1.00	73.8	4.60
	Min	3.50	3.85	141.6	7.33	0.79	1.29	0.31	0.004	0.004	0.002	0.021	0.07	0.08	0.02	0.013	0.042	0.32	6.33	67.0	11.50	0.007	0.04	16.50	4.60
	Av.	25.59	6.14	159.72	8.43	1.20	1.29	0.47	0.14	0.044	0.06	0.11	0.09	0.08	0.04	0.03	0.50	4.96	12.31	73.5	11.50	9.80	0.58	41.49	4.60

Appendix I showing historic water quality data and LVEMP data for pelagic waters.

PARAMETER	PAST DATA	LVEMP DATA
	Pelagic Lake Stations	**Pelagic Lake Stations**
Temperature (mean), °C	23.6 Mavuti, K.M and Litterick, R.M. (1991).	25.48
Dissolved oxygen (mean), mg/l	7.8 Mavuti, K.M and Litterick, R.M. (1991).	6.13
Conductivity, µS /cm	88.1-102.0 Ochumba, O.B.P And Kibaara, ID (1989). 95 -120, Mavuti, K.M and Litterick, R.M (1991).	85 –134
pH	0.6 – 8.85, Ochumba, O.B.P and Kibaara, ID (1989)	6.10 –9.8
Dissolved nitrogen (mean), µg/l	55.6, Mavuti, K.M. and Litterick, R.M. (1991).	450.0
Dissolved Phosphorous (mean), µg/l	15.7 Mavuti, K.M. and Litterick, R.M. (1991).	40.0
Alkalinity, mg/l CaCo3	4.2 - 6.0 Ochumba, O.B.P and Kibaara I.D (1989).	22.0 –59.0
Chlorophyll a, µg/l	15.8 Mavuti, K.M. and Litterick, R.M. (1991). 1.2 – 40 Talling (1960s).	1.0 –10.0
Turbidity, NTU	16 Ochumba, O.B.P. and Kibaara, I.D. (1989).	0.0 –107.7
Secchi; m.	7.8 Worthington (1930).	2.1 –4.2

Appendix J showing historic water quality data and LVEMP data for littoral waters.

PARAMETERS	PAST DATA	LVEMP DATA.
	Pelagic Lake Stations	**Littoral Lake Stations**
Temperature (mean), °C	24.35 Mavuti, K.M. and Litterick, R.M. (1991).	26.06
Dissolved oxygen (mean), mg/l	8.0 Mavuti, K.M. and Litterick, R.M. (1991).	6.28
Conductivity, µS/cm	85-123 Ochumba O.B.P. and Kibaara, I.D. (1989). 120-150 Mavuti, K.M. and Litterick, R.M. (1991).	96 –181
pH	7.42-9.4 Ochumba, O.B.P. and Kibaara, I.D. (1989).	7.0 –10.0
Dissolved nitrogen (mean), mg/l.	108.3 Mavuti, K.M. and Litterick, R.M. (1991).	542.0
Dissolved Phosphorous (mean), µg/l.	6.8 Mavuti, K.M. and Litterick, R.M. (1991).	22.5
Alkalinity, mg/l CaCo3	3.7 –52.5	27.0 –92.0
Chlorophyll a, µg/l.	40.7-50.6 Mavuti, K.M. and Litterick, R.M. (1991). 10.0 –67.1 Talling (1960s).	3 –1560
Turbidity, NTU.	4.1 –33.7 Ochumba, O.B.P and Kibaara, I.D. (1989). 4.0 –25.0 Mavuti, K.M. and Litterick, R.M. (1991).	1.4 –200.3
Secchi, m.	0.7 –1.8 Mavuti, K.M. and Litterick, R.M. (1991).	0.2 –2.4

Appendix K showing Phytoplankton observed in pelagic and littoral waters in the Kenyan side of Lake Victoria.

LITTORAL WATERS		**PELAGIC WATERS**	
CYANOPHYTA (Blue-green algae)	**Ind./l**	**CYANOPHYTA (Blue-green algae)**	**Ind./l**
Microcystis aeruginosa	23051	**Microcystis aeruginosa**	**10867**
Anabaena spoirodes	4008	Cylindrospermopsis	1086
Merismopedia sp.	4003	Anabaena sporoides	1080
Planktolyngbya spp.	3967	Anabaenopsis spp.	768
Anabaenopsis spp.	3961	Rhizosolemia spp.	708
Cylindrospermopsis	2255	Spirulina platensis	640
Anabaena circinalis	1709	Chroocococcus sp.	480
Chroocococcus sp.	1395	Anabaena circinalis	424
Spirulina platensis	1020	Pseudoanabaena sp.	394
Lyngbya sp.	940	Aphanizomezon flos aquae	350
Coelomoron	919	Aphanocapsa sp.	182
Aulacosira nyassensis	898	Aulacosira nyassensis	109
Aulacosira granulata	853	Aulacosira granulate	109
Aphanocapsa sp.	722	Cloeocapsa dispensa	45
Oscillatoria sp.	360	Merismopedia	44
Aphanizomenon flos aquae	350	Glenodinium	22
Crucigenia tetrapedia	349		
Pseudoanabaena sp.	262		
Coelosphaerium panctifera	196		
Dictyolyngbya puchellum	62		
BACILLARIOPHYTA (Diatoms)		**BACILLARIOPHYTA (Diatoms)**	
Nitzschia sp.	20774	Nitzschia sp.	7089
Synedra sp.	13675	Synedra spp.	5748
Navicula sp.	6152	Cymbella	1376
Diatom sp.	640	Surirella	222
Staurastrum sp.	319	Navicula	202
Cyclotella	248	Navicula spp.	80
Cloeocapsa dispensa	218		
Amphora coffaeiforms	42		
CHLOROPHYTA (Green algae)		**CHLOROPHYTA (Green algae)**	
Cloeosterium aciculare	1575	Planktolyngbya spp.	1799
Scenedesmus spp.	1439	Cloeosterium aciculare	1376
Ankistrodesmus	1283	Coelomoron	612
Pediastrum	1156	Ankistrodesmus	452
Glenodium quadricauda	87	Scenedesmus spp.	260
Rhopanida gibba	65	Pediastrum	40
Schroederia	65	Schroederia	22

Arthrodesmus	62	Oocystis	22
Gomphosphaenium	44	Romeria elegans	22
Stigeoclonium	40		
Cosmarium moniliferum	22		
Monaraphidium	22		
Actinastrum sp.	22		
Romeria elegans	22		
EUGLENOPHYTA (Euglenoids)		**EUGLENOPHYTA (Euglenoids)**	
Euglena spp.	760	Euglena spp.	264
Phacus sp.	328	Phacus sp.	66
Trachelomonas	176		
PYROPHYTA (Unicellular flagellates)			
Ceratium bracycerus	88		

Appendix L showing Zooplankton observed in pelagic waters in the Kenyan side of Lake Victoria.

OPEN LAKE SPECIES (KP1 –KP3)	CLASS
Calanoid copepodites	Copepoda
Thermodiaptomus galeboides	Copepoda
Tropodiaptomus stulhmani	Copepoda
Cyclopoid copepodites	Copepoda
Mesocyclops spp	Copepoda
Thermocyclops emini	Copepoda
Thermocyclops neglectus	Copepoda
Thermocyclops incisus	Copepoda
Thermocyclops decipiens	Copepoda
Thermocyclops oblongatus	Copepoda
Tropocyclops confinnis	Copepoda
Tropocyclops tenellus	Copepoda
Nauplii	Copepoda
Moina micrura	Cladocera
Bosmina longrostris	Cladocera
Daphnia barbata	Cladocera
Daphnia lumhortzi	Cladocera
Daphnia longispina	Cladocera
Ceriodaphnia cornuta	Cladocera
Diaphanosoma exiscum	Cladocera
Chaoborus larvae	Rotifera
Branchionus plicatilis	Rotifera
Branchionus caudatus	Rotifera
Branchionus bidentata	Rotifera
Branchionus calyciflorus	Rotifera
Branchionus angularis	Rotifera
Branchionus rubens	Rotifera

Filinia opoliensis	Rotifera
Filinia longiseta	Rotifera

Appendix M: Zooplankton observed in littoral waters in the Kenyan side of Lake Victoria.

ZOOPLANKTON OF LAKE VICTORIA (KL1-KL6)	CLASS
Calanoid copepodites	Copepoda
Thermodiaptomus galeboides	Copepoda
Tropodiaptomus stulmani	Copepoda
Cyclopoid copepodites	Copepoda
Mesocyclops spp	Copepoda
Thermocyclops emini	Copepoda
Thermocyclops neglectus	Copepoda
Thermocyclops incisus	Copepoda
Thermocyclops decipiens	Copepoda
Thermocyclops oblongatus	Copepoda
Tropocyclops confinnis	Copepoda
Tropocyclops tenellus	Copepoda
Nauplii	Copepoda
Moina micrura	Cladocera
Bosmina longirostris	Cladocera
Daphnia barbata	Cladocera
Daphnia lumhortzi	Cladocera
Ceriodaphnia cornuta	Cladocera
Diaphanosoma exiscum	Cladocera
Chaoborus larvae	Rotifera
Branchionus caudatus	Rotifera
Branchionus bidentata	Rotifera
Branchionus calyciflorus	Rotifera

Branchionus angularis	Rotifera
Branchionus quadridentanus	Rotifera
Branchionus falcatus	Rotifera
Platyias patulus	Rotifera
Filinia terminalis	Rotifera
Filinia opoliensis	Rotifera
Trichocerca longiseta	Rotifera
Trichocerca spp.	Rotifera
Karatella tropica	Rotifera
Karatella cochlearis	Rotifera
Asplanchna brightwelli	Rotifera
Polyathra spp.	Rotifera
Hexathra mira	Rotifera
Euchlanis	Rotifera
Lecane spp.	Rotifera

Appendix N showing macro invertebrates observed in Lake Victoria under LVEMP

SAMPLING STATION	DATE OF SAMPLING	*ORGANISMS*		RELATIVE ABUNDANCE INDIVIDUALS PER SQUARE METRE
		SPECIES	**FAMILY**	
KL2	September 2003	Cerithidea (horn snail) Campeloma (snail) Sphaerium (finger-nail clam, bivalve)	Cerithiidae Viviparidae Sphaeridae	1154 222 666
KL3	September 2003	Cerithidea (horn snail) Campeloma (snail) Pisidium (pea shell clam; bivalve) Sphaerium (fingernail clam; bivalve)	Cerithiidae Viviparidae Sphaeridae Sphaeridae	178 133 178 44
KL4	September 2003	Cerithidea (horn snail) Campeloma (snail) Sphaerium (fingernail clam; bivalve) Roundworms	Cerithiidae Viviparidae Sphaeridae	844 133 444 89

KL6	September 2003	Campeloma (snail) Cerithidea (horn snail) Pisidium (Peashell clam; bivalve) Roundworms	Viviparidae Cerithiidae Sphaeridae	110 133 178 89
KP1	September 2003	None detected	-	-
KP3	September 2003	None detected	-	-
KP2	September 2003	None detected	-	-
Yala River mouth	September 2003	Pisidium (pea shell clam; bivalves Sphaerium (finger nail clam; bivalve) Roundworms	Sphaeridae Sphaeridae	3774 444 44
Nzoia River mouth	September 2003	Sphaerium (finger nail clam; bivalve) Pisidium (pea shell clam; bivalve) Margaritifera margaritifera (spectacle case; bivalve Roundworms	Sphaeridae Sphaeriidae Margaritiferidae	8880 1 33 44 2664 89
Mbita West	September 2003	Campeloma (snail) Cerithidea (horn snail) Sphaerium (finger nail clam; bivalve) Pisidium (pea shell clam; bivalve) Roundworms	Viviparidae Cerithiidae Sphaeridae Sphaeridae	400 222 266 133 178 89
Oluch River mouth	September 2003	Cerithidea (horn snail) Campeloma (snail) Sphaerium (finger nail clam; bivalve) Roundworms	Cerithiidae Cerithiidae Sphaeridae	977 44 1288 44
Homa Bay	September 2003	Cerithidea (horn snail) Campeloma (snail) Sphaerium (finger nail clam; bivalve) Margaritifera margaritifera (spectacle case; bivalve)	Cerithiidae Viviparidae Sphaeridae Margaritiferidae	3774 3108 2003 44

Awach Seme River mouth	September 2003	Sphaerium (finger nail clam; bivalve) Pisidium (pea shell clam; bivalve) Roundworms	Sphaeridae Sphaeridae	266 178 44
Asembo Bay	September 2003	Valvata (snail) Cerithidea (horn snail) Campeloma (snail)	Valvatidae Cerithiidae Viviparidae	178 89 44

Kuja River Mouth	September 2003	Campeloma (snail) Valvata (snail) Cerithidea (horn snail) Corbicula (Asiatic clam; bivalve) Unio (bivalves) Roundworms ***Narpus***	Viviparidae Valvatidae Cerithiidae Corbiculidae Unionidae Elmidae	666 220 888 1110 22 666 89
KL2	March 2004	Cerithidea (horn snail) Sphaerium (finger nail clam; bivalve)	Cerithiidae Sphaeridae	266 266
NYRM I	March 2004	Roundworms Sphaerium (finger nail clam; bivalve)	 Sphaeridae	133 44
NYRM II	March 2004	Roundworms Sphaerium (finger nail clam; bivalve)	 Sphaeridae	88 88
NYRM III	March 2004	Sphaerium (finger nail clam) Roundworms	Sphaeridae	133 88
NYRM IV	March 2004	Cerithidea (horn snail) Sphaerium (finger nail clam; bivalve)	Cerithiidae Sphaeridae	266 88
NYRM V	March 2004	Cerithidea (horn snail) Sphaerium (finger nail clam; bivalve)	Cerithiidae Sphaeridae	133 88

KL1	May 2004	Polymesoda (marsh clam; bivalve) Cerithidea (snail) Roundworms	Viviparidae Cerithiidae	310 89 133
KL2	May 2004	Cerithidea (snail) Campeloma (snail) Corbicula (Asiatic clam)	Cerithiidae Viviparidae Corbiculidae	712 89 44
NYRM IV	May 2004	Roundworms		133
NYRM V	May 2004	Corbicula (Asiatic clam) Cerithidea (Snail)	Corbiculidae Cerithiidae	133 89
NYRM VI	May 2004	Polymesoda (marsh clam ; bivalve)	Viviparidae	177
NYRM VII	May 2004	Cerithidea (Snail) Sphaerium (finger nail clam)	Cerithiidae Sphaeridae	177 44
NZRM I	Jan 2005	Margaritifera margaritifera (Spectacle case) Tagelus (Jackknife clam) Cerithidea (Hornsnail) Bithynia (Faucet snail) Polymesoda (Marsh clam)	Margaritiferidae Psammobiidae Cerithiidae Ammicolidae Corbiculidae	400 44 88 88 622
NZRM II	Jan 2005	Margaritifera margaritifera(Spectacle case)	Margaritiferidae	933
NZRM III	Jan 2005	Margaritifera margaritifera(Spectacle case)	Margaritiferidae	311
NZRM IV	Jan 2005	Margaritifera margaritifera	Margaritiferidae	355
NZRM V	Jan 2005	Tagelus (Jackknife clam) Margaritifera margaritifera (Spectacle case) Cerithidea (Hornsnail) Bithynia (Faucet snail) Polymesoda (Marsh clam)	Psammobiidae Margaritiferidae Certhiidae Ammicolidae Corbiculidae	44 977 133 1688 622
NYRM I	Feb 2005	Polymesoda (Marsh clam)	Corbiculidae	44
NYRM II	Feb 2005	Margaritifera margaritifera (Spectacle case)	Margaritiferidae	44
NYRM III	Feb 2005	Cerithidae (Marsh clam) Cerithidae (Horn snail) Margaritifera margaritifera(Spectacle case)	Corbiculidae Cerithiidae Margaritiferidae	88 44 88

NYRM IV	Feb 2005	Polymesoda (Marsh clam) Margaritifera margaritifera(Spectacle case)	Corbiculidae Margaritiferidae	88 133
NYRM V	Feb 2005	Cerithidea (Horn snail) Margaritifera margaritifera (Spectacle case)	Cerithiidae Margaritiferidae	222 400
NYRM VI	Feb 2005	Polymesoda (Marsh clam) Cerithidea (Horn snail)	Corbiculidae Cerithiidae	44 133
NYRM VII	Feb 2005	Polymesoda (Marsh clam) Cerithidea (Horn snail)	Corbiculidae Cerithiidae	44 400
NYRM VIII	Feb 2005	Margaritifera margaritifera (Spectacle case) Cerithidea (Horn snail)	Margaritiferidae Cerithiidae	88 133
KL1	Feb 2005	Cerithidea (Horn snail) Polymesoda (Marsh clam) Margaritifera margaritifera (Spectacle case)	Cerithiidae Corbiculidae Margaritiferidae	88 266 355
KL2	Feb 2005	Cerithidea (Marsh clam) Margaritifera margaritifera(Spectacle case) Cerithidea (Horn snail)	Corbiculidae Margaritiferidae Certhiidae	44 177 177
NZRM PS4	March 2005	Cerithidea (Horn snail) Margaritifera margaritifera (Spectacle case) Polymesoda (Marsh clam) Bithynia (Faucet snail) Campeloma snail) Sphaerium (Fingernail clam) Polinices (Moon snail)	Cerithiidae Margaritiferidae Corbiculidae Ammicolidae Viviparidae Sphaeridae Noticidae	666 44 44 355 355 88 177
NZRM PS2	March 2005	Bithynia (Faucet snail) Polinices (Moon snail) Polymesoda (Marsh clam) Margaritifera margaritifera (Spectacle case) Cerithidea (Horn snail)	Ammicolidae Naticidae Corbiculidae Margariferidae Cerithiidae	222 177 44 88 400
NYRM 0	April 2005	Margaritifera margaritifera (Spectacle case)	Margaritiferidae	133
NYRM II	April 2005	Nematodes		662
NYRM III	April 2005	Margaritifera margaritifera (Spectacle case)	Margaritiferidae	133
NYRM IV	April 2005	Margaritifera margaritifera (Spectacle case)	Margaritiferidae	133

NYRM V	April 2005	Margaritifera margaritifera (Spectacle case) Cerithidea (Horn snail)	Margaritiferidae Cerithiidae	133 133
NYRM VI	April 2005	Polymesoda (Marsh clam) Margaritifera margaritifera (Spectacle case) Cerithidea (Horn snail)	Corbiculidae Margaritiferidae Cerithiidae	88 44 133
NYRM VII	April 2005	Cerithdea (horn snail)		335
NYRM VIII	April 2005	Margaritifera margaritifera (Spectacle case) Cerithidea (Horn snail) Polymesoda (Marsh clam)	Margaritiferidae Cerithiidae Corbiculidae	400 488 44
KL1	April 2005	Compeloma (Campeloma) Polymesoda (Marsh clam)	Viviparidae Corbiculidae	44 177
KL2	April 2005	Compeloma (Compeloma) Cerithidea (Horn snail) Polymesoda(Marsh clam) Margaritifera margaritifera(Spectacle case) Cerithidea (Horn snail) Polymesoda (Marsh clam)	Viviparidae Cerithiidae Corbiculidae Margaritiferidae Cerithiidae Corbiculidae	88 88 88 44 133 44

CHAPTER 9

Sedimentation in the Lake Victoria catchment and the Winam Gulf

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Abstract

The need to carry out sedimentation and sediment characteristics study at the river mouths and the lake was contingent upon the supposition that the rivers in the lake Victoria catchment including surface runoffs convey a great deal of assorted sediments, most of which are deposited in the lake thereby causing the lake to continue filling up and affecting the quality of water.

Introduction

Lake Victoria receives waters of varying quality from several rivers, precipitation, recharge from groundwater; industrial and domestic waste treatment and disposal systems, urban and agricultural run-offs. These waters, rich in nutrients encourage biological activities within the lake that are a source of biogenic sediments. To a small extent, shoreline erosion is also responsible for the sediments found in the lake.

The humid tropical climate of the Kenya catchment of Lake Victoria in combination with the steep relief and slopes, and the presence of easily erodible volcanic soils in relation to intensive agriculture and deforestation, results in tremendous soil erosion, and denudation rates are high. Soil erosion is a major problem in many river catchment areas, being the main source of quartz rich lithogenic sediments. In fact, the total sediment load transported by many rivers is very high, particularly during the rainy season; some of this load is sedimented within the river channels and small basin but some fraction finally ends up in the lake. This has direct impact on the water quality and the life of aquatic ecosystems in the lake.

From historical records, Verschuren et al. (2002) calculated that sediment yields from the catchment have increased dramatically from 1940, with the highest sedimentation rates taking place between 1970-1980. This has been attributed to extensive land use changes in the riparian zone with consequent environmental changes over this period. Verschuren et al. (2002) and LVEMP

(2002) data on sediment cores and settling rates in the lake respectively indicated mean sedimentation rates of 1 mm per year in the offshore areas of the lake where fine sediments accumulate but higher rates can occur in river deltas.

The interplay between sediments and the overlying water of shallow lakes in particular, can have profound effects on the nature of the benthic and planktonic biota, nutrient fluxes and sediment transport. These processes may have impact on the performance of populations of potentially troublesome plants such as water hyacinth (*Eichhornia crassipes*) and blue green algae, and animals such as Dipteran flies. The potential for sediments to retain or release nutrients and the potential for the currents to transport sediments have not been well studied. The pilot study on sedimentation during the final stages of LVEMP Phase I is therefore expected to determine rates of sedimentation, characterizing the sediments and assessing their potential for retaining or releasing nutrients such as phosphorous and nitrogen, and their capacity for harboring particular invertebrates under certain conditions occurring in the deltas of rivers and in Winam Gulf of Lake Victoria.

The river mouths and the Winam Gulf have been identified on the Kenyan part of the lake to be the major sediment recipients and transport routes into Lake Victoria. Similarly the river mouths and Winam Gulf receive the highest loads of nutrients and have high populations of benthic and planktonic biota. Additionally, they can also receive certain other pollutants from domestic, industrial and other activities in the vicinity of urban areas that are also found near some river mouths.
The results of the present study on benthic invertebrates represent the first data on fauna associated with the lakes bottom sediments characterized on the basis of the constituent grain size of the sediments.

Objectives

The main objectives of the pilot study include;

- To characterize sediments and determining their sources;
- To determine particle size distribution along the rivers;
- To determine the rate of sedimentation at the mouths of rivers Nyando and Nzoia, and Winam Gulf of Lake Victoria;
- To determine the mechanisms involved in the transport and deposition of sediments in the gulf;
- To determine the effects of sediments in the gulf and the lake;
- To recommend appropriate measures to control sediment flux in the rivers and the lake;
- To determine the role played by benthic organisms in nutrient flux between the sediments and the water column.

Study areas

Winam Gulf

Winam Gulf is an arm of Lake Victoria, which is drained by several rivers, which include Nyando, Sondu-Miriu, Nyamasaria, Awach Kano, Awach Seme, Awach Kibwon and a few seasonal streams. The gulf covers an area of 1400 km^2. It has a maximum depth of 43 m in the offshore areas and 14 m at the inshore stations and a mean depth of 12 m offshore and 4 m for inshore stations .

Apart from receiving sediments from the rivers and surface runoffs, Winam Gulf also receives wastes from industrial and domestic waste treatment and disposal systems located within Kisumu City, Homa Bay and Mbita Urban Centers. Agricultural and urban run-offs also add to the sediment load into the gulf. The gulf is an important fishing ground and is also the main source of water for domestic use for the above-mentioned urban centers along the gulf. It also serves as a major source of fresh-water supply to many millions of people and domesticated animals that are living along the shores of the lake

The level of eutrophication is high in the gulf, resulting in prolific growth of algae, increased turbidity/reduced water transparency and increased biological oxygen demand. There is also regular occurrence of the water hyacinth in the gulf especially in sheltered areas like bays and river mouths.

River Nyando

River Nyando, which drains into the Winam Gulf of Lake Victoria is 70 km long. It receives water from its many tributaries, which originate from two main sub-catchments, namely; Kericho and Nandi escarpment. The river's catchment covers an area of 3652 km^2. The catchment receives an average annual rainfall of 1298 mm. A large part of the catchment is cultivated for crops that include maize, tea, coffee, horticultural crops, vegetables, sugar cane and potatoes. Fertilizers and pesticides are applied to enhance the production of food and cash crops. The vegetation cover is fairly dense in the upper reaches of the river and gradually becomes sparse in the middle and lower reaches. Poor agricultural land use practices and livestock rearing have contributed to increased soil erosion through gulleys and sediment delivery through surface run-off. As a result, high amounts of suspended sediment loads have severely affected the quality of water not only in the rivers, but also in the Winam Gulf.

River Nzoia

River Nzoia drains on the western side of the country into Lake Victoria.. Its major tributaries originate from Mount Elgon and Cherangani Hills, flowing through Transzoia, Lugari, and Uasin Gishu districts. Its catchment covers an area of 12,842 km^2. The drainage area receives an average of 1424 mm of rainfall per annum.

River Nzoia is the largest river draining from the Kenyan catchment into the lake; the mean annual discharge is about 3.6 billion m^3 of water.

Flooding affects the low-lying lakeshore areas where clearing of vegetation has occurred, especially in floodplains that are characterized by wetlands. The floods originate from heavy precipitation in the upper catchments of the river. During flash floods, Lake Victoria is slow in absorbing water, and instead sends it back, inundating the nearby floodplains.

Field and Laboratory Methods

Field sampling for sediments was done between 2001-2005, at sampling points shown in Figure 1. The sampling locations were geo-referenced for convenience of identification during subsequent field campaigns.

River catchment sampling

Samples are collected by scooping using a shovel. This is done on geo-referenced stations on a river course and its tributaries, upstream from the rivers catchment and downstream to the river mouth respectively. Where the river is shallow, cross sectional sampling is done by wading and where it is deep convenient access is by bridge with both left and right bank samples are collected and treated as separate samples. These samples are taken in polythene bags, sealed and properly labeled.

-From 18 and 36 geo-referenced stations scooping of riverbeds along rivers Nzoia and Nyando was undertaken to collect sediment samples.

The collected samples are dried for about one week before sieving and weighing. First the bulk weight of the individual samples are weighed/taken and recorded . The samples are then sieved using various sieve sizes diameters and reweighed for all samples after sieving. The standard sieve size diameters are >2.0mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and >0.075mm.

Determination of grain size distribution

The sediments were washed with distilled water in the laboratory and oven-dried. The oven-dried samples were then split to obtain 100 g for sieve analysis. A nest of sieves with apertures of 2, 1.18, 0.6, 0.3, 0.15, and 0.075 mm were selected. The sieves were shaken by hand for about 15 minutes. The sieves were chosen to correspond to size classifications for gravel, coarse sand, fine grained sand and silt/clay mixtures.
Composite samples were created for the upper, middle and lower sections of both Rivers Nzoia and Nyando following the method of Abuodha (2002). Grain size analysis was carried out on the basis of these composite samples.

Grab Sampling

An Ekman Grab Sampler was used to collect samples at the river mouth, the littoral (KL's) and the pelagic (KP's) zones of the lake. Along ten arbitrarily selected transects, samples were collected at global stations designated as KL1, KL2, KL3, KL4, KL5, KL6, KP1, KP2 and KP3. The grab sampler was suspended on a nylon rope and lowered to the bottom of the lake while it is open. A messenger was then released to move downward along the rope and this activated a mechanism that controlled the closing of the sampler.

At each point two sediment samples were taken; one for benthos identification for and count, and the other sample for sediment characterization.

The one for benthic communities' analysis was washed through a 1.18 mm sieve size using distilled water. They were then picked using a forceps and preserved in formalin for identification and count. The one for sediment characterization was placed in polythene bags that were properly sealed and labeled for laboratory analysis.

Sediment traps

Suspended sediments in water columns are collected by setting two sets of traps at two meters from the surface, at 2.3 m **x** secchi depth, at mid depth and at 2m from the bottom. The traps are deployed overnight and as close to a twenty-four hour period as possible before retrieval. The volume of water in the traps is measured using a measuring cylinder and kept in plastic containers for laboratory analysis. Nutrient concentrations TBSi, TPN, TPP, TPC are calculated using the plotted graphs of absorbance vs concentration. Other parameters analyzed are LOI and TSS

Core Sampling

An improvised method consisting of a PVC pipe was driven into the lake bottom and the sediment was retrieved and cut using a hack saw. The cores were kept in a deep freezer aired for a few hours to harden and then split vertically. Using a magnifying glass, individual stratigraphical layers were measured and used for description of sediment characteristics.

Bedload Transport

Near the River Nzoia river mouth, a bedload sediment transport experiment was undertaken during an expedition in March 2005. The technique involved excavation of a trench trap across the bottom of the riverbed.

The amount of bedload sediments caught was measured for a duration of 15 minutes, and this experiment was repeated three times each day in order to obtain an average sediment transport rate. Also the quantity of water (volume) was estimated at each time bedload measurements were taken

Results

Grain size distribution and composition of river sediments

The results of grain size distribution are shown in Table 1. By dividing each river into upper, Middle and Lower, interpretation of results becomes easier.

Table 1: Composite sample statistics based on graphical data for Nyando and Nzoia rivers.

Sample statistics and sediment description	**Station**					
	NYUPPER	NYMIDDLE	NYLOWER	NZUPPER	NZMIDDLE	NZLOWER
Mean Size	0.82252 (0.282187)	0.73225 (0.44959)	0.73737 (0.43955)	0.85134 (0.23219)	0.76401 0(.38834)	0.62335 (0.68188)
Sorting	1.28134	1.22213	1.36186	1.32816	1.36136	1.34355
Skewness	0.39518	0.22549	0.46815	0.37837	0.26241	0.25329
Kurtosis	-0.58176	-0.45965	-0.29287	-0.8405	-0.88577	-0.48144
Composite Sample Description						
Size	Coarse grained	Coarse grained	Coarse grained	Coarse grained	Coarse grained	Coarse grained
Sorting	Moderately sorted	moderately sorted	moderately sorted	moderately sorted	moderately sorted	moderately sorted
Kurtosis	platykurtic	platykurtic	platykurtic	platykurtic	Very small (~symmetrical)	platykurtic
Number of Spot Samples	28	22	21	10	15	26
Max Mean Size	1.35	1.66	1.92	1.65	1.47	1.45
Min Mean Size	0.34	0.28	0.31	0.28	0.48	0.16

Max Sorting	1.7	1.55	111.31	1.54	1.54	2.14
Min Sorting	0.76	0.69	0.48	0.9	0.97	0.76
Max Skewness	1.47	2.45	3.89	1.98	1.56	2.13
Mean Skewness	0.11	-0.91	-0.3	-0.09	0.12	-0.59
Max Kurtosis	7.1	9.84	14.94	5.51	1.45	7.16
Min Kurtosis	-0.64	-1.23	-1.23	-0.34	-0.36	-0.35
% Gravels	29.52	22.50	26.20	32.22	30.20	18.81

In the Nzoia system, the mean grain size decreased systematically from the upper zone to the river mouth. In the Nyando system there was decrease only from the upper zone to the middle zone, after which there was a gradual increase in the lower zone. Percentage gravels also decreased from the upper zone towards the lower areas for Nzoia river while percent gravels for Nyando is lower in the middle zone, suggesting the cause for the decrease in grain size.

In Table 2 results of chemical analysis of river sediments are presented. The Nzoia sediments show higher contents of SiO_2, which confirms its traverse through acid igneous and metamorphic terrain (Fig. 2). On the other hand, Nyando passes through alkaline igneous rocks; this is represented by higher concentrations of sodium and potassium ions in the sediments.

Table 2: Chemical composition of river sediment of the Lake Victoria basin (after Maturwe et al., this volume). Are some of the values in this table really zero! That seems unusual The percent sodium values are also inappropriate Check this table carefully.

Date	Station	% SiO_2	% Al_2O_3	% CaO	% MgO	% Na_2O	% K_2O	% TiO_2	% MnO	% Fe_2O_3
8/4/2004	Awach Kibuon-S	0	19.4	4.2	13	822	49	60.5	17.4	9
6/11/2003	Awach Seme-S	88.5	10.23	0.82	0.44	1.86	1.43	0.61	0.12	6.1
8/4/2004	Kuja-Migori-Watho.	0	3	1.75	4	262	28.8	70.7	3.1	0
8/4/2004	Mara-Bridge-S	0.02	20.8	6.65	8	720	71.6	69.1	23.5	14
8/4/2004	Miriu-Nyakwere-S	0	12.7	3.71	14	465	52.3	158.9	9.7	9
8/4/2004	Nyando-Ogilo-S	0.03	16.6	2.87	15	623	52.3	71	12.6	9
6/11/2003	Nzoia-Rwambua-S	92.2	4.62	0.81	0.2	1.34	1.79	0.29	0.02	1.33
6/11/2003	Sio-Mundika-S	90.7	4.19	0.73	0.26	1.02	1.43	0.51	0.03	1.39
6/11/2003	Yala-Kadenge-S	80.6	12.97	0.25	1.46	1.36	1.55	1.14	0.18	8.93

Bedload Transport

During the sediment trapping period the average water flow in the channel was 19.97 m^3s^{-1} with a mean bedload sediment transport as $2.1x10^{-3}$ $kgs^{-1}m^{-1}$. Assuming similar hydrological and sediment transport conditions in all the five channels of river Nzoia delta, the bedload transport is calculated to be 0.01kg $s^{-1}m^{-1}$ Check units and reverse m and s. For five deltas estimated as measuring about 50m wide, the total bedload is calculated to be 1.5kg $s^{-1}m^{-1}$ for Nzoia river.

Benthic invertebrates

Station	Species Organisms	Relative Abundance Individuals per m ^{2}
KL2	Cerithidea	1154
	Campeloma	222
	Sphaerium	666
KL3	Cerithidea	178
	Campeloma	133
	Pisidium	178
	Sphaerium	44
KL4	Cerithidea	844
	Campeloma	
	Sphaerium	133
	Roundworms	444
KL6	Campeloma	110
	Cerithidea	133
	Pisidium	178
	Roundworms	89
Nzoia River mouth	Sphaerium	8880
	Campeloma	400
Mbita West (Rusinga channel	Cerithidea	222
	Sphaerium	266
	Roundworms	133
Oluch River mouth	Cerithidea	977
	Campeloma	44
	Sphaerium	1288
Homa Bay	Cerithidea	3774
	Campeloma	3108
	Sphaerium	2003
	Margaritifera margaritifera	44
Awach Seme River mouth	Sphaerium	266
	Pisidium	178
	Roundworms	133
	Valvata	178
Asembo Bay	Cerithidea	89
	Campeloma	44
Kuja River Mouth	Campeloma	666
	Valvata	220
	Cerithidea	888
	Corbicula	1110
	Roundworms	222

From the figure Nzoia River mouth had the highest densities and was dominated by *Sphaerium* present. Cerithidea were identified in most stations except in Nzoia and Awach Seme River mouths .Asembo Bay had the smallest number of benthic invertebrates identified. *Campeloma* species were identified in small numbers except in Homa Bay, which recorded the highest abundance of about 3100 individual per m^2. Stations KL2, KL4, Oluch and Kuja River mouths had almost same numbers of Cerithidea identified.
Kuja and Awach Seme river mouths, Mbita West (Rusinga Channel),KL6 and KL4 stations had small number of species of Roundworms identified. Margaritifera were identified only in Homa Bay but in a negligible number.Valvata species were only identified in two stations namely Kuja river mouth and Asembo Bay. *Pisidium* species were present only in stations KL3 which is in the gulf and KL6 which in the open lake.

Definitions

Molluscs

This group includes many of the largest aquatic invertebrates and contains more species – 80,000 than any other phylum except the Arthropods. Mollusca are basically bilaterally symmetrical, and posses a protective shell, which is usually made of calcium carbonate, secreted by the mantle. Locomotion is by a muscular foot drawn into the shell by powerful retractor muscles. Most molluscs are marine but many species occur in freshwater habitats.

***Snails (Gastropoda*)**

The gastropoda, mainly various snails contain more than 35000 living species. Typically each is enclosed in a shell, which has the form of a spire. The foot is a flattened creeping sole used for locomotion or attachment. The foot in many groups has a hard operculum, which completely fills the shell opening after the animal has withdrawn, acting as a protective door. Some are ciliary feeders herbivores, carnivores and parasites but most freshwater forms are herbivorous feeding by means of a radula. This is tongue-like with numerous rows of rasping teeth; it may act as a rasp, brush, grater or comb tearing off pieces of macrophytes or collecting organic debris or algae and transporting them to the mouth. There are two main sub-classes; the Prosobranchia, which have gills and are mainly marine forms (a few are fresh water), and the Pulmonata, which have no true gills and are mainly fresh water or terrestrial with only a few marine species.

Bivalves (Pelecypoda)

All bivalves are laterally compressed, and the shell is made up of two valves, which are hinged dorsally and pulled together by two large abductor muscles. The foot is large, and is used for burrowing and locomotion, while the head is small. The mantle cavity within the shell is large, as are the gills lining it. Most bivalves are ciliary feeders on small organic particles swept into the mantle cavity by currents created by cilia or the gills. These also trap food (by secreted mucus) and pass it along grooves to the mouth. A few species feed on detritus by means of a muscular proboscis. All bivalves are aquatic, and most are marine; a number do occur in fresh water, however, and can be important in certain habitats. Most occur in soft substrates, but some viz: Dreissenia, attach themselves to hard substrates.

Round worms (Nematoda)

Nematodes, commonly known as roundworms may reach a length of several centimeters, but most species are less than 1mm in length. The body is cylindrical and extremely elongate with tapered ends. Many are parasites but there are also numerous free-living species, many of which are carnivorous feeding on other nematodes; the herbivorous species eat algae or suck the tissues of higher plants. Some species in decaying organic matter feed on bacteria. The class includes some of the most widely distributed and abundant of all animals; free- living forms being found in all parts of the world. Fresh water forms are normally benthic in habit and occur in many fresh waters, including fast flowing streams, where anchorage is obtained by means of caudal adhesive glands.

Results

The benthos found in the bottom sediments from the river mouths of Nyando and Nzoia and the lake are tabulated below. They include the gastropoda (snails), pelecypoda (bivalves) and nematoda (roundworms). The organisms are mostly found in sediments with decaying organic debris and detritus.

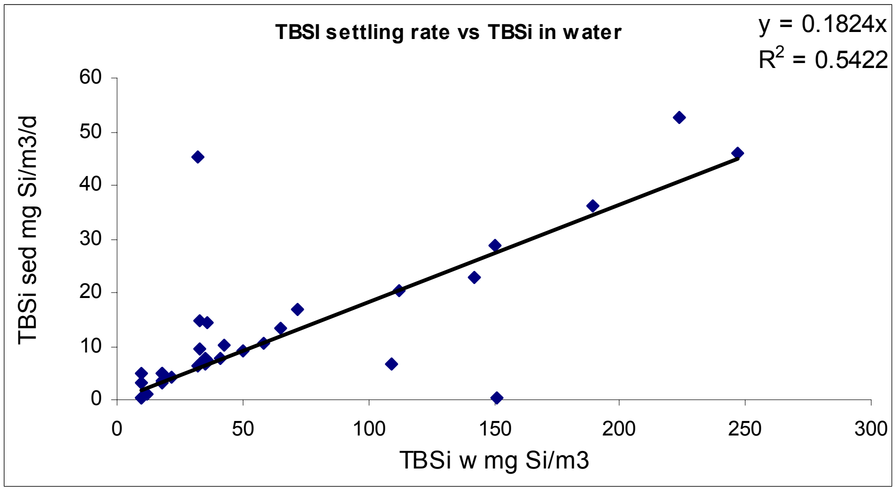
SEDIMENTATION RATES

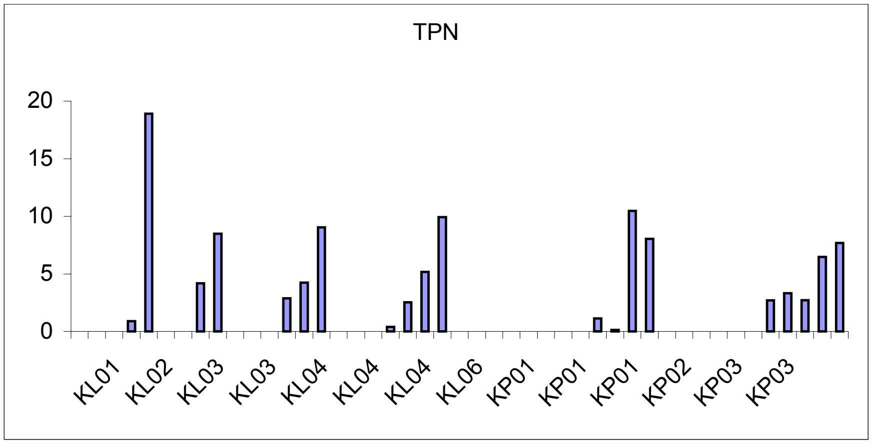
The calculated sedimentation rates are shown in Table **. Sampling and measurements were carried out during three months with moderate rainfall and one wet month. Lower settling rates were observed during September- a wet month. There is also an increase in values with depth of the sediment trap. The littoral and river mouths stations have higher deposition rates compared to pelagic zones.

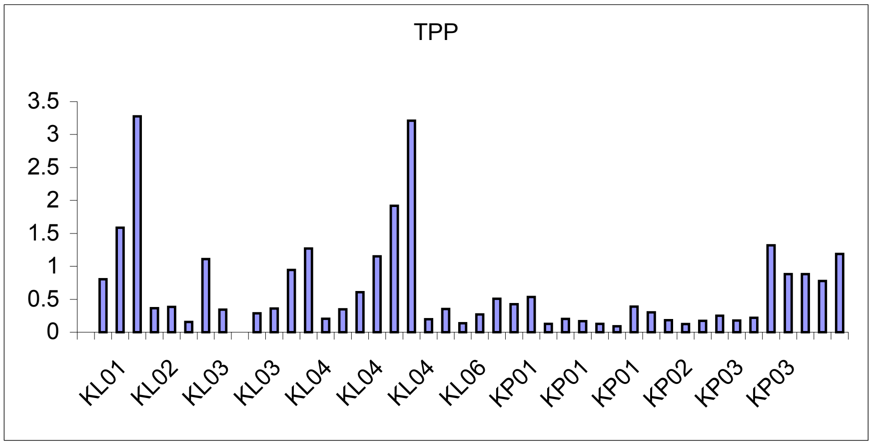
Table **: Distribution of sedimentation rates for TPN, TPP, TBSi, TPC and LOI at littoral and pelagic stations during the months of May, September and October 2001.

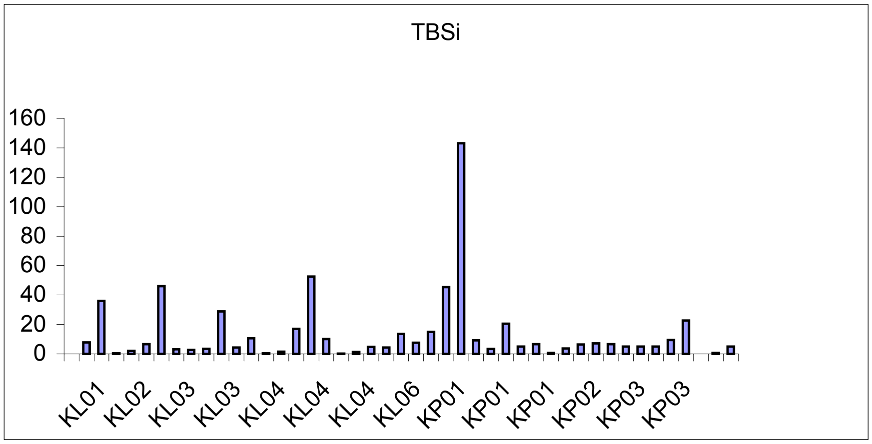
StNo	***Date***	***Period***	***Depth***	***TPN***	***TPP***	***TBSi***	***TPC***	***LOI***
		(hrs)	**(m)**	**mg/m2/d**	**mg/m2/d**	**mg/m2/d**	**mg/m2/d**	***(mgl^{-1})***
KL01	18-May-01	0.9549	2.0	NA	0.8	7.8	9844.4	10.0
KL01	18-May-01	0.9549	2.5	NA	1.6	36.0	9479.3	8.0
KL01	08-Sep-01	0.3958	1.0	0.9	3.3	0.5	2296.7	14.3
KL01	15-Oct-01	0.5889	1.3	18.9	0.4	2.0	1790.7	14.5
KL02	18-May-01	0.9757	2.0	NA	0.4	6.5	335.4	20.0
KL02	18-May-01	0.9757	3.0	NA	0.2	46.0	391.3	11.0
KL02	07-Sep-01	0.6771	2.5	4.2	1.1	3.2	913.0	9.7
KL02	14-Oct-01	0.5549	2.5	8.5	0.3	2.6	852.0	13.0
KL03	17-May-01	0.9465	2.0	NA	NA	3.5	2420.3	7.0
KL03	17-May-01	0.9465	4.0	NA	0.3	28.8	1191.0	16.0
KL03	17-May-01	0.9465	5.0	NA	0.4	4.2	1287.0	12.0
KL03	06-Sep-01	0.8750	2.0	2.9	0.9	10.7	394.8	9.5
KL03	06-Sep-01	0.8750	4.5	4.2	1.3	0.3	415.6	10.0
KL03	12-Oct-01	0.7653	4.0	9.0	0.2	1.4	736.5	10.3
KL04	15-May-01	0.7743	2.0	NA	0.3	16.9	NA	15.2
KL04	15-May-01	0.7743	10.0	NA	0.6	52.6	1315.0	24.0
KL04	15-May-01	0.7743	11.0	NA	1.2	10.1	93.9	10.0
KL04	05-Sep-01	0.3854	2.0	0.4	1.9	0.3	1132.2	6.9
KL04	05-Sep-01	0.3854	11.0	2.5	3.2	1.2	1226.5	26.0
KL04	06-Oct-01	0.6910	2.0	5.2	0.2	4.7	842.0	10.7
KL04	06-Oct-01	0.6910	11.0	9.9	0.4	4.4	2052.4	19.5
KL05	14-May-01	0.8826	23.0	NA	0.1	13.4	41.2	2.1
KL05	14-May-01	0.8389	24.0	NA	0.3	7.6	43.3	5.4
KL06	13-May-01	0.2326	2.0	NA	0.5	14.8	2266.5	10.0
KL06	13-May-01	0.2326	12.0	NA	0.4	45.3	312.6	5.7
KL06	13-May-01	0.2326	13.0	NA	0.5	143.0	312.6	6.5
KP01	13-May-01	0.9931	2.0	NA	0.1	9.2	NA	11.4
KP01	13-May-01	0.9931	55.0	NA	0.2	3.3	36.6	2.5
KP01	13-May-01	0.9931	56.0	NA	0.2	20.5	201.4	4.3
KP01	01-Sep-01	1.0833	2.0	1.1	0.1	5.0	151.0	2.6
KP01	01-Sep-01	1.0833	45.0	0.1	0.1	6.5	251.7	4.3
KP01	10-Oct-01	0.5833	2.0	10.5	0.4	0.7	779.2	6.9
KP01	10-Oct-01	0.5833	41.0	8.1	0.3	3.6	935.1	7.5
KP02	12-May-01	0.9097	2.0	NA	0.2	6.4	239.8	5.5
KP02	12-May-01	0.9097	62.0	NA	0.1	7.2	NA	14.9
KP02	12-May-01	0.9097	63.0	NA	0.2	6.6	40.0	4.5
KP03	11-May-01	0.6569	2.0	NA	0.3	5.0	NA	43.0
KP03	11-May-01	0.6569	53.0	NA	0.2	5.0	NA	19.0
KP03	11-May-01	0.6569	54.0	NA	0.2	5.0	138.4	15.0
KP02	29-Aug-01	1.0000	57.5	2.7	1.3	9.3	600.0	9.4
KP03	28-Aug-01	0.4097	2.0	3.3	0.9	22.7	621.3	4.0
KP03	28-Aug-01	0.4097	24.0	2.7	0.9	NA	443.8	2.9
NY2A	15-Oct-01	0.8750	0.5	6.5	0.8	0.6	6690.9	NA
NY2B	15-Oct-01	0.8681	0.7	7.7	1.2	5.0	62.8	3.0
Maximum				18.9	3.3	143.0	9844.4	43.0
Minimum				0.1	0.1	0.3	36.6	2.1
Average				5.5	0.7	13.7	1363.5	10.9

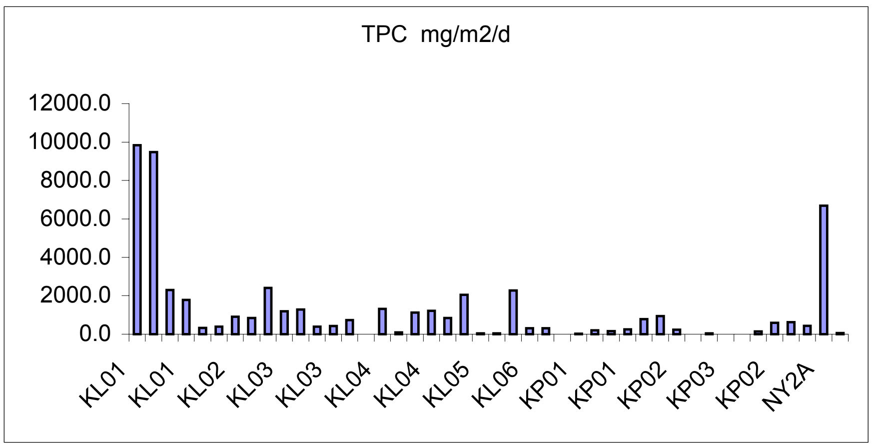
Settling velocity The figures below need captions and units on the y axis and explanation of bars on the x axis

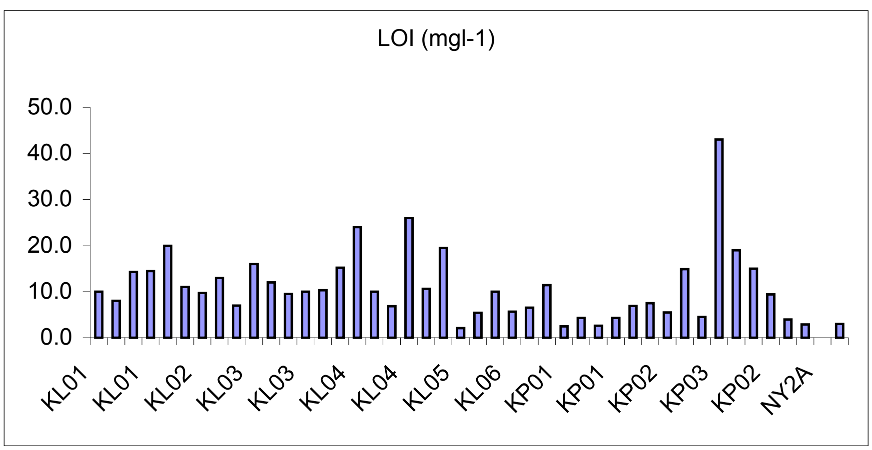







TBSi
160
140
120
100
80
60
40
20
0
KL01
KL02
KL03
KL03
KL04
KL04
KL04
KL06
KP01
KP01
KP01
KP02
KP03
KP03


TPC mg/m2/d
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
KL01
KL01
KL02
KL03
KL03
KL04
KL04
KL05
KL06
KP01
KP01
KP02
KP03
KP02
NY2A


LOI (mgl-1)
50.0
40.0
30.0
20.0
10.0
0.0
KL01
KL01
KL02
KL03
KL03
KL04
KL04
KL05
KL06
KP01
KP01
KP02
KP03
KP02
NY2A

DISCUSSION

From the catchment area of River Nzoia and its tributaries, it has been observed that deposits in the river channels derived from the upstream are composed of fine grain sand, medium grain sand to coarse grain sand and gravels.

These are emanating from the parent rocks where erosion had taken place and deposition while on transit took place by the denser (heavier) particles remaining on the upper course and less dense (fine particles) setting down stream.

At the River mouth and the littoral and Pelagic zones of the lake the samples from the catchment area of river Nzoia can still be detected. However, the distribution are categorized from loose sands and silty sandy clays.

Settling velocities

Setting velocities reduces at the river mouths while it is very minimal at pelagic stations. Most sediments are deposited upstream while small particles which are carried by wave action find their way to the inshore waters.

Larger, heavier particles are deposited at the river banks since they loose velocity fast whereas fine silt sand are transported into the lake.
In general, sediments deposition at the river mouth vary from one catchment to the other and the determining factor is as a result of the original parent rocks predominantly found in the catchment area where the river originates, erosion mechanism and the area it traverses.

Based on the findings made after carrying out a number of sediments analysis on Nyando, riverine sediments range from gravely and coarse grain sand to fine sand in the upper catchment to loose silty clay of alluvial formation to compact clay/silt sand at the river mouths.

The entrainment, transport and deposition of sediment particles is controlled partly by the physical and chemical properties of the particles themselves and entrainment of grains from the bed is controlled not only by individual grain characteristics but also by the bulk sediment properties which include the grain size distribution, sorting, grain orientation, parking arrangement,movement, porosity and degree of cohesion or cementation. During transport sediment particles are frequently sorted according to size, shape and density and changes in particle characteristics may be brought about through intergrain and grain-bed collisions. (Pye, KENNETH?)

The sediments getting into the lake after leaving river mouths consist largely of fine grain sands, silts and clays while larger particles are deposited upstream of the river mouths. Some sediments particularly the silts and clays carry materials such as organic matter, nutrients and pesticides and other polluting substances. The lake also receives sediments from precipitation and atmospheric deposition. These sediments also carry polluting substances. Industrial and domestic wastes (effluents and solid wastes) discharged into the lake or in the vicinity of the lake consist of sediments of various types, which carry pollutants. Urban and agricultural run-offs also convey sediments of various types into the lake, which carry polluting materials. Shoreline erosion due to wave action also plays a role in adding sediments eroded from the shoreline into the lake. Biological activity especially due to eutrophic processes in the lake produces organic particulate matter that eventually settles to the bottom, where it combines with inorganic sediments. Contribution in the lake by recharge from ground water is not well known. There is limited information in this area and studies are encouraged.

There are several factors that influence the movement/transport and deposition of sediments in the lake. These include the location of discharge i.e. whether the location is open or sheltered, river flow patterns and wave action or water movement within the lake.

The Winam Gulf and the river mouths of Nzoia and Nyando has a relatively low average depth of between 0.5 at the river mouths and 14 meters at the littoral stations with an exception of the Rusinga channel which has a varying depth of between 23-30 meters . Consequently, sedimentary processes become very important in the lake justifying the comprehensive sediment sub-model as an important part of the Lake Victoria Model. Pore water concentration, labile and stable particulate nutrient fractions and diffusive fluxes are state variables and processes constituting important parts of the sediment model that are yet to be investigated.

Under the pilot study ‘ Sedimentation and Sediment Characteristics in the mouths of rivers Nyando and Nzoia and Winam Gulf of Lake Victoria’ has been the study area. Much of the work involved in the study has been concentrated in the two rivers namely Nyando and Nzoia systems and quite satisfactory information/data has been collected on grain sizes, characteristics, benthic biota association and core layers characterizaton. The sediments contributed to the Lake Victoria by river Nzoia have not been reported here for lack of satisfactory information/data. I don’t understand there is Nzoia data in this report?

It has emerged from the findings of the study that the streams feeding river Nyando including the upper and middle reaches of the river convey sediments that are composed of cobles, pebbles, gravels, coarse grain sand, silty fine grain sand and clays. Sediments that consist of fine grain sand, silts and clays are deposited in the lower reaches of the river, the river mouth and the gulf.

The sediments deposited in the lake have been found to have significant effects on the quality of the lake water and the lake's ecology. The effects include increased turbidity hence reduced water transparency, increased suspended and benthic sediment loads in the gulf, increased nutrient concentrations that have enhanced eutrophication particularly in the gulf, periodical proliferation of water hyacinth at such localities as river mouths, bays and some sections of the littoral zone, increased oxygen demand and reduced biodiversity.

Benthic biota associated with sediments particularly benthic invertebrates (molluscs and nematodes) in the river mouths and the lakes have been studied and it has emerged that these organisms occur in shallow areas (littoral zone) of the lake where conditions for their survival are favourable.

The effects associated with sediments coupled with undesirable changes caused by other undesirable materials getting into the lake have had severe consequences on socio-economic activities carried out in the lake by riparian communities.

The results of the pilot study will be used as a baseline for carrying out further studies in the lake's catchment in relation to sediment transport.

CONCLUSION

_Quite Substantial amount of sediments find its way to the lake and for the first time an estimate of bedload transport has been made..

.Destruction of Natural vegetation has led to erosion and surface runoff thus contributing to sediment s in Rivers and their tributaries. This statement requires analysis of land use in the catchments—not done in this section can the statement be supported from the other sections e.g. the Loading Chapter does estimate TSS loadings that are fine grained and carried to the lake

.Poor land use in the lower and middle course of the rivers contributes to sediment transport hence to deposition in the lake.

Fine grain particles silt sand / clays find their way to the inlake waters.

Sedimentation rates measured in traps are not discussed. At least discuss the patterns of sedimentation rates and the composition of these sediments i.e. nutrient ratios. Also settling velocity figure is not discussed and only one figure for one element. Either discuss it or leave it out.

INTERVENTION

1. Intervention measures are required to arrest soil degradation in the upper areas.

Catchment conservation measures need to be put in place.

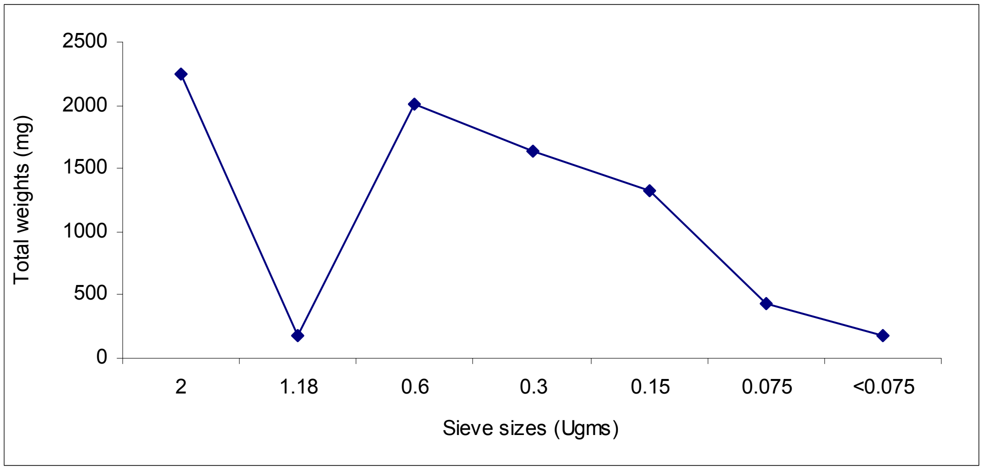
Soil conservation be prioritized from the catchment down to the river mouth.

More studies should be carried out to asses the intervention.

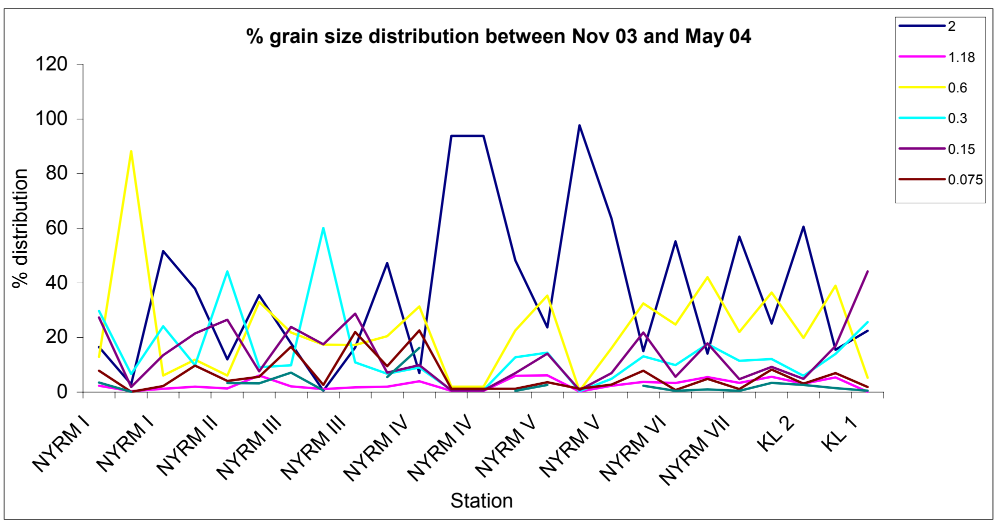
Other catchment and River mouths i.e sondu Miriu, Gucha, Migori aand Kissi should be incorporated in the study to know the bedload transported into the lake.by these rivers.

Table 1: Sediment percentage grain size distribution at Nyando River Mouth (NYRM)in December 2003, March & May 2004

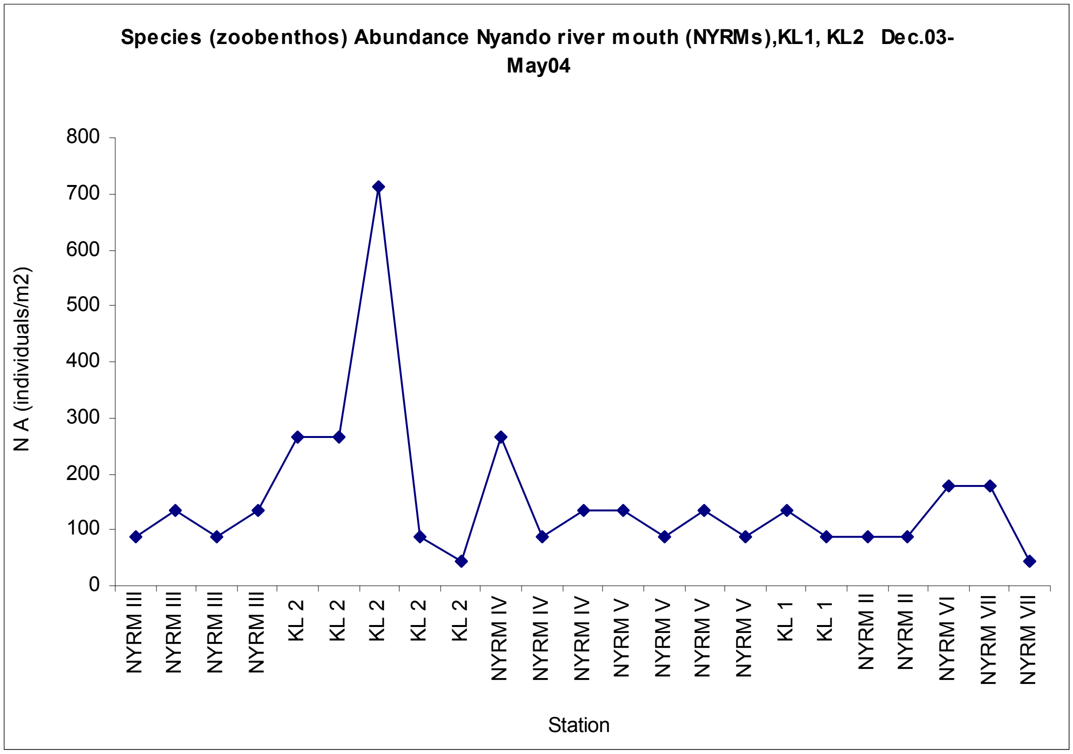
			Sieve Size mm			
Sampling Station	2	1.18	0.6	0.3	0.15	<0.075
NYRM I	51.630367	1.240247	6.0880027	24.072469	13.504715	2.2381062
NYRM I	37.857264	1.9695512	11.885223	9.7628615	21.449997	9.6779671
NYRM I	16.541516	2.3502941	12.887311	29.691778	27.26287	7.8072054
NYRM I	0.3672595	0.3672595	88.249963	6.5641967	1.870303	0.0714116
NYRM II	11.958045	1.2686314	6.0257336	44.115461	26.526604	4.0935921
NYRM II	36.582512	6.2623153	34.137931	9.4519704	7.8078818	5.7573892
NYRM III	16.25055	1.7982842	17.240431	10.844699	28.745051	21.975363
NYRM III	17.813297	2.0653796	21.802834	9.850272	23.909939	16.569576
NYRM III	0.4995451	1.1501554	17.410262	60.154842	17.549311	2.5938578
NY RM IV	93.771102	0.4478743	1.9844278	0.8199545	0.6408048	1.2402673
NYRM IV	6.9722441	3.9729092	31.329745	9.0584749	9.8687791	22.591764
NYRM IV	47.184064	2.0072224	20.452163	6.668638	7.1865731	9.4429062
NYRM V	97.685921	0.2384738	0.4504505	0.3797916	0.7772478	1.2365306
NYRM V	63.528994	2.3443744	16.073173	4.8130717	6.9620815	2.7883847
NYRM V	23.70642	6.2192304	35.305938	14.432834	14.116347	3.6220235
NYRM V	97.685921	0.2384738	0.4504505	0.3797916	0.7772478	1.2365306
NYRM V	48.177377	5.9710218	22.566704	12.739572	6.9376592	1.2463986
NYRM V	63.528994	2.3443744	16.073173	4.8130717	6.9620815	2.7883847
NYRM VI	14.980511	3.7630402	32.448699	13.08896	21.818755	7.7725553
NYRM VI	55.12869	3.2551098	24.750189	9.9432248	5.6396669	0.8062074
NYRM VII	14.080709	5.5378985	42.044688	17.610517	17.822402	4.7914861
NYRM VII	56.903797	3.4642032	22.034604	11.422406	4.6795139	1.0865862
KL 1	15.51932	5.405606	38.96711	13.998182	16.817853	6.9230341
KL 1	22.413775	0.0722032	5.249272	25.666339	44.185935	1.8581191
KL 2	60.586339	3.0869358	19.80535	5.9111536	4.8841653	3.0391689
KL 2	25.084432	5.5920936	36.428597	12.154716	9.2466849	8.2299406

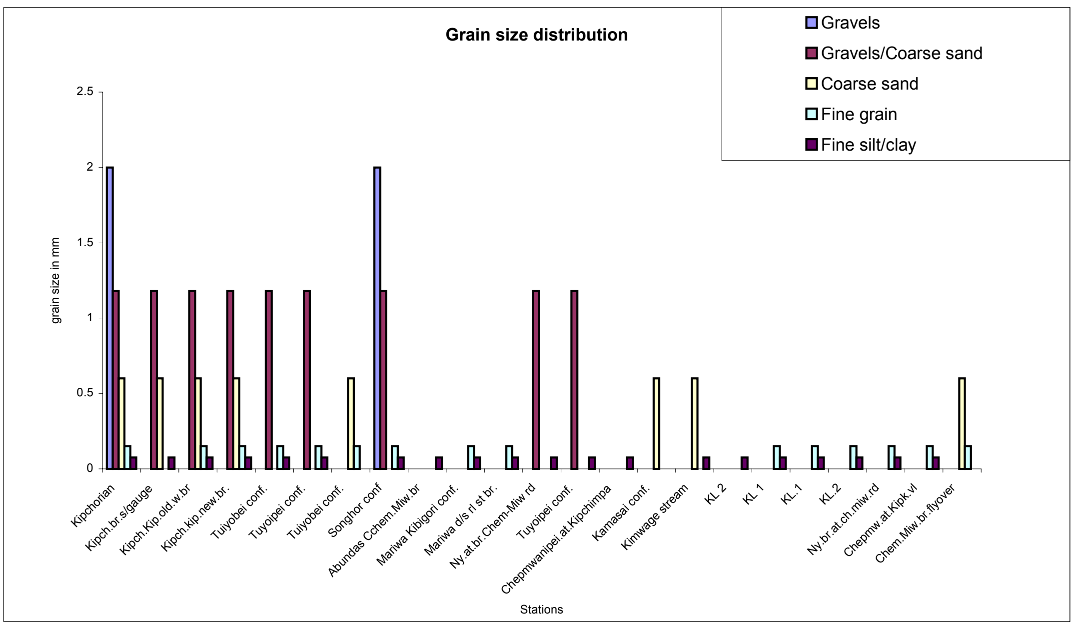


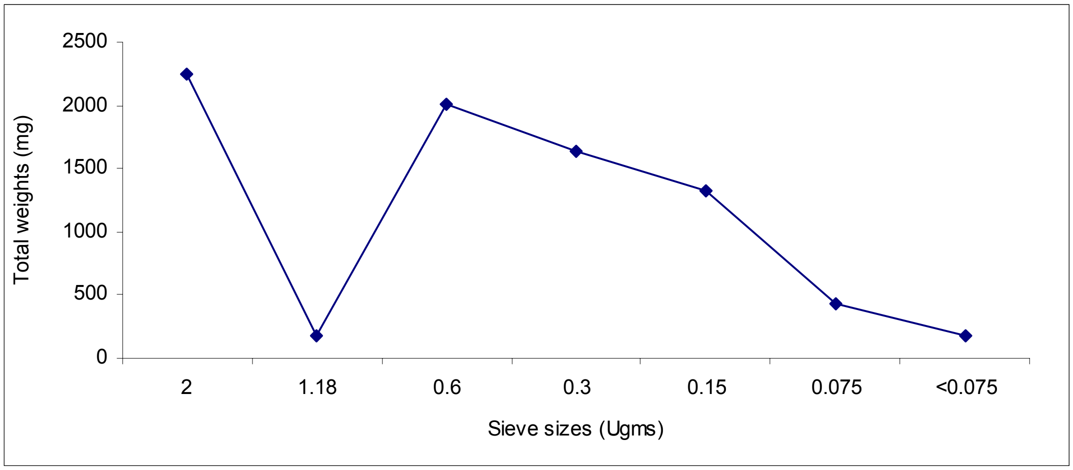
2500
2000
1500
1000
500
0
Total weights (mg)
2
1.18
0.6
0.3
0.15
0.075
<0.075
Sieve sizes (Ugms)

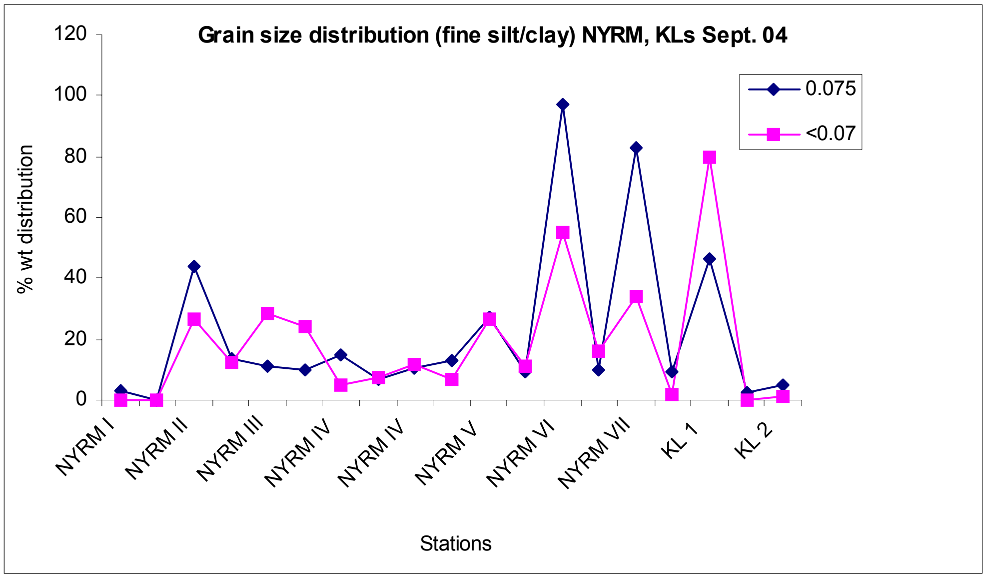


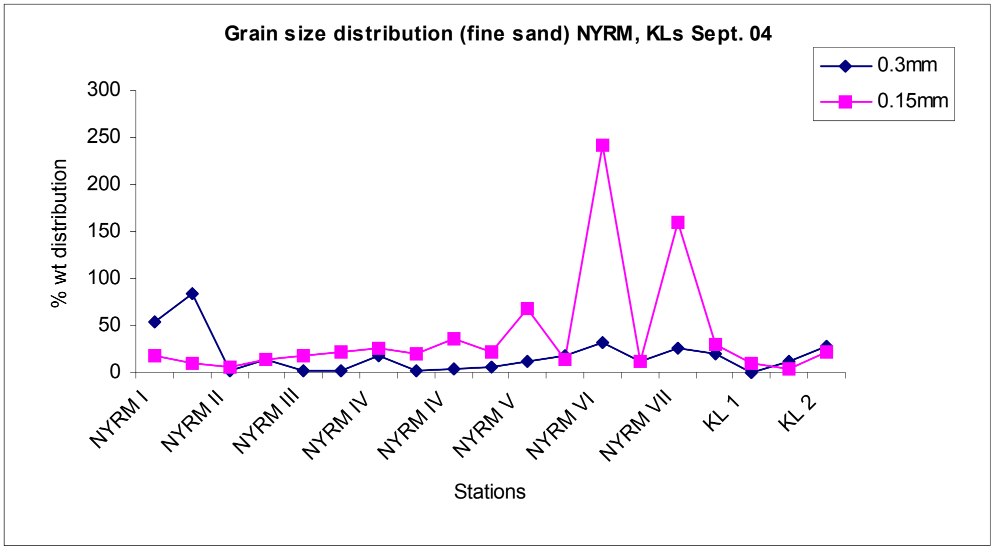
% grain size distribution between Nov 03 and May 04
2
1.18
0.6
0.3
0.15
0.075
120
100
80
60
40
20
0
% distribution
NYRM I
NYRM I
NYRM II
NYRM III
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM VI
NYRM VII
KL 2
KL 1
Station

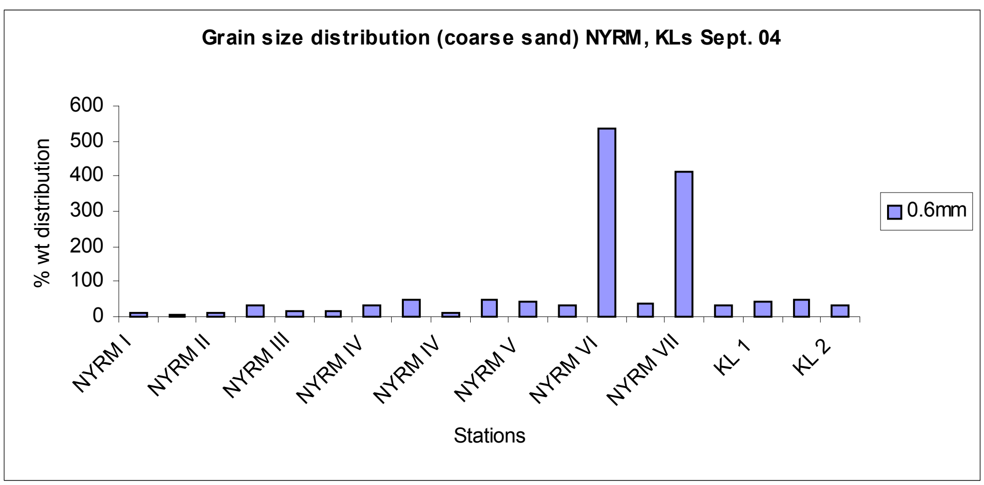

Species (zoobenthos) Abundance Nyando river mouth (NYRMs),KL1, KL2 Dec.03-May04
N A (individuals/m2)
800
700
600
500
400
300
200
100
0
NYRM III
NYRM III
NYRM III
NYRM III
KL 2
KL 2
KL 2
KL 2
KL 2
NYRM IV
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM V
NYRM V
KL 1
KL 1
NYRM II
NYRM II
NYRM VI
NYRM VII
NYRM VII
Station


Grain size distribution
Gravels
Gravels/Coarse sand
Coarse sand
Fine grain
Fine silt/clay
grain size in mm
2.5
2
1.5
1
0.5
0
Kipchorian
Kipch.br.s/gauge
Kipch.Kip.old.w.br
Kipch.kip.new.br.
Tuiyobei conf.
Tuyoipei conf.
Tuiyobei conf.
Songhor conf
Abundas Cchem.Miw.br
Mariwa Kibigori conf.
Mariwa d/s rl st br.
Ny.at.br.Chem-Miw rd
Tuyoipei conf.
Chepmwanipei.at.Kipchimpa
Kamasai conf.
Kimwage stream
KL 2
KL 1
KL.1
KL.2
Ny.br.at.ch.miw.rd
Chepmw.at.Kipk.vl
Chem.Miw.br.flyover
Stations


2500
2000
1500
1000
500
0
Total weights (mg)
2
1.18
0.6
0.3
0.15
0.075
<0.075
Sieve sizes (Ugms)


Grain size distribution (fine silt/clay) NYRM, KLs Sept. 04
120
100
80
60
40
20
0
% wt distribution
0.075
<0.07
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations


Grain size distribution (fine sand) NYRM, KLs Sept. 04
0.3mm
0.15mm
300
250
200
150
100
50
0
% wt distribution
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations


Grain size distribution (coarse sand) NYRM, KLs Sept. 04
600
500
400
300
200
100
0
% wt distribution
0.6mm
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations

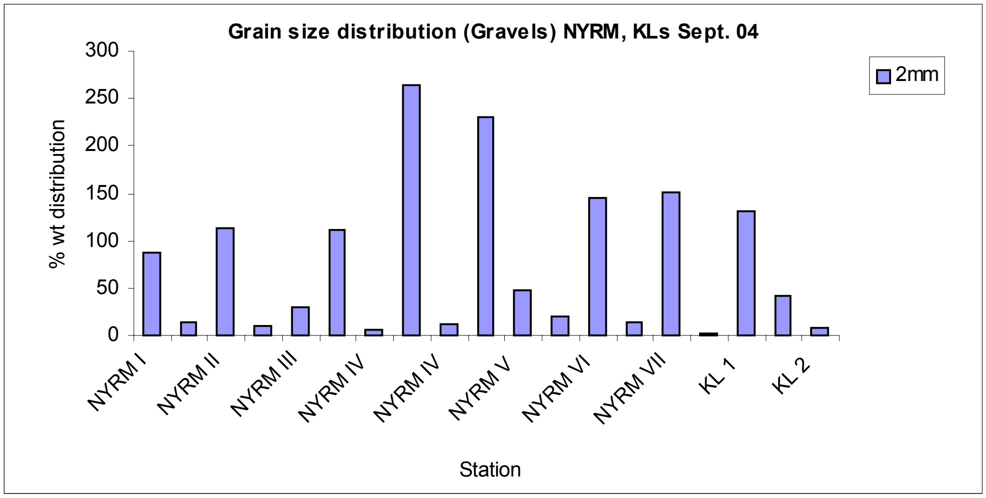
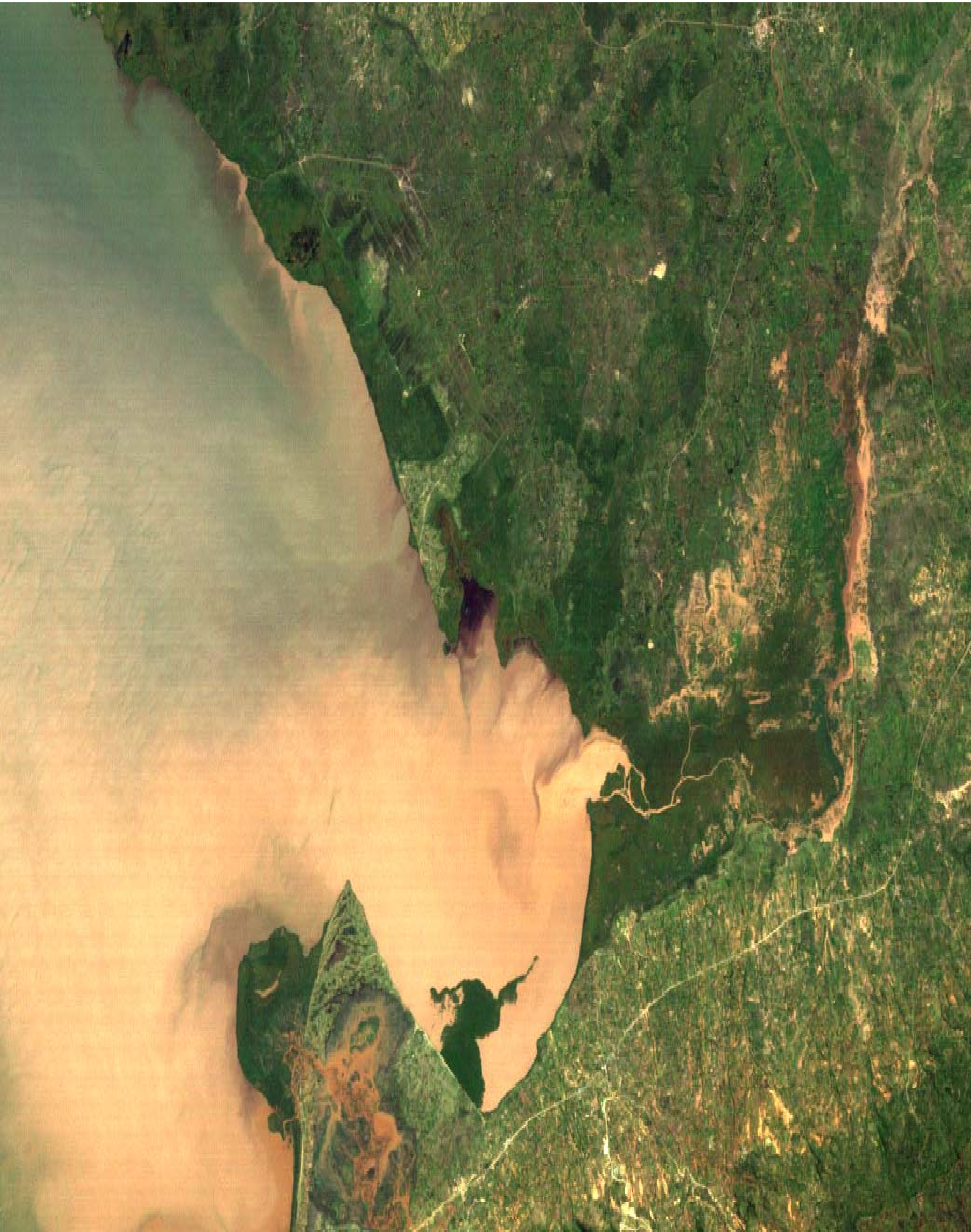
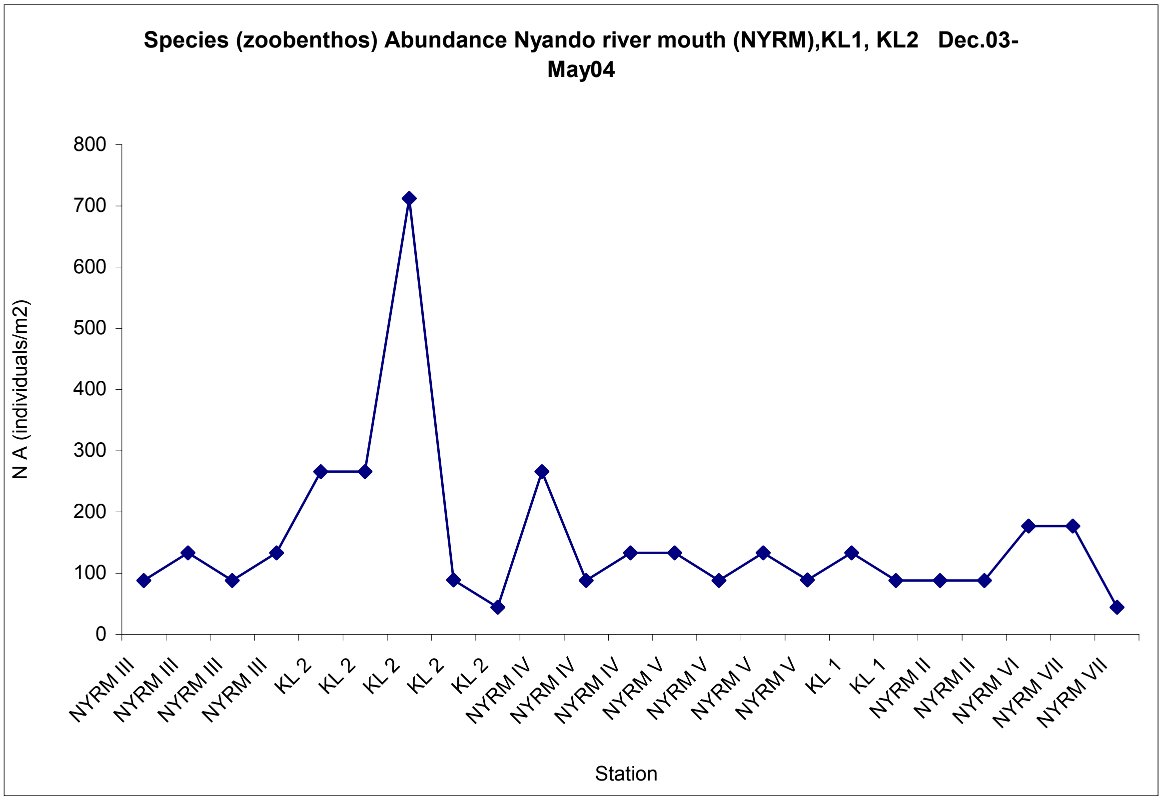
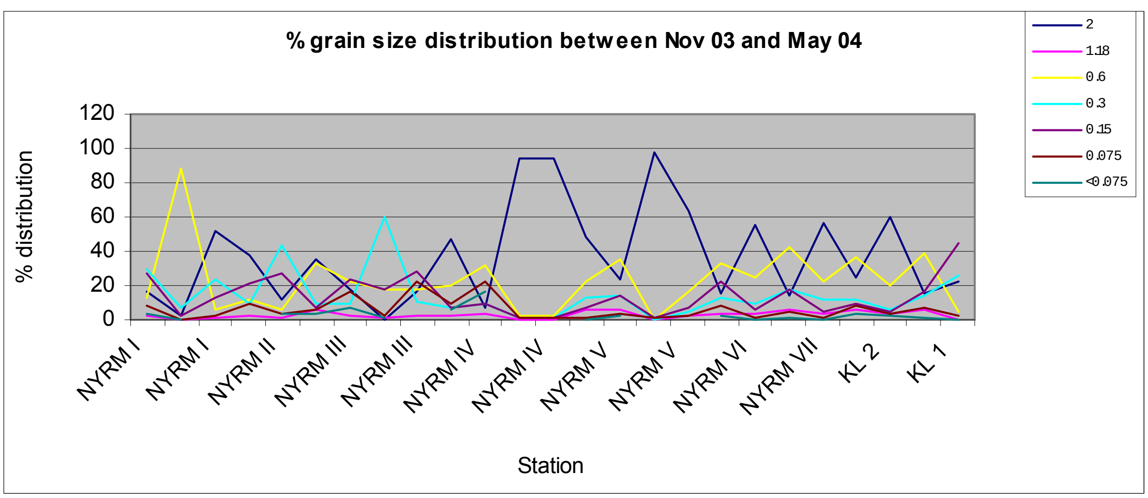


Fig 6: Showing an aerial imagery of the sediment bloom at Nyando river mouth of Winam Gulf




Species (zoobenthos) Abundance Nyando river mouth (NYRM),KL1, KL2 Dec.03-May04
N A (individuals/m2)
800
700
600
500
400
300
200
100
0
NYRM III
NYRM III
NYRM III
NYRM III
KL 2
KL 2
KL 2
KL 2
KL 2
NYRM IV
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM V
NYRM V
KL 1
KL 1
NYRM II
NYRM II
NYRM VI
NYRM VII
NYRM VII
Station


% grain size distribution between Nov 03 and May 04
% distribution
120
100
80
60
40
20
0
NYRM I
NYRM I
NYRM II
NYRM III
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM VI
NYRM VII
KL 2
KL 1
Station
2
1.18
0.6
0.3
0.15
0.075
<0.075

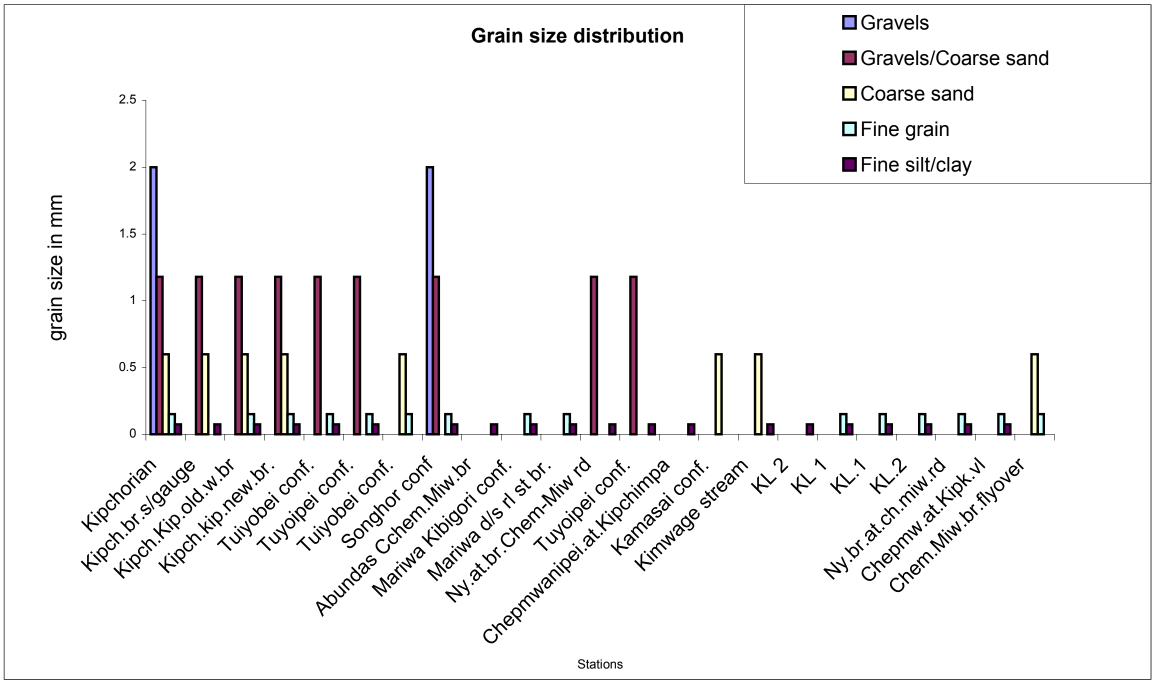
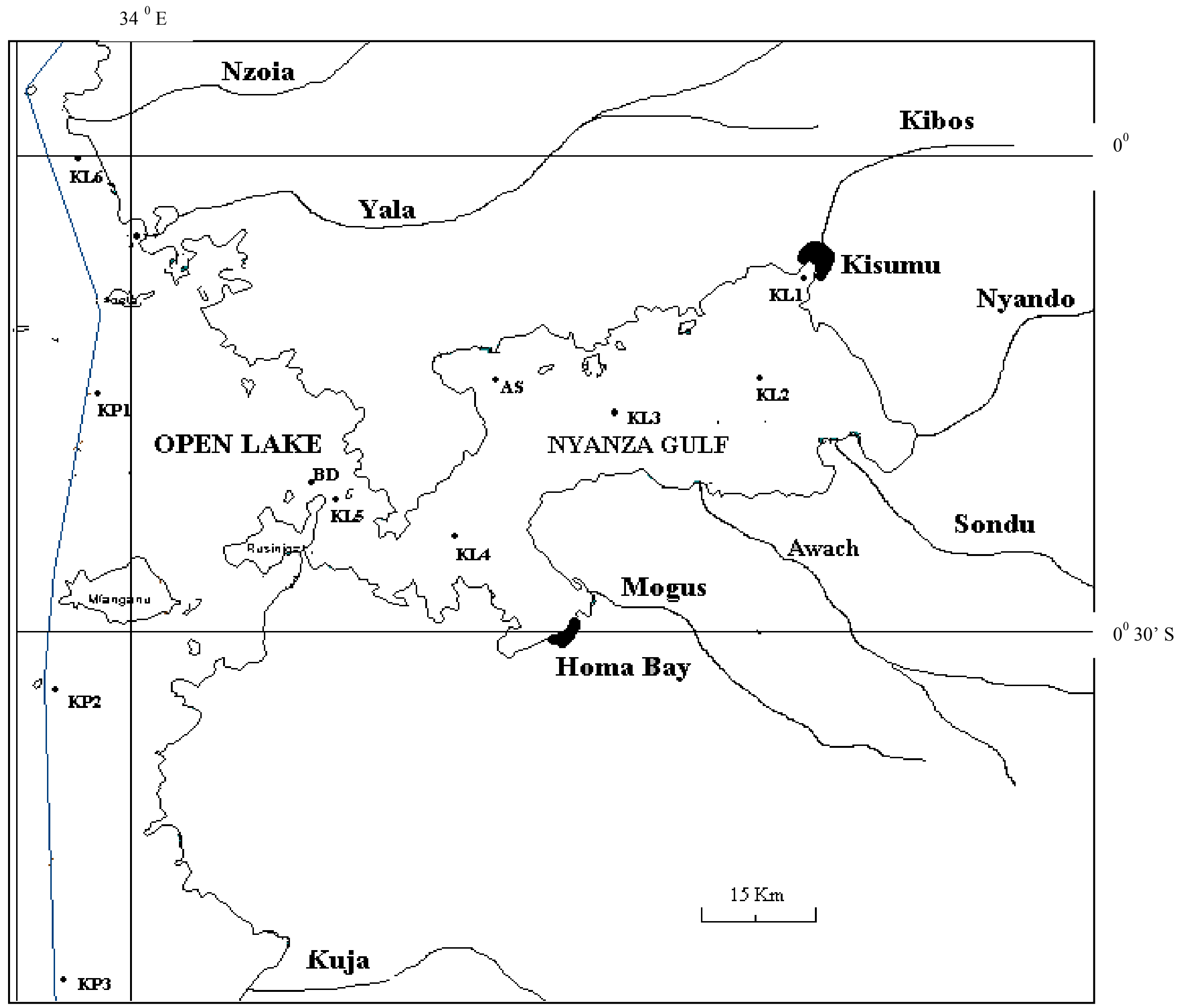


Figure 6 showing sampling stations at the Nyando River



Need a caption

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Grain size distribution vs total weights in grams.??
References need finishing

CHAPTER 9

Sedimentation in the Lake Victoria catchment and the Winam Gulf

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[5]University of Waterloo, Biology Department, 200 University Ave, West Waterloo, Ontario N2L 3G1

Abstract

The need to carry out sedimentation and sediment characteristics study at the river mouths and the lake was contingent upon the supposition that the rivers in the lake Victoria catchment including surface runoffs convey a great deal of

assorted sediments, most of which are deposited in the lake thereby causing the lake to continue filling up and affecting the quality of water.

Introduction

Lake Victoria receives waters of varying quality from several rivers, precipitation, recharge from groundwater; industrial and domestic waste treatment and disposal systems, urban and agricultural run-offs. These waters, rich in nutrients encourage biological activities within the lake that are a source of biogenic sediments. To a small extent, shoreline erosion is also responsible for the sediments found in the lake.

The humid tropical climate of the Kenya catchment of Lake Victoria in combination with the steep relief and slopes, and the presence of easily erodible volcanic soils in relation to intensive agriculture and deforestation, results in tremendous soil erosion, and denudation rates are high. Soil erosion is a major problem in many river catchment areas, being the main source of quartz rich lithogenic sediments. In fact, the total sediment load transported by many rivers is very high, particularly during the rainy season; some of this load is sedimented within the river channels and small basin but some fraction finally ends up in the lake. This has direct impact on the water quality and the life of aquatic ecosystems in the lake.

From historical records, Verschuren et al. (2002) calculated that sediment yields from the catchment have increased dramatically from 1940, with the highest sedimentation rates taking place between 1970-1980. This has been attributed to extensive land use changes in the riparian zone with consequent environmental changes over this period. Verschuren et al. (2002) and LVEMP (2002) data on sediment cores and settling rates in the lake respectively indicated mean sedimentation rates of 1 mm per year in the offshore areas of the lake where fine sediments accumulate but higher rates can occur in river deltas.

The interplay between sediments and the overlying water of shallow lakes in particular, can have profound effects on the nature of the benthic and planktonic biota, nutrient fluxes and sediment transport. These processes may have impact on the performance of populations of potentially troublesome plants such as water hyacinth (*Eichhornia crassipes*) and blue green algae, and animals such as Dipteran flies. The potential for sediments to retain or release nutrients and the potential for the currents to transport sediments have not been well studied. The pilot study on sedimentation during the final stages of LVEMP Phase I is therefore expected to determine rates of sedimentation, characterizing the sediments and assessing their potential for retaining or releasing nutrients such as phosphorous and nitrogen, and their capacity for harboring particular invertebrates under certain conditions occurring in the deltas of rivers and in Winam Gulf of Lake Victoria.

The river mouths and the Winam Gulf have been identified on the Kenyan part of the lake to be the major sediment recipients and transport routes into Lake Victoria. Similarly the river mouths and Winam Gulf receive the highest loads of nutrients and have high populations of benthic and planktonic biota. Additionally, they can also receive certain other pollutants from domestic, industrial and other activities in the vicinity of urban areas that are also found near some river mouths.
The results of the present study on benthic invertebrates represent the first data on fauna associated with the lakes bottom sediments characterized on the basis of the constituent grain size of the sediments.

Objectives

The main objectives of the pilot study include;

- To characterize sediments and determining their sources;
- To determine particle size distribution along the rivers;
- To determine the rate of sedimentation at the mouths of rivers Nyando and Nzoia, and Winam Gulf of Lake Victoria;
- To determine the mechanisms involved in the transport and deposition of sediments in the gulf;
- To determine the effects of sediments in the gulf and the lake;
- To recommend appropriate measures to control sediment flux in the rivers and the lake;
- To determine the role played by benthic organisms in nutrient flux between the sediments and the water column.

Study areas

Winam Gulf

Winam Gulf is an arm of Lake Victoria, which is drained by several rivers, which include Nyando, Sondu-Miriu, Nyamasaria, Awach Kano, Awach Seme, Awach Kibwon and a few seasonal streams. The gulf covers an area of 1400 km^2. It has a maximum depth of 43 m in the offshore areas and 14 m at the inshore stations and a mean depth of 12 m offshore and 4 m for inshore stations .

Apart from receiving sediments from the rivers and surface runoffs, Winam Gulf also receives wastes from industrial and domestic waste treatment and disposal systems located within Kisumu City, Homa Bay and Mbita Urban Centers. Agricultural and urban run-offs also add to the sediment load into the gulf. The gulf is an important fishing ground and is also the main source of water for domestic use for the above-mentioned urban centers along the gulf.

It also serves as a major source of fresh-water supply to many millions of people and domesticated animals that are living along the shores of the lake

The level of eutrophication is high in the gulf, resulting in prolific growth of algae, increased turbidity/reduced water transparency and increased biological oxygen demand. There is also regular occurrence of the water hyacinth in the gulf especially in sheltered areas like bays and river mouths.

River Nyando

River Nyando, which drains into the Winam Gulf of Lake Victoria is 70 km long. It receives water from its many tributaries, which originate from two main sub-catchments, namely; Kericho and Nandi escarpment. The river's catchment covers an area of 3652 km^2. The catchment receives an average annual rainfall of 1298 mm. A large part of the catchment is cultivated for crops that include maize, tea, coffee, horticultural crops, vegetables, sugar cane and potatoes. Fertilizers and pesticides are applied to enhance the production of food and cash crops. The vegetation cover is fairly dense in the upper reaches of the river and gradually becomes sparse in the middle and lower reaches. Poor agricultural land use practices and livestock rearing have contributed to increased soil erosion through gulleys and sediment delivery through surface run-off. As a result, high amounts of suspended sediment loads have severely affected the quality of water not only in the rivers, but also in the Winam Gulf.

River Nzoia

River Nzoia drains on the western side of the country into Lake Victoria.. Its major tributaries originate from Mount Elgon and Cherangani Hills, flowing through Transzoia, Lugari, and Uasin Gishu districts. Its catchment covers an area of 12,842 km^2. The drainage area receives an average of 1424 mm of rainfall per annum.

River Nzoia is the largest river draining from the Kenyan catchment into the lake; the mean annual discharge is about 3.6 billion m^3 of water.

Flooding affects the low-lying lakeshore areas where clearing of vegetation has occurred, especially in floodplains that are characterized by wetlands. The floods originate from heavy precipitation in the upper catchments of the river. During flash floods, Lake Victoria is slow in absorbing water, and instead sends it back, inundating the nearby floodplains.

Field and Laboratory Methods

Field sampling for sediments was done between 2001-2005, at sampling points shown in Figure 1. The sampling locations were geo-referenced for convenience of identification during subsequent field campaigns.

River catchment sampling

Samples are collected by scooping using a shovel. This is done on geo-referenced stations on a river course and its tributaries, upstream from the rivers catchment and downstream to the river mouth respectively. Where the river is shallow, cross sectional sampling is done by wading and where it is deep convenient access is by bridge with both left and right bank samples are collected and treated as separate samples. These samples are taken in polythene bags, sealed and properly labeled.

-From 18 and 36 geo-referenced stations scooping of riverbeds along rivers Nzoia and Nyando was undertaken to collect sediment samples.

The collected samples are dried for about one week before sieving and weighing. First the bulk weight of the individual samples are weighed/taken and recorded . The samples are then sieved using various sieve sizes diameters and reweighed for all samples after sieving. The standard sieve size diameters are >2.0mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and >0.075mm.

Determination of grain size distribution

The sediments were washed with distilled water in the laboratory and oven-dried. The oven-dried samples were then split to obtain 100 g for sieve analysis. A nest of sieves with apertures of 2, 1.18, 0.6, 0.3, 0.15, and 0.075 mm were selected. The sieves were shaken by hand for about 15 minutes. The sieves were chosen to correspond to size classifications for gravel, coarse sand, fine grained sand and silt/clay mixtures.
Composite samples were created for the upper, middle and lower sections of both Rivers Nzoia and Nyando following the method of Abuodha (2002). Grain size analysis was carried out on the basis of these composite samples.

Grab Sampling

An Ekman Grab Sampler was used to collect samples at the river mouth, the littoral (KL's) and the pelagic (KP's) zones of the lake. Along ten arbitrarily selected transects, samples were collected at global stations designated as KL1, KL2, KL3, KL4, KL5, KL6, KP1, KP2 and KP3. The grab sampler was suspended on a nylon rope and lowered to the bottom of the lake while it is open. A messenger was then released to move downward along the rope and this activated a mechanism that controlled the closing of the sampler.

At each point two sediment samples were taken; one for benthos identification for and count, and the other sample for sediment characterization.

The one for benthic communities' analysis was washed through a 1.18 mm sieve size using distilled water. They were then picked using a forceps and preserved in formalin for identification and count. The one for sediment characterization was placed in polythene bags that were properly sealed and labeled for laboratory analysis.

Sediment traps

Suspended sediments in water columns are collected by setting two sets of traps at two meters from the surface, at 2.3 m **x** secchi depth, at mid depth and at 2m from the bottom. The traps are deployed overnight and as close to a twenty-four hour period as possible before retrieval. The volume of water in the traps is measured using a measuring cylinder and kept in plastic containers for laboratory analysis. Nutrient concentrations TBSi, TPN, TPP, TPC are calculated using the plotted graphs of absorbance vs concentration. Other parameters analyzed are LOI and TSS

Core Sampling

An improvised method consisting of a PVC pipe was driven into the lake bottom and the sediment was retrieved and cut using a hack saw. The cores were kept in a deep freezer aired for a few hours to harden and then split vertically. Using a magnifying glass, individual stratigraphical layers were measured and used for description of sediment characteristics.

Bedload Transport

Near the River Nzoia river mouth, a bedload sediment transport experiment was undertaken during an expedition in March 2005. The technique involved excavation of a trench trap across the bottom of the riverbed.

The amount of bedload sediments caught was measured for a duration of 15 minutes, and this experiment was repeated three times each day in order to obtain an average sediment transport rate. Also the quantity of water (volume) was estimated at each time bedload measurements were taken

Results

Grain size distribution and composition of river sediments

The results of grain size distribution are shown in Table 1. By dividing each river into upper, Middle and Lower, interpretation of results becomes easier.

Table 1: Composite sample statistics based on graphical data for Nyando and Nzoia rivers.

Sample statistics and sediment description	**Station**					
	NYUPPER	NYMIDDLE	NYLOWER	NZUPPER	NZMIDDLE	NZLOWER
Mean Size	0.82252 (0.282187)	0.73225 (0.44959)	0.73737 (0.43955)	0.85134 (0.23219)	0.76401 0(.38834)	0.62335 (0.68188)
Sorting	1.28134	1.22213	1.36186	1.32816	1.36136	1.34355
Skewness	0.39518	0.22549	0.46815	0.37837	0.26241	0.25329
Kurtosis	-0.58176	-0.45965	-0.29287	-0.8405	-0.88577	-0.48144
Composite Sample Description						
Size	Coarse grained	Coarse grained	Coarse grained	Coarse grained	Coarse grained	Coarse grained
Sorting	Moderately sorted	moderately sorted	moderately sorted	moderately sorted	moderately sorted	moderately sorted
Kurtosis	platykurtic	platykurtic	platykurtic	platykurtic	Very small (~symmetrical)	platykurtic
Number of Spot Samples	28	22	21	10	15	26
Max Mean Size	1.35	1.66	1.92	1.65	1.47	1.45
Min Mean Size	0.34	0.28	0.31	0.28	0.48	0.16
Max Sorting	1.7	1.55	111.31	1.54	1.54	2.14
Min Sorting	0.76	0.69	0.48	0.9	0.97	0.76
Max Skewness	1.47	2.45	3.89	1.98	1.56	2.13
Mean Skewness	0.11	-0.91	-0.3	-0.09	0.12	-0.59
Max Kurtosis	7.1	9.84	14.94	5.51	1.45	7.16
Min Kurtosis	-0.64	-1.23	-1.23	-0.34	-0.36	-0.35
% Gravels	29.52	22.50	26.20	32.22	30.20	18.81

In the Nzoia system, the mean grain size decreased systematically from the upper zone to the river mouth. In the Nyando system there was decrease only from the upper zone to the middle zone, after which there was a gradual increase in the lower zone. Percentage gravels also decreased from the upper zone towards the lower areas for Nzoia river while percent gravels for Nyando is lower in the middle zone, suggesting the cause for the decrease in grain size.

In Table 2 results of chemical analysis of river sediments are presented. The Nzoia sediments show higher contents of SiO_2, which confirms its traverse through acid igneous and metamorphic terrain (Fig. 2). On the other hand, Nyando passes through alkaline igneous rocks; this is represented by higher concentrations of sodium and potassium ions in the sediments.

Table 2: Chemical composition of river sediment of the Lake Victoria basin (after Maturwe et al., this volume). Are some of the values in this table really zero! That seems unusual The percent sodium values are also inappropriate Check this table carefully.

Date	Station	% SiO_2	% Al_2O_3	% CaO	% MgO	% Na_2O	% K_2O	% TiO_2	% MnO	% Fe_2O_3
8/4/2004	Awach Kibuon-S	0	19.4	4.2	13	822	49	60.5	17.4	9
6/11/2003	Awach Seme-S	88.5	10.23	0.82	0.44	1.86	1.43	0.61	0.12	6.1
8/4/2004	Kuja-Migori-Watho.	0	3	1.75	4	262	28.8	70.7	3.1	0
8/4/2004	Mara-Bridge-S	0.02	20.8	6.65	8	720	71.6	69.1	23.5	14
8/4/2004	Miriu-Nyakwere-S	0	12.7	3.71	14	465	52.3	158.9	9.7	9
8/4/2004	Nyando-Ogilo-S	0.03	16.6	2.87	15	623	52.3	71	12.6	9
6/11/2003	Nzoia-Rwambua-S	92.2	4.62	0.81	0.2	1.34	1.79	0.29	0.02	1.33
6/11/2003	Sio-Mundika-S	90.7	4.19	0.73	0.26	1.02	1.43	0.51	0.03	1.39
6/11/2003	Yala-Kadenge-S	80.6	12.97	0.25	1.46	1.36	1.55	1.14	0.18	8.93

Bedload Transport

During the sediment trapping period the average water flow in the channel was 19.97 m^3s^{-1} with a mean bedload sediment transport as $2.1x10^{-3}$ $kgs^{-1}m^{-1}$. Assuming similar hydrological and sediment transport conditions in all the five channels of river Nzoia delta, the bedload transport is calculated to be 0.01kg $s^{-1}m^{-1}$ Check units and reverse m and s. For five deltas estimated as measuring about 50m wide, the total bedload is calculated to be 1.5kg $s^{-1}m^{-1}$ for Nzoia river.

Benthic invertebrates

Station	Species Organisms	Relative Abundance Individuals per m^2
KL2	Cerithidea	1154
	Campeloma	222
	Sphaerium	666
KL3	Cerithidea	178
	Campeloma	133
	Pisidium	178
	Sphaerium	44
KL4	Cerithidea	844
	Campeloma	
	Sphaerium	133
	Roundworms	444

KL6	Campeloma	110
	Cerithidea	133
	Pisidium	178
	Roundworms	89
Nzoia River mouth	Sphaerium	8880
	Campeloma	400
Mbita West (Rusinga channel	Cerithidea	222
	Sphaerium	266
	Roundworms	133
	Cerithidea	977
Oluch River mouth	Campeloma	44
	Sphaerium	1288
	Cerithidea	3774
Homa Bay	Campeloma	3108
	Sphaerium	2003
	Margaritifera margaritifera	44
	Sphaerium	266
Awach Seme River mouth	Pisidium	178
	Roundworms	133
	Valvata	178
Asembo Bay	Cerithidea	89
	Campeloma	44
Kuja River Mouth	Campeloma	666
	Valvata	220
	Cerithidea	888
	Corbicula	1110
	Roundworms	222

From the figure Nzoia River mouth had the highest densities and was dominated by *Sphaerium* present. Cerithidea were identified in most stations except in Nzoia and Awach Seme River mouths .Asembo Bay had the smallest number of benthic invertebrates identified. *Campeloma* species were identified in small numbers except in Homa Bay, which recorded the highest abundance of about 3100 individual per m^2. Stations KL2, KL4, Oluch and Kuja River mouths had almost same numbers of Cerithidea identified.
Kuja and Awach Seme river mouths, Mbita West (Rusinga Channel),KL6 and KL4 stations had small number of species of Roundworms identified. Margaritifera were identified only in Homa Bay but in a negligible number.Valvata species were only identified in two stations namely Kuja river mouth and Asembo Bay. *Pisidium* species were present only in stations KL3 which is in the gulf and KL6 which in the open lake.

Definitions

Molluscs

This group includes many of the largest aquatic invertebrates and contains more species – 80,000 than any other phylum except the Arthropods. Mollusca are basically bilaterally symmetrical, and posses a protective shell, which is usually made of calcium carbonate, secreted by the mantle. Locomotion is by a muscular foot drawn into the shell by powerful retractor muscles. Most molluscs are marine but many species occur in freshwater habitats.

***Snails (Gastropoda*)**

The gastropoda, mainly various snails contain more than 35000 living species. Typically each is enclosed in a shell, which has the form of a spire. The foot is a flattened creeping sole used for locomotion or attachment. The foot in many groups has a hard operculum, which completely fills the shell opening after the animal has withdrawn, acting as a protective door. Some are ciliary feeders herbivores, carnivores and parasites but most freshwater forms are herbivorous feeding by means of a radula. This is tongue-like with numerous rows of rasping teeth; it may act as a rasp, brush, grater or comb tearing off pieces of macrophytes or collecting organic debris or algae and transporting them to the mouth. There are two main sub-classes; the Prosobranchia, which have gills and are mainly marine forms (a few are fresh water), and the Pulmonata, which have no true gills and are mainly fresh water or terrestrial with only a few marine species.

Bivalves (Pelecypoda)

All bivalves are laterally compressed, and the shell is made up of two valves, which are hinged dorsally and pulled together by two large abductor muscles. The foot is large, and is used for burrowing and locomotion, while the head is small. The mantle cavity within the shell is large, as are the gills lining it. Most bivalves are ciliary feeders on small organic particles swept into the mantle cavity by currents created by cilia or the gills. These also trap food (by secreted mucus) and pass it along grooves to the mouth. A few species feed on detritus by means of a muscular proboscis. All bivalves are aquatic, and most are marine; a number do occur in fresh water, however, and can be important in certain habitats. Most occur in soft substrates, but some viz: Dreissenia, attach themselves to hard substrates.

Round worms (Nematoda)

Nematodes, commonly known as roundworms may reach a length of several centimeters, but most species are less than 1mm in length. The body is cylindrical and extremely elongate with tapered ends. Many are parasites but there are also numerous free-living species, many of which are carnivorous feeding on other nematodes; the herbivorous species eat algae or suck the tissues of higher plants. Some species in decaying organic matter feed on bacteria. The class includes some of the most widely distributed and abundant of all animals; free- living forms being found in all parts of the world. Fresh water forms are normally benthic in habit and occur in many fresh waters, including fast flowing streams, where anchorage is obtained by means of caudal adhesive glands.

Results

The benthos found in the bottom sediments from the river mouths of Nyando and Nzoia and the lake are tabulated below. They include the gastropoda (snails), pelecypoda (bivalves) and nematoda (roundworms). The organisms are mostly found in sediments with decaying organic debris and detritus.

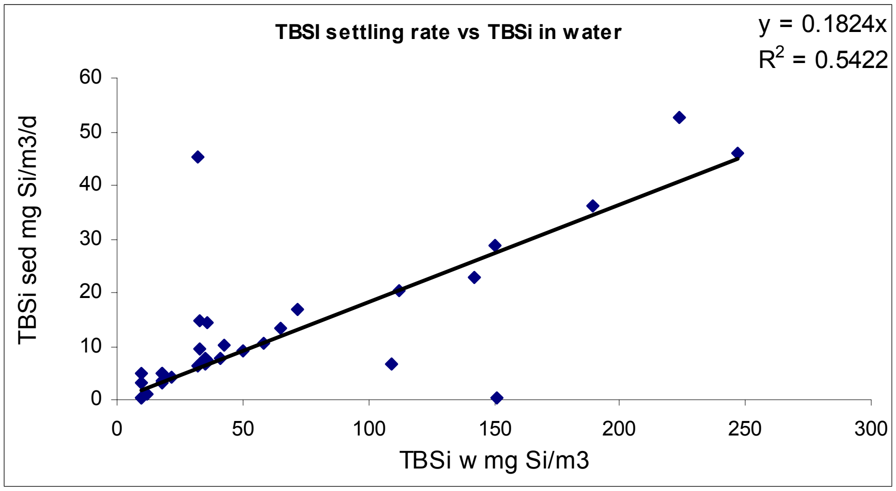
SEDIMENTATION RATES

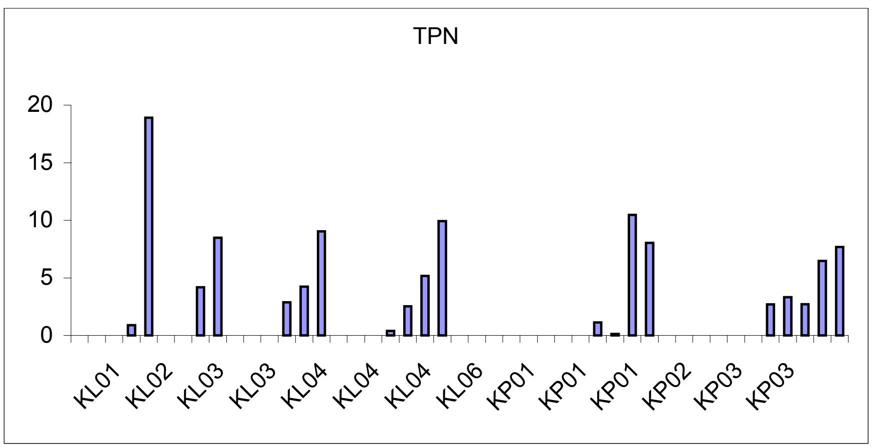
The calculated sedimentation rates are shown in Table **. Sampling and measurements were carried out during three months with moderate rainfall and one wet month. Lower settling rates were observed during September- a wet month. There is also an increase in values with depth of the sediment trap. The littoral and river mouths stations have higher deposition rates compared to pelagic zones.

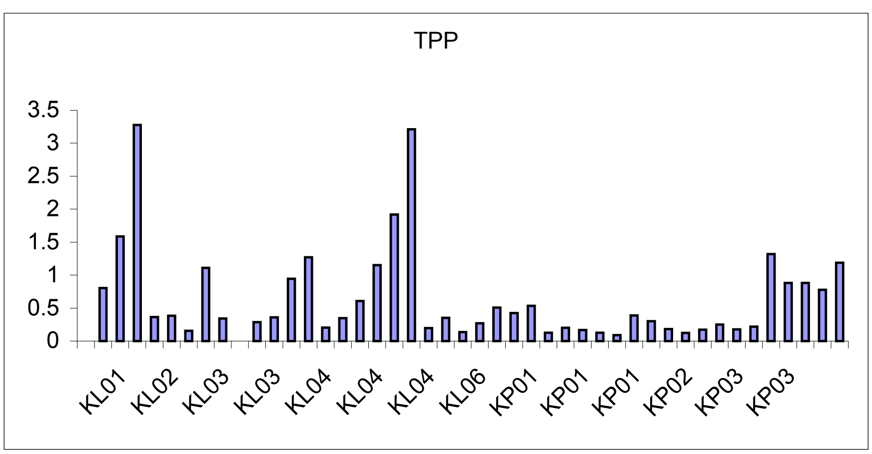
Table **: Distribution of sedimentation rates for TPN, TPP, TBSi, TPC and LOI at littoral and pelagic stations during the months of May, September and October 2001.

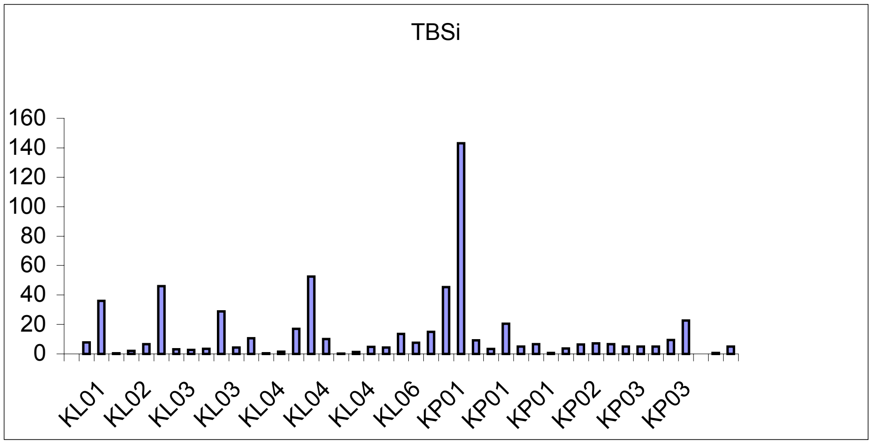
StNo	***Date***	***Period***	***Depth***	***TPN***	***TPP***	***TBSi***	***TPC***	***LOI***
		(hrs)	**(m)**	**mg/m2/d**	**mg/m2/d**	**mg/m2/d**	**mg/m2/d**	***(mgl^{-1})***
KL01	18-May-01	0.9549	2.0	NA	0.8	7.8	9844.4	10.0
KL01	18-May-01	0.9549	2.5	NA	1.6	36.0	9479.3	8.0
KL01	08-Sep-01	0.3958	1.0	0.9	3.3	0.5	2296.7	14.3
KL01	15-Oct-01	0.5889	1.3	18.9	0.4	2.0	1790.7	14.5
KL02	18-May-01	0.9757	2.0	NA	0.4	6.5	335.4	20.0
KL02	18-May-01	0.9757	3.0	NA	0.2	46.0	391.3	11.0
KL02	07-Sep-01	0.6771	2.5	4.2	1.1	3.2	913.0	9.7
KL02	14-Oct-01	0.5549	2.5	8.5	0.3	2.6	852.0	13.0
KL03	17-May-01	0.9465	2.0	NA	NA	3.5	2420.3	7.0
KL03	17-May-01	0.9465	4.0	NA	0.3	28.8	1191.0	16.0
KL03	17-May-01	0.9465	5.0	NA	0.4	4.2	1287.0	12.0
KL03	06-Sep-01	0.8750	2.0	2.9	0.9	10.7	394.8	9.5
KL03	06-Sep-01	0.8750	4.5	4.2	1.3	0.3	415.6	10.0
KL03	12-Oct-01	0.7653	4.0	9.0	0.2	1.4	736.5	10.3
KL04	15-May-01	0.7743	2.0	NA	0.3	16.9	NA	15.2
KL04	15-May-01	0.7743	10.0	NA	0.6	52.6	1315.0	24.0
KL04	15-May-01	0.7743	11.0	NA	1.2	10.1	93.9	10.0
KL04	05-Sep-01	0.3854	2.0	0.4	1.9	0.3	1132.2	6.9
KL04	05-Sep-01	0.3854	11.0	2.5	3.2	1.2	1226.5	26.0
KL04	06-Oct-01	0.6910	2.0	5.2	0.2	4.7	842.0	10.7
KL04	06-Oct-01	0.6910	11.0	9.9	0.4	4.4	2052.4	19.5
KL05	14-May-01	0.8826	23.0	NA	0.1	13.4	41.2	2.1
KL05	14-May-01	0.8389	24.0	NA	0.3	7.6	43.3	5.4
KL06	13-May-01	0.2326	2.0	NA	0.5	14.8	2266.5	10.0
KL06	13-May-01	0.2326	12.0	NA	0.4	45.3	312.6	5.7
KL06	13-May-01	0.2326	13.0	NA	0.5	143.0	312.6	6.5
KP01	13-May-01	0.9931	2.0	NA	0.1	9.2	NA	11.4
KP01	13-May-01	0.9931	55.0	NA	0.2	3.3	36.6	2.5
KP01	13-May-01	0.9931	56.0	NA	0.2	20.5	201.4	4.3
KP01	01-Sep-01	1.0833	2.0	1.1	0.1	5.0	151.0	2.6
KP01	01-Sep-01	1.0833	45.0	0.1	0.1	6.5	251.7	4.3
KP01	10-Oct-01	0.5833	2.0	10.5	0.4	0.7	779.2	6.9
KP01	10-Oct-01	0.5833	41.0	8.1	0.3	3.6	935.1	7.5
KP02	12-May-01	0.9097	2.0	NA	0.2	6.4	239.8	5.5
KP02	12-May-01	0.9097	62.0	NA	0.1	7.2	NA	14.9
KP02	12-May-01	0.9097	63.0	NA	0.2	6.6	40.0	4.5
KP03	11-May-01	0.6569	2.0	NA	0.3	5.0	NA	43.0
KP03	11-May-01	0.6569	53.0	NA	0.2	5.0	NA	19.0
KP03	11-May-01	0.6569	54.0	NA	0.2	5.0	138.4	15.0
KP02	29-Aug-01	1.0000	57.5	2.7	1.3	9.3	600.0	9.4
KP03	28-Aug-01	0.4097	2.0	3.3	0.9	22.7	621.3	4.0
KP03	28-Aug-01	0.4097	24.0	2.7	0.9	NA	443.8	2.9
NY2A	15-Oct-01	0.8750	0.5	6.5	0.8	0.6	6690.9	NA
NY2B	15-Oct-01	0.8681	0.7	7.7	1.2	5.0	62.8	3.0
Maximum				18.9	3.3	143.0	9844.4	43.0
Minimum				0.1	0.1	0.3	36.6	2.1
Average				5.5	0.7	13.7	1363.5	10.9

Settling velocity The figures below need captions and units on the y axis and explanation of bars on the x axis





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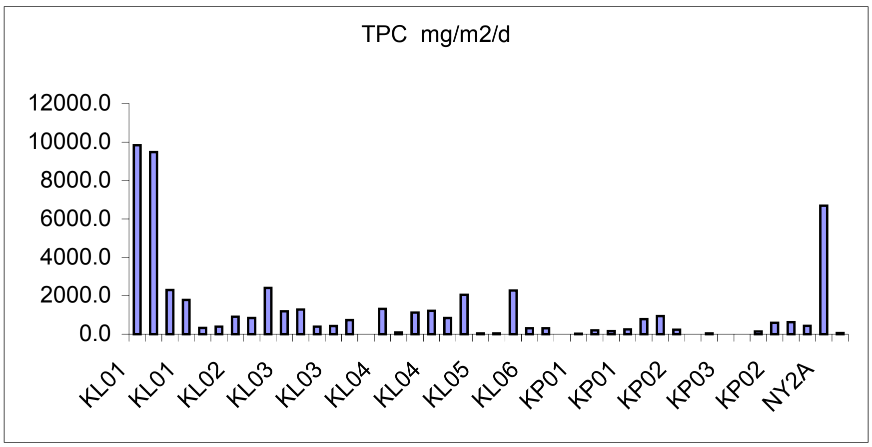
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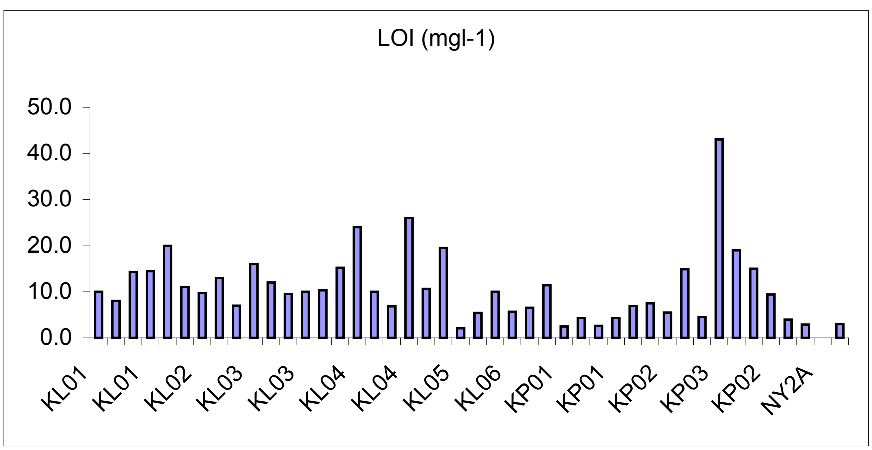
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KP01
KP02
KP03
KP02
NY2A

DISCUSSION

From the catchment area of River Nzoia and its tributaries, it has been observed that deposits in the river channels derived from the upstream are composed of fine grain sand, medium grain sand to coarse grain sand and gravels.

These are emanating from the parent rocks where erosion had taken place and deposition while on transit took place by the denser (heavier) particles remaining on the upper course and less dense (fine particles) setting down stream.

At the River mouth and the littoral and Pelagic zones of the lake the samples from the catchment area of river Nzoia can still be detected. However, the distribution are categorized from loose sands and silty sandy clays.

Settling velocities

Setting velocities reduces at the river mouths while it is very minimal at pelagic stations. Most sediments are deposited upstream while small particles which are carried by wave action find their way to the inshore waters.

Larger, heavier particles are deposited at the river banks since they loose velocity fast whereas fine silt sand are transported into the lake.
In general, sediments deposition at the river mouth vary from one catchment to the other and the determining factor is as a result of the original parent rocks predominantly found in the catchment area where the river originates, erosion mechanism and the area it traverses.

Based on the findings made after carrying out a number of sediments analysis on Nyando, riverine sediments range from gravely and coarse grain sand to fine sand in the upper catchment to loose silty clay of alluvial formation to compact clay/silt sand at the river mouths.

The entrainment, transport and deposition of sediment particles is controlled partly by the physical and chemical properties of the particles themselves and entrainment of grains from the bed is controlled not only by individual grain characteristics but also by the bulk sediment properties which include the grain size distribution, sorting, grain orientation, parking arrangement,movement, porosity and degree of cohesion or cementation. During transport sediment particles are frequently sorted according to size, shape and density and changes in particle characteristics may be brought about through intergrain and grain-bed collisions. (Pye, KENNETH?)

The sediments getting into the lake after leaving river mouths consist largely of fine grain sands, silts and clays while larger particles are deposited upstream of the river mouths. Some sediments particularly the silts and clays carry materials such as organic matter, nutrients and pesticides and other polluting substances. The lake also receives sediments from precipitation and atmospheric deposition. These sediments also carry polluting substances. Industrial and domestic wastes (effluents and solid wastes) discharged into the lake or in the vicinity of the lake consist of sediments of various types, which carry pollutants. Urban and agricultural run-offs also convey sediments of various types into the lake, which carry polluting materials. Shoreline erosion due to wave action also plays a role in adding sediments eroded from the shoreline into the lake. Biological activity especially due to eutrophic processes in the lake produces organic particulate matter that eventually settles to the bottom, where it combines with inorganic sediments. Contribution in the lake by recharge from ground water is not well known. There is limited information in this area and studies are encouraged.

There are several factors that influence the movement/transport and deposition of sediments in the lake. These include the location of discharge i.e. whether the location is open or sheltered, river flow patterns and wave action or water movement within the lake.

The Winam Gulf and the river mouths of Nzoia and Nyando has a relatively low average depth of between 0.5 at the river mouths and 14 meters at the littoral stations with an exception of the Rusinga channel which has a varying depth of between 23-30 meters . Consequently, sedimentary processes become very important in the lake justifying the comprehensive sediment sub-model as an important part of the Lake Victoria Model. Pore water concentration, labile and stable particulate nutrient fractions and diffusive fluxes are state variables and processes constituting important parts of the sediment model that are yet to be investigated.

Under the pilot study ‘ Sedimentation and Sediment Characteristics in the mouths of rivers Nyando and Nzoia and Winam Gulf of Lake Victoria’ has been the study area. Much of the work involved in the study has been concentrated in the two rivers namely Nyando and Nzoia systems and quite satisfactory information/data has been collected on grain sizes, characteristics, benthic biota association and core layers characterizaton. The sediments contributed to the Lake Victoria by river Nzoia have not been reported here for lack of satisfactory information/data. I don’t understand there is Nzoia data in this report?

It has emerged from the findings of the study that the streams feeding river Nyando including the upper and middle reaches of the river convey sediments that are composed of cobles, pebbles, gravels, coarse grain sand, silty fine grain sand and clays. Sediments that consist of fine grain sand, silts and clays are deposited in the lower reaches of the river, the river mouth and the gulf.

The sediments deposited in the lake have been found to have significant effects on the quality of the lake water and the lake's ecology. The effects include increased turbidity hence reduced water transparency, increased suspended and benthic sediment loads in the gulf, increased nutrient concentrations that have enhanced eutrophication particularly in the gulf, periodical proliferation of water hyacinth at such localities as river mouths, bays and some sections of the littoral zone, increased oxygen demand and reduced biodiversity.

Benthic biota associated with sediments particularly benthic invertebrates (molluscs and nematodes) in the river mouths and the lakes have been studied and it has emerged that these organisms occur in shallow areas (littoral zone) of the lake where conditions for their survival are favourable.

The effects associated with sediments coupled with undesirable changes caused by other undesirable materials getting into the lake have had severe consequences on socio-economic activities carried out in the lake by riparian communities.

The results of the pilot study will be used as a baseline for carrying out further studies in the lake's catchment in relation to sediment transport.

CONCLUSION

_Quite Substantial amount of sediments find its way to the lake and for the first time an estimate of bedload transport has been made..

.Destruction of Natural vegetation has led to erosion and surface runoff thus contributing to sediment s in Rivers and their tributaries. This statement requires analysis of land use in the catchments—not done in this section can the statement be supported from the other sections e.g. the Loading Chapter does estimate TSS loadings that are fine grained and carried to the lake

.Poor land use in the lower and middle course of the rivers contributes to sediment transport hence to deposition in the lake.

Fine grain particles silt sand / clays find their way to the inlake waters.

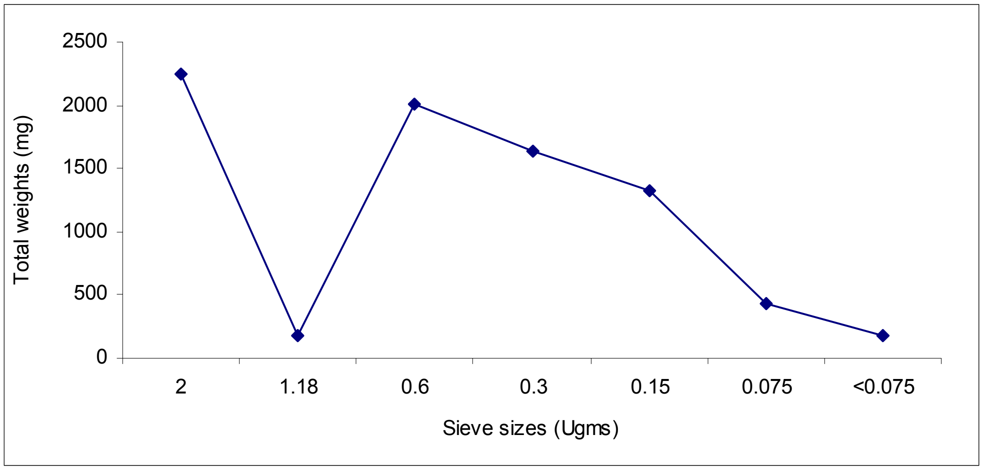
Sedimentation rates measured in traps are not discussed. At least discuss the patterns of sedimentation rates and the composition of these sediments i.e. nutrient ratios. Also settling velocity figure is not discussed and only one figure for one element. Either discuss it or leave it out.

INTERVENTION

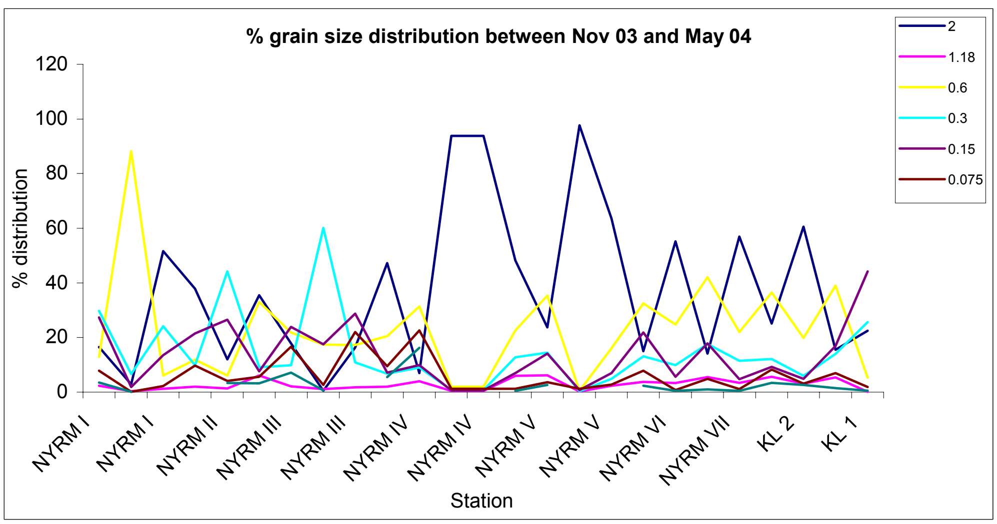
1. Intervention measures are required to arrest soil degradation in the upper areas.
Catchment conservation measures need to be put in place.
Soil conservation be prioritized from the catchment down to the river mouth.
More studies should be carried out to asses the intervention.
Other catchment and River mouths i.e sondu Miriu, Gucha, Migori aand Kissi should be incorporated in the study to know the bedload transported into the lake.by these rivers.

Table 1: Sediment percentage grain size distribution at Nyando River Mouth (NYRM)in December 2003, March & May 2004

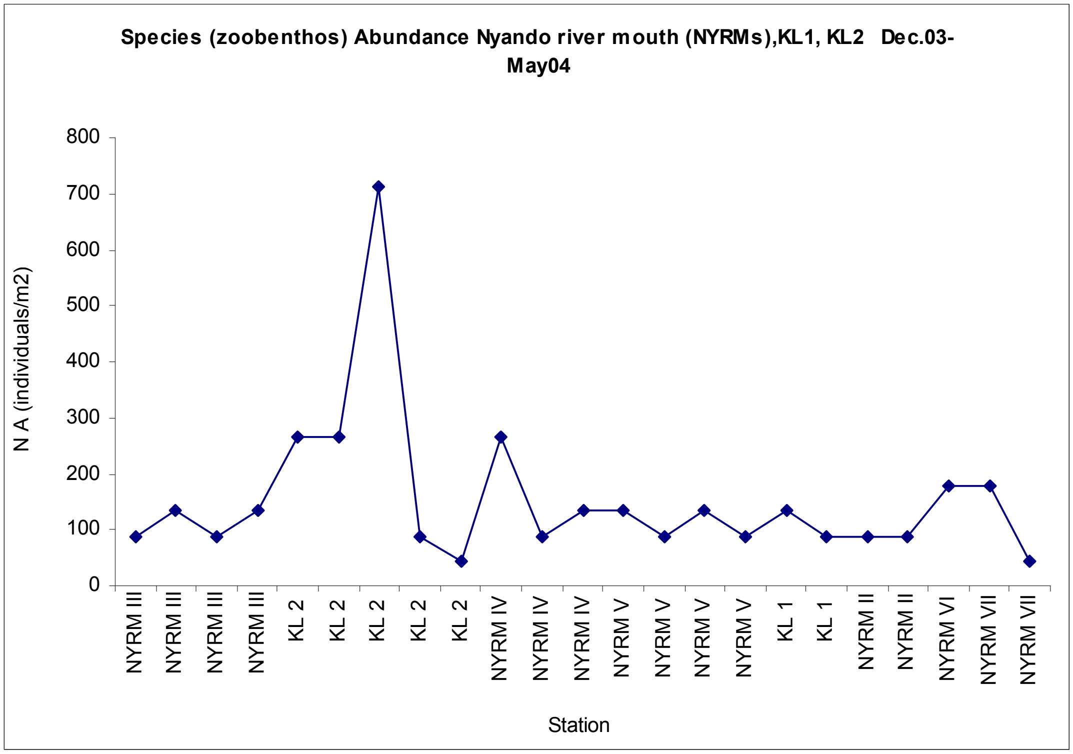
			Sieve Size mm			
Sampling Station	2	1.18	0.6	0.3	0.15	<0.075
NYRM I	51.630367	1.240247	6.0880027	24.072469	13.504715	2.2381062
NYRM I	37.857264	1.9695512	11.885223	9.7628615	21.449997	9.6779671
NYRM I	16.541516	2.3502941	12.887311	29.691778	27.26287	7.8072054
NYRM I	0.3672595	0.3672595	88.249963	6.5641967	1.870303	0.0714116
NYRM II	11.958045	1.2686314	6.0257336	44.115461	26.526604	4.0935921
NYRM II	36.582512	6.2623153	34.137931	9.4519704	7.8078818	5.7573892
NYRM III	16.25055	1.7982842	17.240431	10.844699	28.745051	21.975363
NYRM III	17.813297	2.0653796	21.802834	9.850272	23.909939	16.569576
NYRM III	0.4995451	1.1501554	17.410262	60.154842	17.549311	2.5938578
NY RM IV	93.771102	0.4478743	1.9844278	0.8199545	0.6408048	1.2402673
NYRM IV	6.9722441	3.9729092	31.329745	9.0584749	9.8687791	22.591764
NYRM IV	47.184064	2.0072224	20.452163	6.668638	7.1865731	9.4429062
NYRM V	97.685921	0.2384738	0.4504505	0.3797916	0.7772478	1.2365306
NYRM V	63.528994	2.3443744	16.073173	4.8130717	6.9620815	2.7883847
NYRM V	23.70642	6.2192304	35.305938	14.432834	14.116347	3.6220235
NYRM V	97.685921	0.2384738	0.4504505	0.3797916	0.7772478	1.2365306
NYRM V	48.177377	5.9710218	22.566704	12.739572	6.9376592	1.2463986
NYRM V	63.528994	2.3443744	16.073173	4.8130717	6.9620815	2.7883847
NYRM VI	14.980511	3.7630402	32.448699	13.08896	21.818755	7.7725553
NYRM VI	55.12869	3.2551098	24.750189	9.9432248	5.6396669	0.8062074
NYRM VII	14.080709	5.5378985	42.044688	17.610517	17.822402	4.7914861
NYRM VII	56.903797	3.4642032	22.034604	11.422406	4.6795139	1.0865862
KL 1	15.51932	5.405606	38.96711	13.998182	16.817853	6.9230341
KL 1	22.413775	0.0722032	5.249272	25.666339	44.185935	1.8581191
KL 2	60.586339	3.0869358	19.80535	5.9111536	4.8841653	3.0391689
KL 2	25.084432	5.5920936	36.428597	12.154716	9.2466849	8.2299406

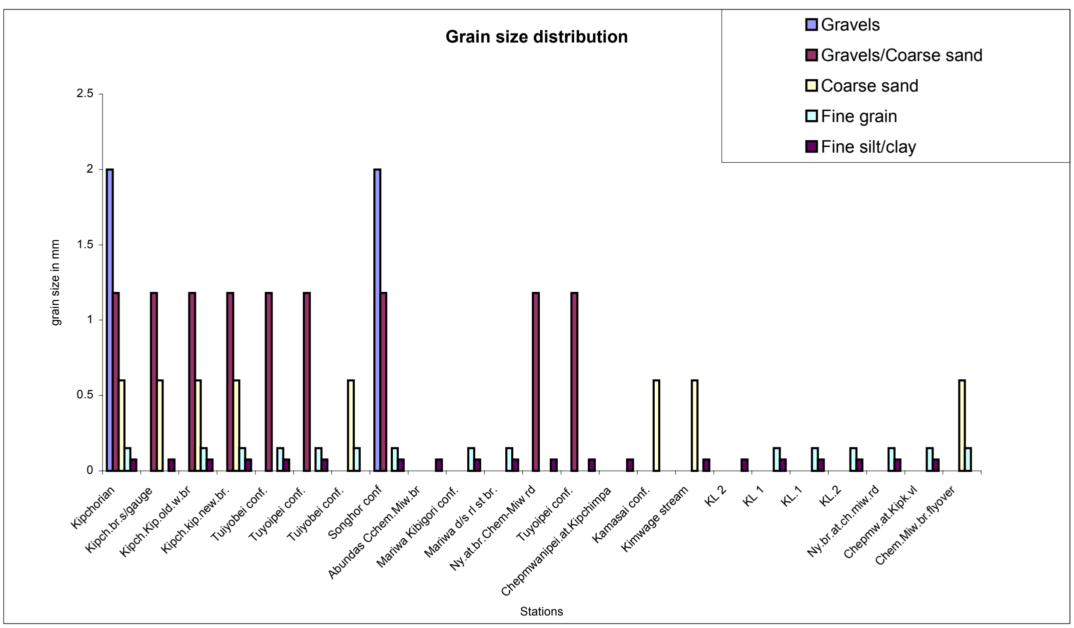


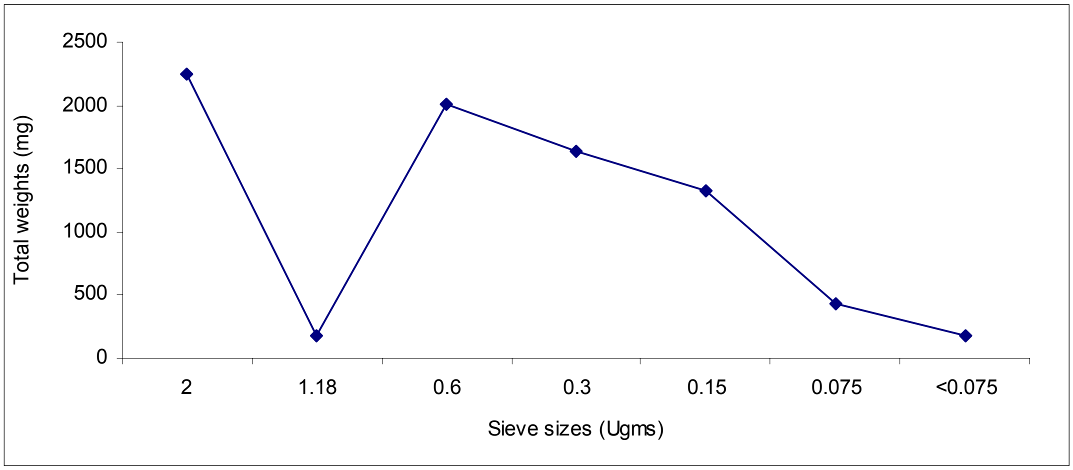
2500
2000
1500
1000
500
0
Total weights (mg)
2
1.18
0.6
0.3
0.15
0.075
<0.075
Sieve sizes (Ugms)

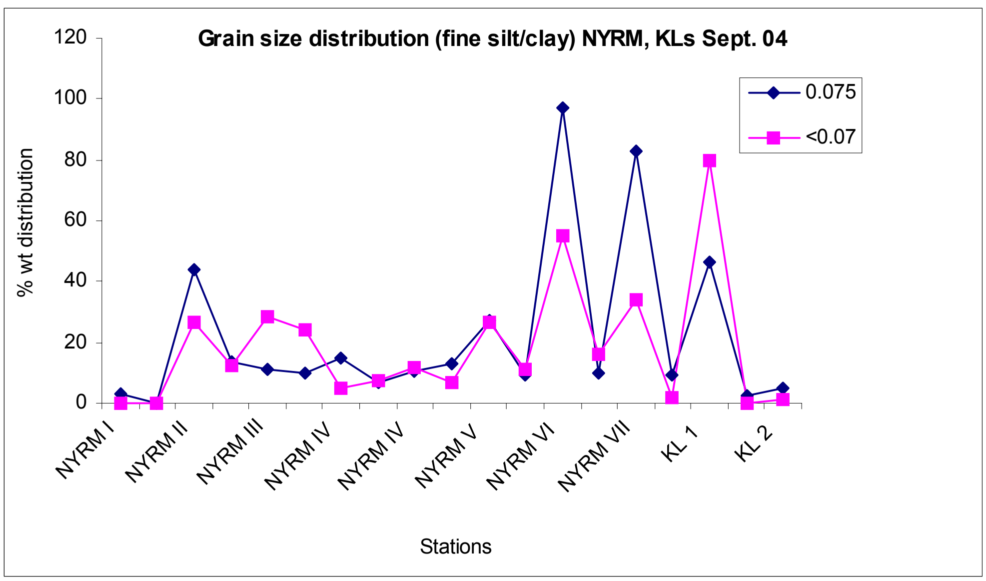


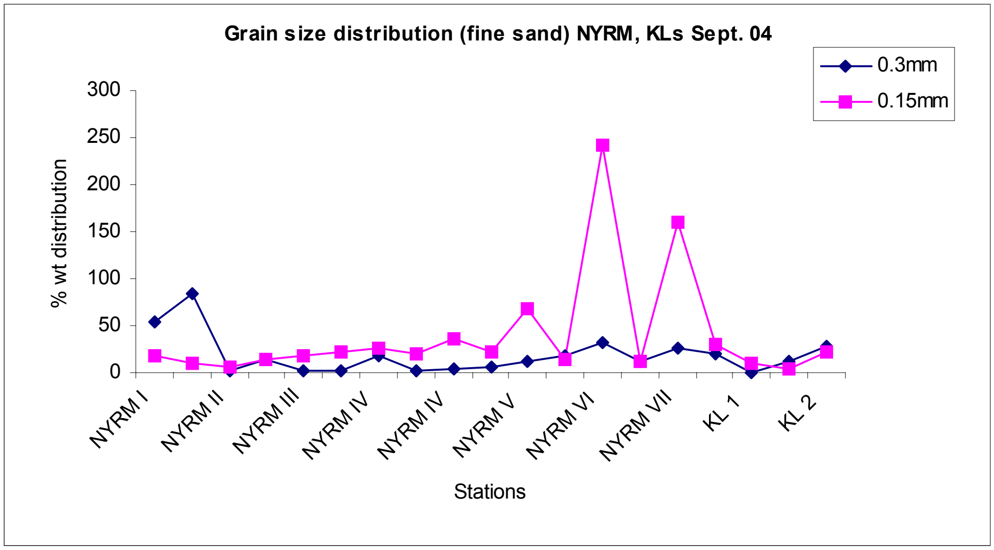
% grain size distribution between Nov 03 and May 04
2
1.18
0.6
0.3
0.15
0.075
120
100
80
60
40
20
0
% distribution
NYRM I
NYRM I
NYRM II
NYRM III
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM VI
NYRM VII
KL 2
KL 1
Station

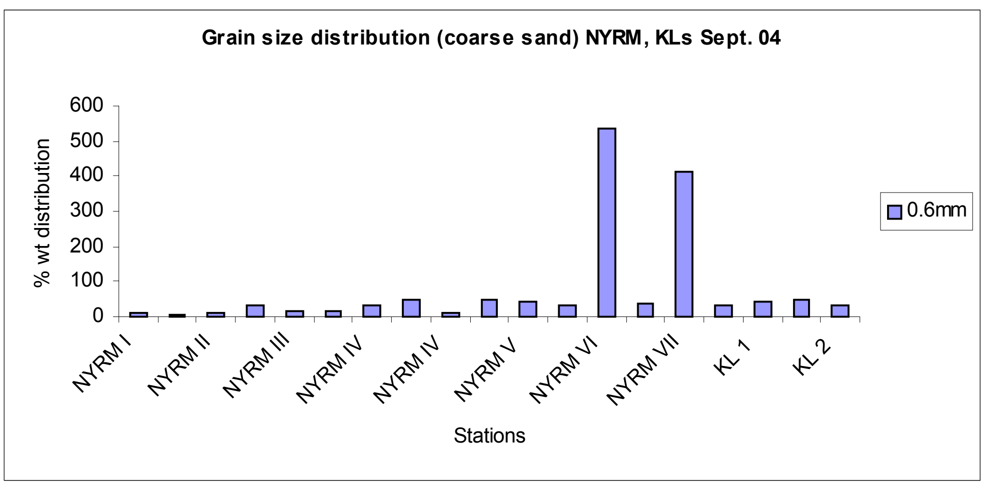

Species (zoobenthos) Abundance Nyando river mouth (NYRMs),KL1, KL2 Dec.03-May04
N A (individuals/m2)
800
700
600
500
400
300
200
100
0
NYRM III
NYRM III
NYRM III
NYRM III
KL 2
KL 2
KL 2
KL 2
KL 2
NYRM IV
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM V
NYRM V
KL 1
KL 1
NYRM II
NYRM II
NYRM VI
NYRM VII
NYRM VII
Station


Grain size distribution
Gravels
Gravels/Coarse sand
Coarse sand
Fine grain
Fine silt/clay
grain size in mm
2.5
2
1.5
1
0.5
0
Kipchorian
Kipch.br.s/gauge
Kipch.Kip.old.w.br
Kipch.kip.new.br.
Tuiyobei conf.
Tuyoipei conf.
Tuiyobei conf.
Songhor conf
Abundas Cchem.Miw.br
Mariwa Kibigori conf.
Mariwa d/s rl st br.
Ny.at.br.Chem-Miw rd
Tuyoipei conf.
Chepmwanipei.at.Kipchimpa
Kamasai conf.
Kimwage stream
KL 2
KL 1
KL.1
KL.2
Ny.br.at.ch.miw.rd
Chepmw.at.Kipk.vl
Chem.Miw.br.flyover
Stations


2500
2000
1500
1000
500
0
Total weights (mg)
2
1.18
0.6
0.3
0.15
0.075
<0.075
Sieve sizes (Ugms)


Grain size distribution (fine silt/clay) NYRM, KLs Sept. 04
120
100
80
60
40
20
0
% wt distribution
0.075
<0.07
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations


Grain size distribution (fine sand) NYRM, KLs Sept. 04
0.3mm
0.15mm
300
250
200
150
100
50
0
% wt distribution
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations


Grain size distribution (coarse sand) NYRM, KLs Sept. 04
600
500
400
300
200
100
0
% wt distribution
0.6mm
NYRM I
NYRM II
NYRM III
NYRM IV
NYRM IV
NYRM V
NYRM VI
NYRM VII
KL 1
KL 2
Stations

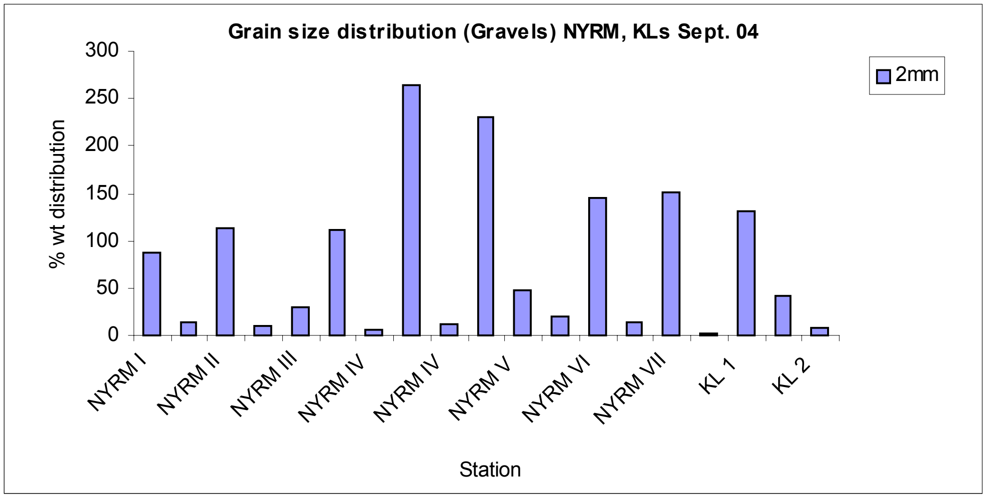
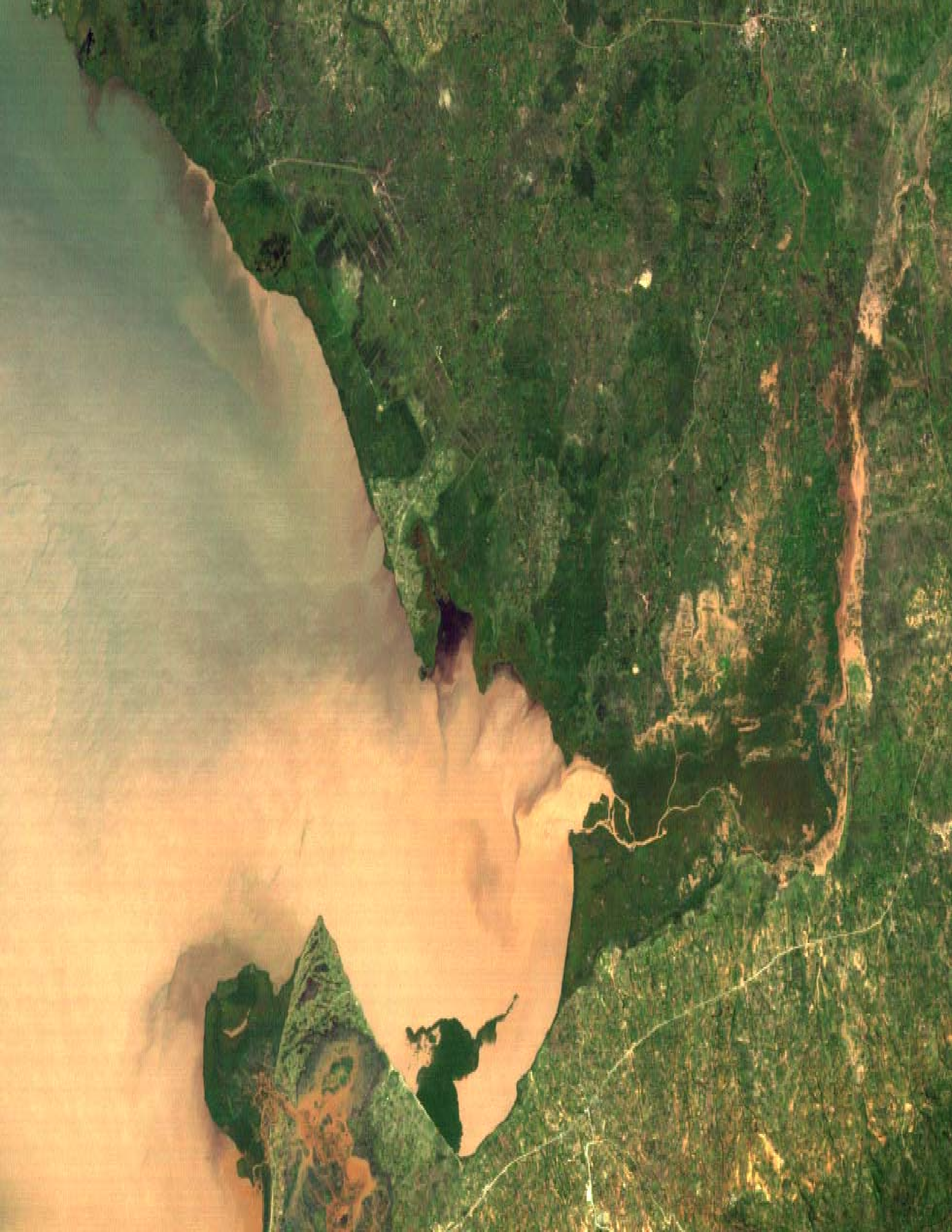
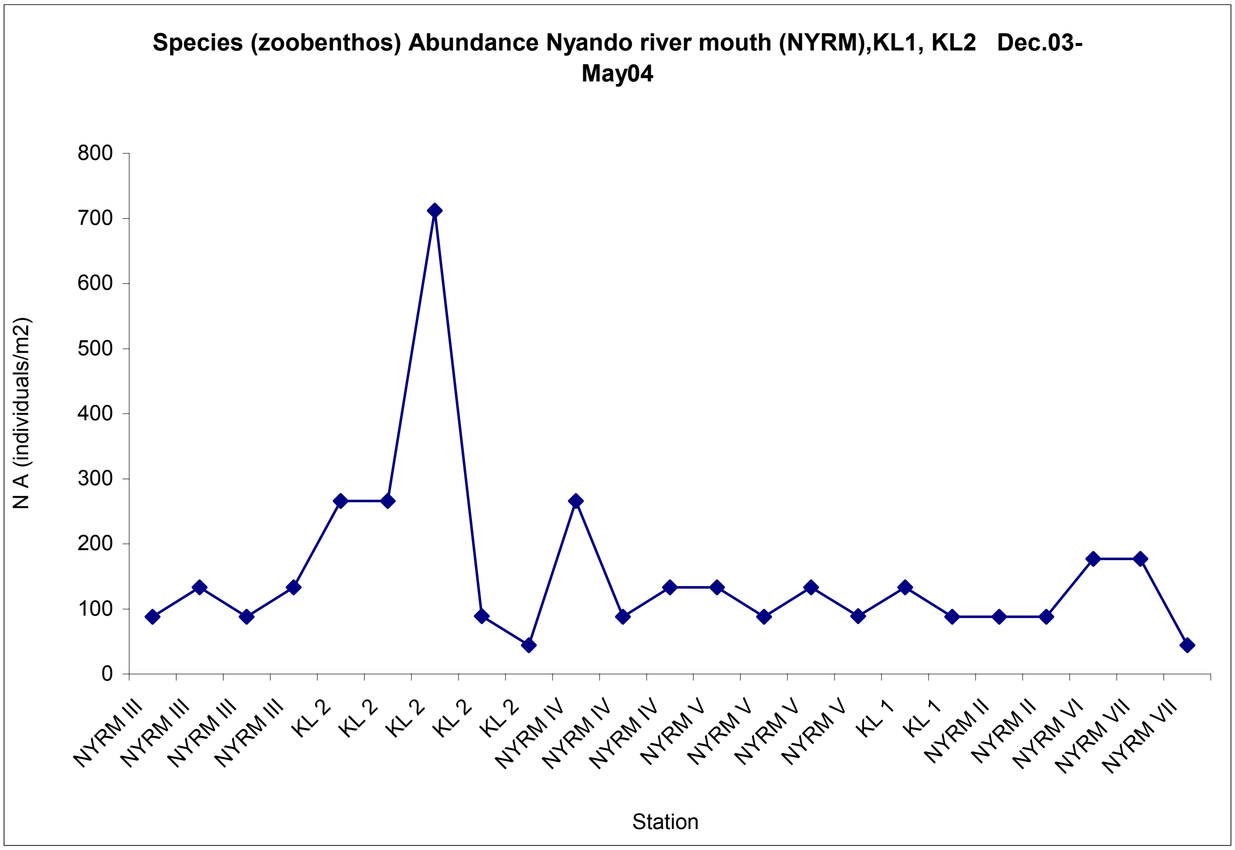
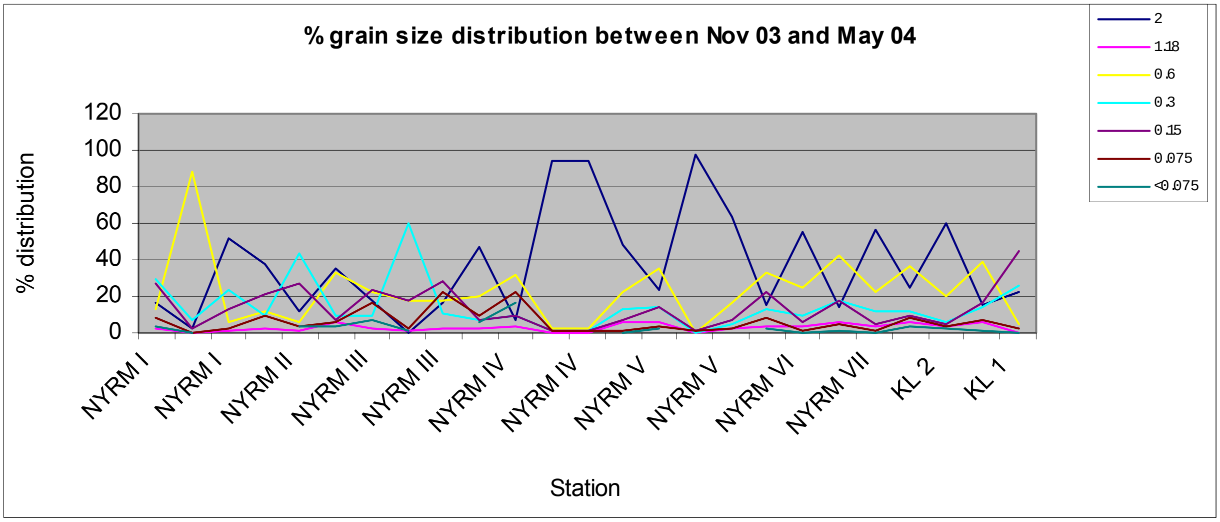


Fig 6: Showing an aerial imagery of the sediment bloom at Nyando river mouth of Winam Gulf




Species (zoobenthos) Abundance Nyando river mouth (NYRM),KL1, KL2 Dec.03-May04
N A (individuals/m2)
800
700
600
500
400
300
200
100
0
NYRM III
NYRM III
NYRM III
NYRM III
KL 2
KL 2
KL 2
KL 2
KL 2
NYRM IV
NYRM IV
NYRM IV
NYRM V
NYRM V
NYRM V
NYRM V
KL 1
KL 1
NYRM II
NYRM II
NYRM VI
NYRM VII
NYRM VII
Station



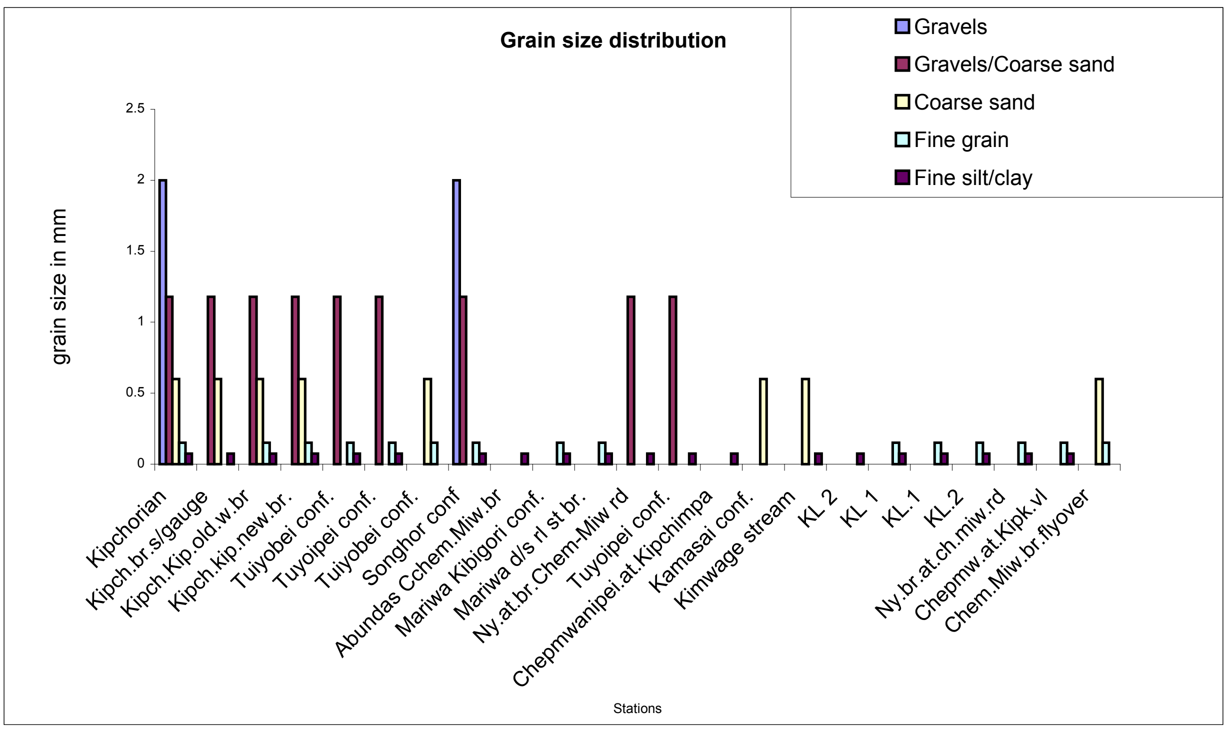
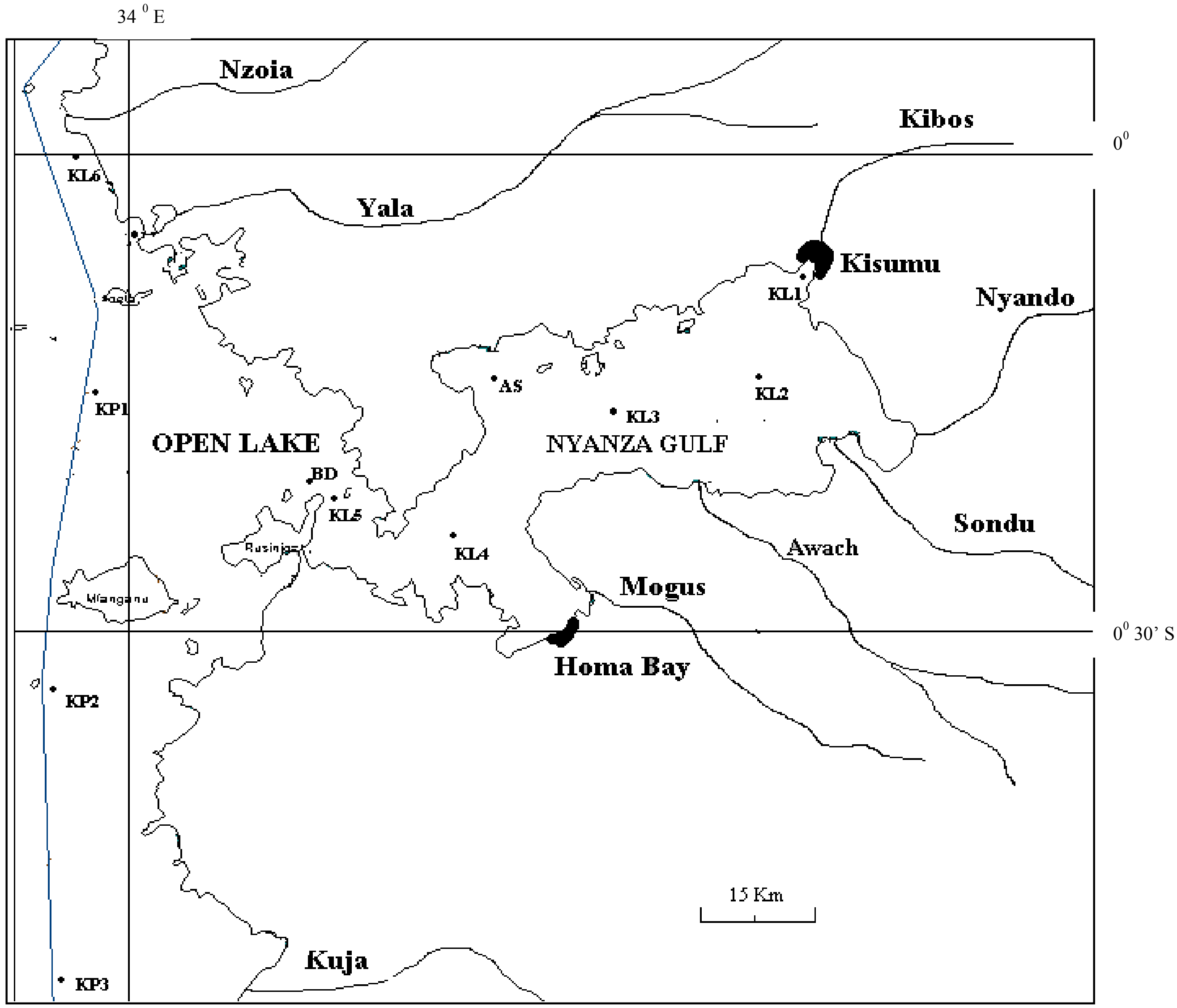


Figure 6 showing sampling stations at the Nyando River



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Grain size distribution vs total weights in grams.??

References need finishing

CHAPTER 10

Eutrophication of Lake Victoria, Kenya: *lessons for Water quality management*

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INTRODUCTION

During the last 4 decades, the East African Lake Victoria has undergone major water quality and biological changes, which have threatened the long-term sustainable utilization of lake resources and have attracted local and international attention (World Bank, 1996).

The introduction in the 1950s and early 1960s of the exotic Nile Perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) has lead to a dramatic loss of the native cichlid species (Witte et al 1992). The phytoplankton species composition in the lake has changed from one dominated by large diatoms, mainly *Melosira* and *Stephanodiscus* (Talling 1966) to that presently dominated by cyanobacteria (blue green algae) (Ochumaba and Kibaara 1989; Mugidde 1993; Lung'aiya et al 2000; Kling et al 2001) and primary productivity and chlorophyll have increased 2-fold and 8 to 10-fold respectively (Mugidde 1992, 1993). Other reported changes to the lake are decline in the euphotic zone SRSi, more thermally stable water column, leading to more regularly anoxic deep waters and an increase in SRP in the water column (Hecky 1993; Lehman & Branstrator 1993).

The bulk of limnological studies on Lake Victoria has been done in the northern part of the lake (Ugandan waters), from UFFRO (FIRRI) research center where European and other local and international scientists were based from the early colonial days (Worthington 1930) and it is only in the mid-1980s that the Kenyan waters (to the northeast of the lake) started receiving scientific attention possibly due to the visible water quality changes caused by increased algal blooms (Ochumba & Kibaara 1989) and massive fish kills (Ochumba 1990). A group of national scientists under the Kenya Academy of Sciences, undertook an extensive limnological sampling of the Kenyan waters in 1985 (Lake Victoria, Kenya baseline survey; unpublished report) and since then several researchers have reported on the phytoplankton, zooplankton, nutrients, physical limnology, food web structure and pollution of the Kenyan Lake Victoria (Ochumba & Kibaara 1989; Mavuti & Litterick 1991; Calamari et al 1995; Ochumba 1996; Lung'aiya et al 2000; Lung'aiya & Sitoki 2001; Campbell et al 2003[1], 2003[2] and Gikuma-Njuru & Hecky 2005).

In the past five years, scientists from the three east African countries of Kenya, Tanzania and Uganda have been undertaking extensive lake-wide water quality studies in order to establish the current water quality status, identify and quantify limnological changes and predict possible future water quality changes in relation to the human activities in the catchment. These studies aimed at enhancing sustainable management and exploitation of Lake Victoria resources for economic well-being of the riparian communities.

This paper reports on the major limnological and water quality findings in Lake Victoria, Kenya and offers suggestions on sustainable management of lake water quality.

MATERIALS AND METHODS

Study Area

The Kenyan waters of Lake Victoria lie around the equator between 0^0 13' N/0^0 55'S and 33^0 56'E/ 34^0 45'E at an altitude of 1134 m asl and cover an area of 3600 Km^2 (approximately 6% of the whole lake) of which 1400 Km^2 comprises the Nyanza Gulf (Fig 1). It has a catchment area of 49000 Km^2, which is drained by 5 major rivers (Nzoia, Yala, Nyando, Sondu, and Kuja) through which it contributes approximately 30% of total riverine inflow into Lake Victoria (LVEMP 2002). The catchment falls in some of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centers including Kisumu (approx. 0.5m population). Increased agricultural and municipal input into the lake has continued to endanger the environmental health of the lake and continue to raise concern (Chege, 1995).

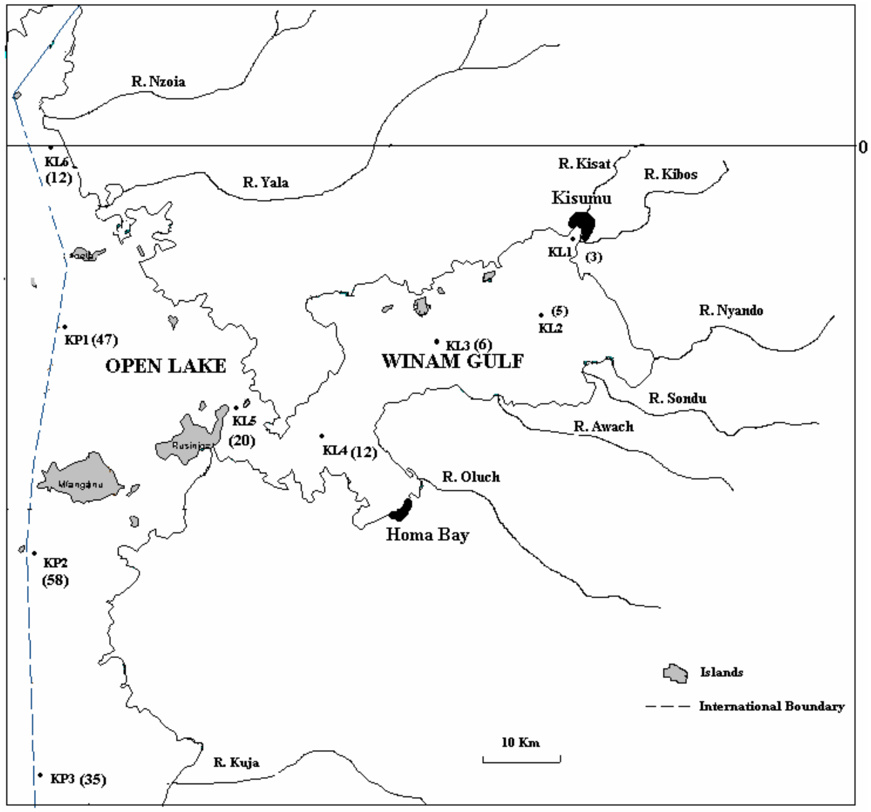


Figure 1 – Lake Victoria, Kenya showing sampling stations, KL1-6 (littoral) and KP1-3 (pelagic). Values in parenthesis beside the stations are station depth (m)

Between December 2000 and March 2005, 9 in-lake stations (6 inshore and 3 offshore) were sampled a total of 15 times, for the analysis of nutrients (orthophosphate (PO_4-P), total phosphorus (TP), dissolved organic phosphorus (DOP), nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_3-N), total nitrogen (TN), dissolved organic nitrogen (DON), dissolved reactive silica (SiO_2-Si), particulate biogenic silica (PBSi) and total particulate carbon (TPC)), algal biomass and species composition, zooplankton abundance and species composition, and TSS. In-situ measurements of pH, temperature, conductivity, dissolved oxygen, turbidity and transparency (secchi depth) were done at each station and primary productivity assays were also carried out.

Sampling stations were selected to fall within the lake-wide transects established by the three countries of Kenya, Tanzania and Uganda, and were categorized according to depth and distance from the shore as littoral (<20m deep and <5km from the shore) and pelagic (>20m deep and > 5km from the shore) (Fig 1). Five littoral stations were within the Nyanza Gulf (KL1-5) and one was in the northeastern part of the main lake (KL6) and the three pelagic stations were all in the main lake (KP1 – KP3) (Fig 1).

Field sampling and laboratory analysis

Water samples were collected at different depths; at the surface, Secchi depth, photic depth, mid and 1m above bottom, using a 2-l Van Dorn sampler and immediately filtered on board through 0.45µm GFF filter paper for analysis of chlorophyll and TSS in the residue and dissolved nutrients in the filtrate. Water samples for analysis of phytoplankton species composition and zooplankton abundance were immediately preserved using Lugol's iodine and formalin, respectively. Primary productivity assays were incubated at different depths in light and dark bottles and the oxygen concentration was analysed using the Winkler titration method. Samples were kept under ice during transportation to the Kisumu, Ministry of Water and Irrigation, laboratory where analysis was immediately done.

In the laboratory, samples were analysed using specrophotometric methods as outlined in APHA (1995). Soluble reactive phosphate (PO_4-P) was analysed using the ascorbic acid method, nitrate-nitrogen (NO_3-N) using cadmium reduction and diazoic complex method and silica (SiO_2-Si) using heteropoly blue method. For the analysis of particulate biogenic silica (PBSi), an appropriate sample volume was filtered through 0.2µm membrane filter and the contents digested using wet alkaline method (2ml of 0.5M NaOH added and heated in oven for 15 minutes at 85^oC) to release the bound silica, which was then analysed as silica (SiO_2-Si). Samples for the analysis of total and total dissolved (filtered through 0.45µm GFF filter) nutrients were digested and analysed as outlined in APHA (1995). TP and DOP were analysed as PO_4-P whereas TN and DON was analysed as NO_3-N.

TSS samples (pre-weighed filter paper and residue) were dried in an oven for 24 hours at 105^oC and after weighing, the samples were combusted in a furnace for 30 minutes at 550^oC to get loss on ignition (LOI) weight, which was multiplied by 0.4 (the estimated dry weight ratio of carbon in algae) to get total particulate carbon (TPC) content. Algal biomass (chlorophyll) was extracted from the filter residues using 90% ethanol and analysed spectrophometrically according to the Witzel and Likens (1991) method.

In-situ measurements of pH, temperature, conductivity, turbidity and DO were carried out using a Hydrolab Surveyor 4a multi-probe with a depth sensor.

RESULTS

Physico-chemical Status

There were differences in physico-chemical parameters between the gulf and the main lake. Conductivity was higher in the gulf than in the main lake, showing a decreasing trend from 161.8µS/cm (KL1) to 98.2µS/cm (KP2) (Fig. 2). KL6 within the lake proper had an average value of 101.1µS/cm which was considerably lower than other littoral stations. Figure 3 shows average euphotic pH and chlorophyll values for all the stations. pH values in the littoral stations were higher than in the pelagic stations and followed the same trend as chlorophyll (Fig 3).

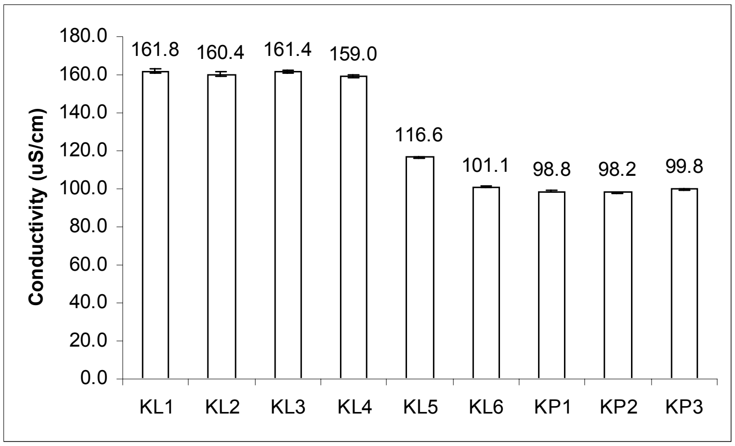


Figure 2. Average electrical conductivity (EC) in the littoral and pelagic stations

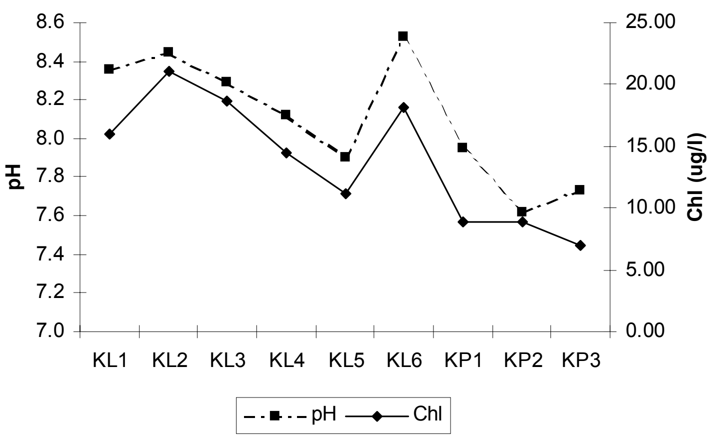
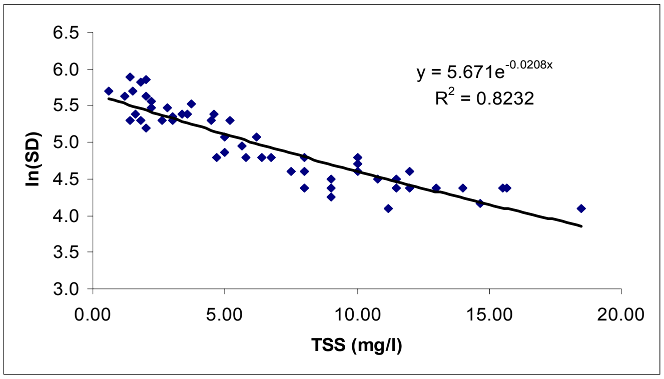


Figure 3 – Spatial variation of chlorophyll and pH in the lake

Water transparency (Secchi depth) was higher in the pelagic stations (2 - 3.5m) than in the littoral stations (0.4 – 1.6m) and varied exponentially with TSS and chlorophyll (Fig. 4 a and b). In the shallow littoral stations (<20m), dissolved oxygen was higher throughout the water column (>5mg/l) than in the deep pelagic stations, where it reduced with depth and was anoxic below 30m during stratification period (January-March and August-November) (Fig 5). Water temperature was higher in the gulf than in the pelagic stations, both for the whole column and for the mixed layer (Fig 6).

(a)



(b)

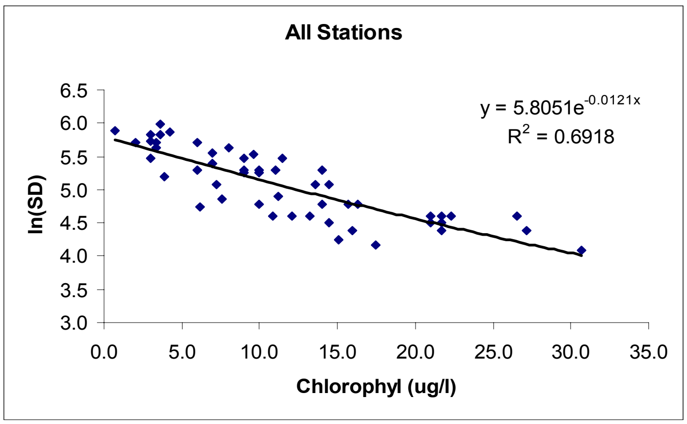


Figure 4 – Relationship between water transparency (Secchi depth) and TSS (a) and Chlorophyll (b) in the lake (all stations i.e. KL and KP)

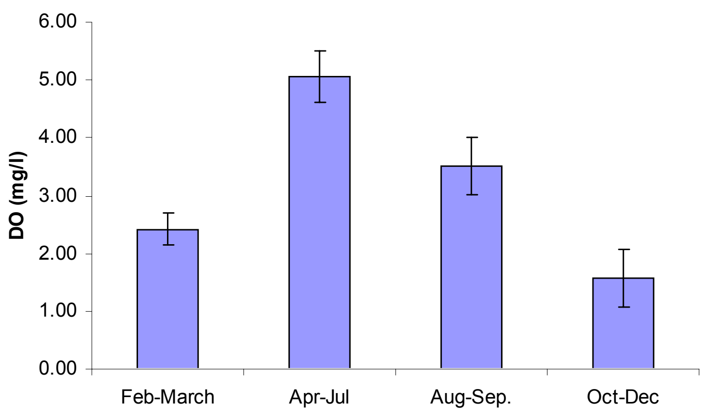


Figure 5 – Seasonal dissolved oxygen in the pelagic stations for depth >40m

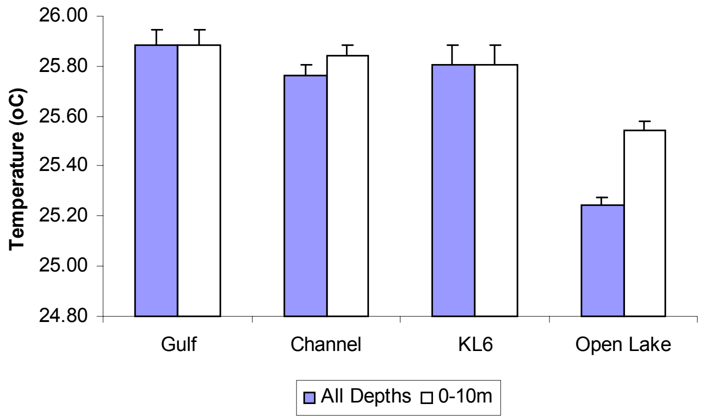


Figure 6 – Mean water temperature in the lake (Gulf, Rusinga Channel and main lake) for all depth and for 0-10m

Dissolved Nutrients

The main lake (including the littoral station KL6) had higher PO_4-P than in the gulf with KP1 having the highest average value of 56.5 µg PO_4-P/l and KL2 having the lowest value of 19.4 µg-PO_4-P/l. KP1 and KL2 also had the lowest and the highest average phytoplankton biomass respectively (Fig. 7). Spatial analysis of NO_3-N concentration revealed three zones with similar concentration; eastern gulf stations (KL1-3), the two stations along the Rusinga channel and the pelagic stations (KP1-3). KL4 and KL5 had relatively high NO_3-N concentrations (90.8 and 88.9 µg/l respectively) and KL3 had the lowest concentration (27.4 µg/l). SiO_2-Si average concentration decreased along the gulf from 4.51mg/l (KL2) to 1.28 mg/l (KL5) and the values in the main lake ranged between 0.6 mg/l (KP3) and 0.84 mg/l (KL6) (Fig. 7).

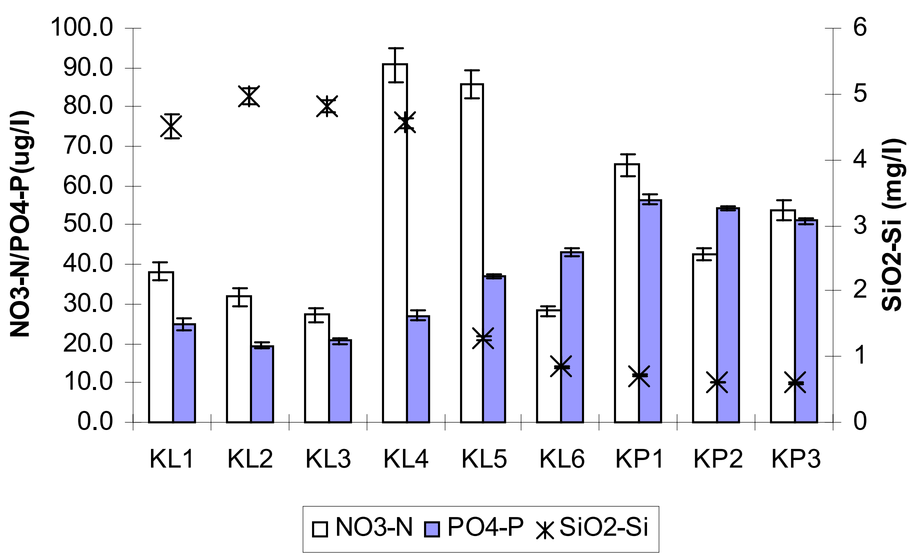


Figure 7 – Spatial variation of dissolved nutrients (PO_4-P, NO_3-N and SiO_2-Si) in the lake

Total, Total Dissolved and Particulate Nutrients

Total nitrogen and total phosphorus showed opposite spatial variation along the gulf into the main lake with TP being higher in the main lake than in the gulf, whereas TN was higher in the gulf than in the main lake (Figure 8). Particulate biogenic silica PBSi varied between 0.1 to 0.9 mg/l and showed no particular spatial variation between the littoral and pelagic stations. DOP ranged between 0.022 and 0.046 mg/l and was higher in the main lake than in the gulf but DON was higher in the gulf than in the main lake and had values ranging between 0.34 and 0.47 mg/l. The average TN:TP ratios ranged between 40 (KP2) and 80.8 (KL4) and were on average higher in the gulf than in the main lake (Fig 9). The values for all the gulf stations were within the zone where P can be limiting to algal growth (>50) whereas the main lake value were in the intermediate area where either P or N can be limiting (20 to 50).

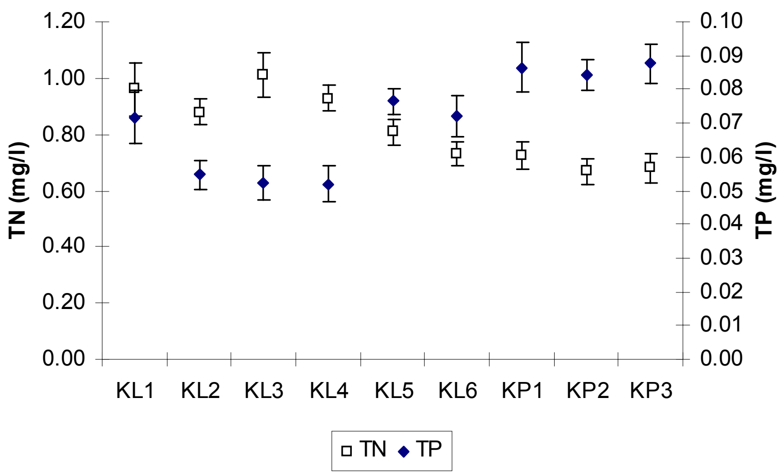


Figure 8 – Spatial variation of TN and TP

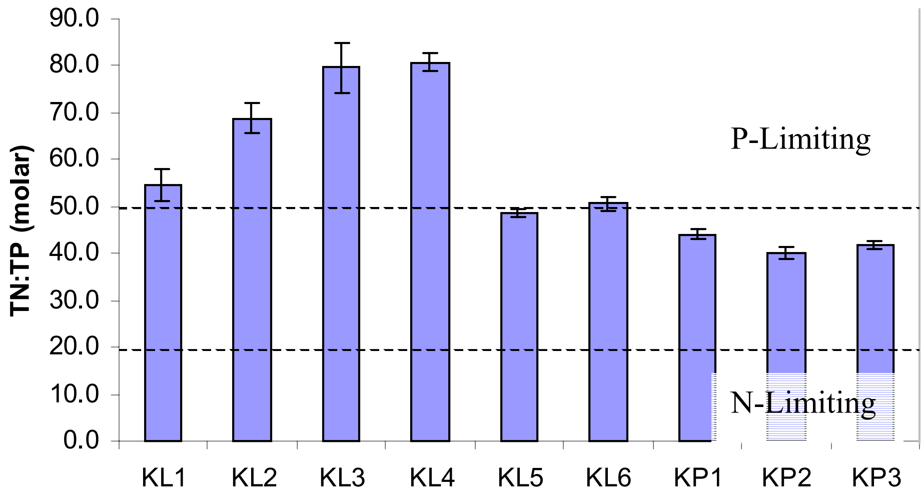


Figure 9 – TN:TP (molar) for the gulf . The ratios above which P can be limiting to the algal growth and below which N is limiting is indicated by the doted line Explain where the lines come from --reference

Phytoplankton biomass, abundance and productivity

Biomass

Phytoplankton biomass (chlorophyll) showed a reducing trend along the gulf into the main lake with the highest average value of 21.1µg/l (KL2) and lowest value of 6.9µg/l (KP3). KL6, a littoral station in the main lake, had an average value of 18.18 (Fig. 8). A comparison of 4 seasons, Jan-March (dry and long stratification); April-July (cool and mixing); August-September (short stratification) and November-December (short mixing) showed the maximum biomass in the gulf and the in the main lake to be that of August-October (29.6µg/l and 15.8µg/l respectively) but in KL6, the littoral station in the main lake, it was that of November-December (31.4 µg/l) (Fig 10). Chlorophyll showed a negative variation with PO_4-P and IN (inorganic nitrogen compounds), but varied randomly with SiO_2-Si (Fig 11 a, b and c).

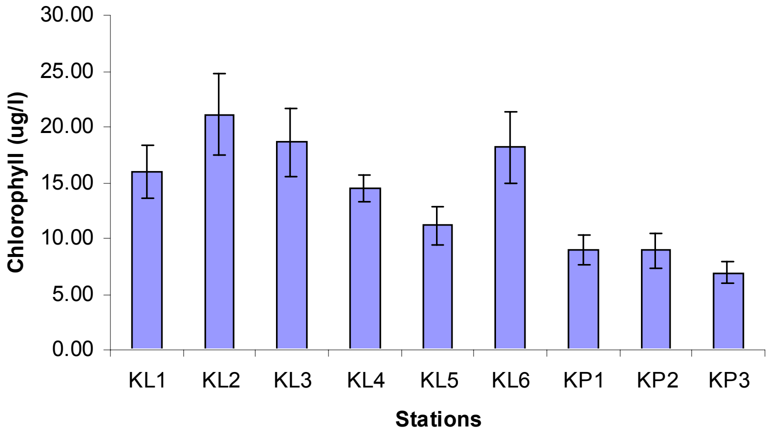


Figure 10 – Spatial variation of phytoplankton biomass (chlorophyll) in the lake

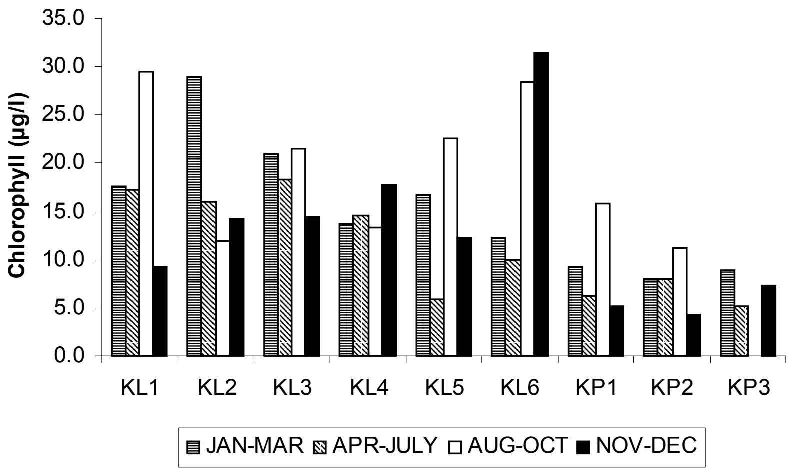
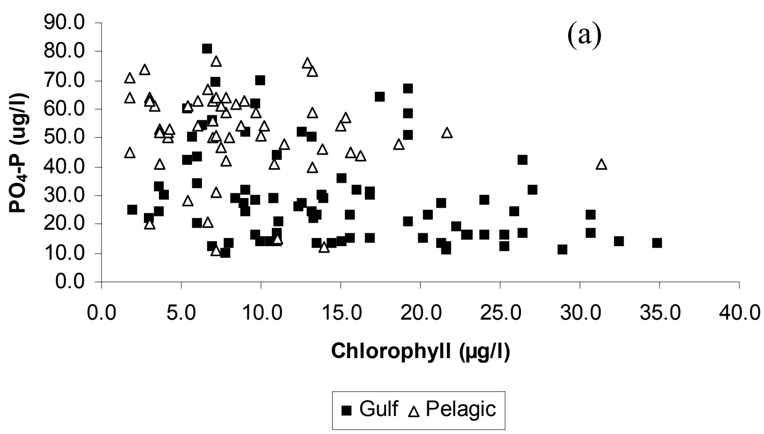
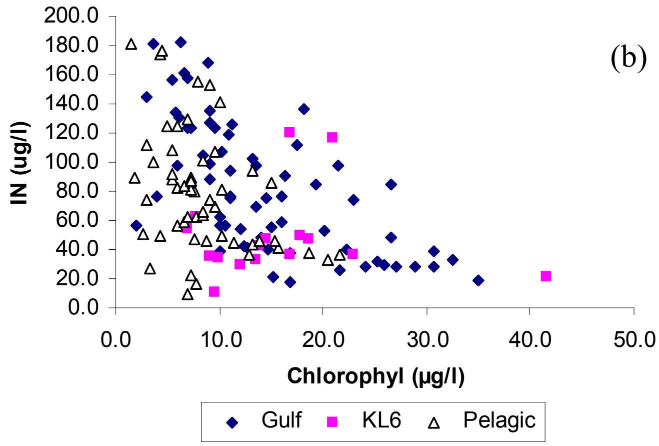


Figure 11 – Seasonal variation of phytoplankton biomass (chlorophyll) in the lake





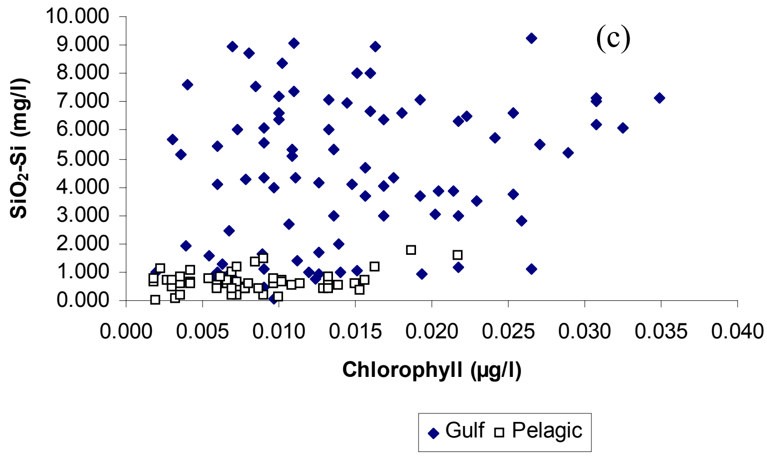


Figure 12 – Variation of phytoplankton biomass (chlorophyll) with (a) PO_4-P (b) NO_3-N and (c) SiO_2-Si

Phytoplankton biomass (estimated as chlorophyll) is photosynthetic and so produces oxygen and consumes carbon dioxide thus increasing pH in the illuminated upper water column but at greater depths beyond the depth of adequate light for photosynthesis algal biomass will consume oxygen and lower pH. So these parameters interact with light availability (time of day) over depth. In Figure 13, the depth profile of chlorophyll, DO and pH for KP2 (September 2003, 10:30am) is presented. Chlorophyll had a maximum value of 13.9µg/l at about 3m depth but decreased to 5.4 µg/l at 50m. pH increased with chlorophyll in the upper depth (0-5m) and DO decreased with depth from 5m depth (7.4 to 3.2 mg/l).

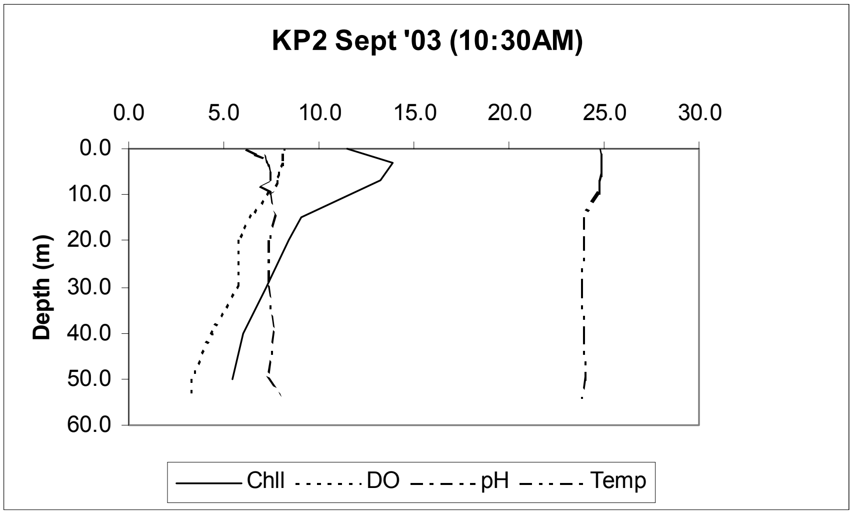


Figure 13 – Depth variation of chlorophyll, DO, temperature and pH in KP2 on September 2003, 10:30am

Species composition and abundance

In both littoral and pelagic areas, Cyanobacteria was the most abundant, contributing between 45 and 65% of the total phytoplankton abundance and diatoms contributed between 20 and 40% of total abundance, with the main lake having higher relative diatom abundance than the gulf (Fig 14 a and b). In Tables 1 and 2, the three most abundant species and the relative abundance for each station for November 2003 and March 2004 are presented. There was a difference between the two months indicating inter-seasonal variation in algal species composition and abundance. Phytoplankton abundance was higher in the gulf than in the main lake and followed a similar spatial pattern with phytoplankton biomass (chlorophyll) (Fig. 8).

Table 1 – Spatial variation of dominant phytoplankton species and their abundance for March 2004

Station	Species	Cells/ml	% of Total
KL1	Cylindriospermopsis africana	1025.8	23.4
	Chrooccocus sp.	567.5	12.9
	Cyclotella sp.	327.4	7.5
KL2	Cymbella sp.	763.9	25.9
	Pseudoanabeana sp.	261.9	8.9
	Chroococcus limnetica	240.1	8.1
KL3	Chrooccocus sp.	763.9	15.2
	Planktolyngbya contrata	567.5	11.3

	Cylindriospermopsis africana	392.9	7.8
KL4	Cylindriospermopsis africana	720.2	15.9
	Aphanocapsa rivularis	436.5	9.6
	Synedra cunningtonii	371.0	8.2
KL5	Nitzschia acicularis	349.2	13.8
	Synedra cunningtonii	349.2	13.8
	Closterium sp.	261.9	10.3
KL6	Chrooccocus sp.	763.9	18.3
	Cylindriospermopsis africana	480.2	11.5
	Synedra cunningtonii	436.5	10.5
KP1	Synedra cunningtonii	261.9	14.8
	Planktolyngbya tallingii	240.1	13.6
	Cyclotella sp.	152.8	8.6
KP2	Planktolyngbya circumcreta	196.4	12.0
	Planktolyngbya limnetica	174.6	10.7
	Closterium sp.	109.1	6.7
KP3	Nitzschia acicularis	240.1	22.9
	Planktolyngbya limnetica	218.3	20.8
	Synedra cunningtonii	131.0	12.5

Table 2 – Spatial variation of phytoplankton species composition and abundance for November 2003.

Station	Species	Cells/ml	% of Total
KL1	Merismopedia tennuissima	196	13.8
	Aphanocapsa sp	153	10.8
	Crucigenia tetrapedia	131	9.2
KL2	Aulacosira nyassensis	284	26.0
	Merismopedia tennuissima	196	18.0
	Planktolyngbya tallingii	109	10.0
KL3	Merismopedia tennuissima	196	16.7
	Pediastrum duplex	131	11.1
	Aulacosira nyanssensis	87	7.4
KL4	Microcystis aeruginosa	153	14.0
	Cymbella sp	131	12.0
	Nitzshia acicularis	109	10.0
KL5	Nitzschia acicularis	458	29.2
	Microcystis aeruginosa	153	9.7
	Merismopedia tennuissima	131	8.3
KL6	Nitzschia acicularis	1004	39.7
	Cylindrospermopsis africana	196	7.8
	Anabaena sporoides	153	6.0
KP1	Nitzshia acicularis	306	13.2
	Chroococcus sp	240	10.4

	Coelomoron pasillus	218	9.4
KP2	Anabaena sporoides	153	17.1
	Closterium kuzingii	131	14.6
	Cylindrospermpsis africana	131	14.6
KP3	Nitzschia acicularis	327	33.3
	Anabaena sporoides	131	13.3
	Cymbella sp	131	13.3

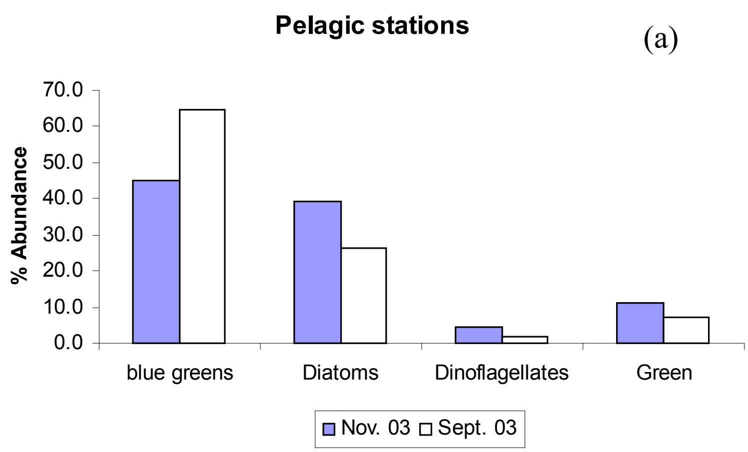


Table above is for November 03 and March 04 should this figure be the same?

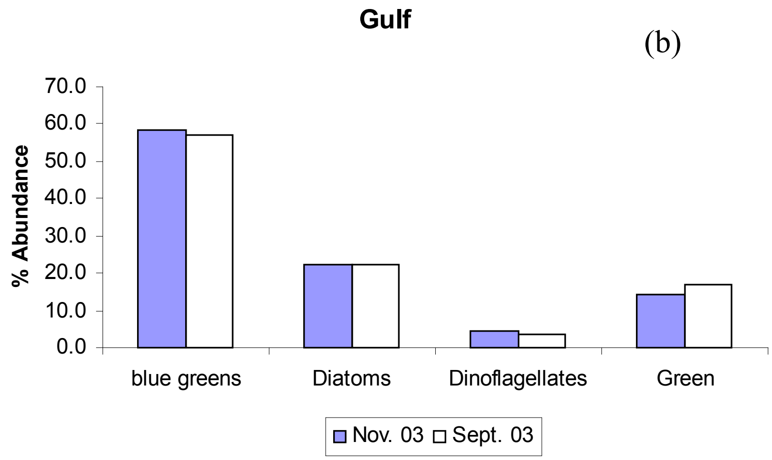


Figure 14 – Abundance of different phytoplankton groups in the (a) pelagic stations and (b) gulf stations

Productivity

Primary productivity rate measured as phytoplankton photosynthesis in the lake ranged between 0.56 and 1.94gC/m^3/day and showed seasonal variation within and between stations (Fig. 15).

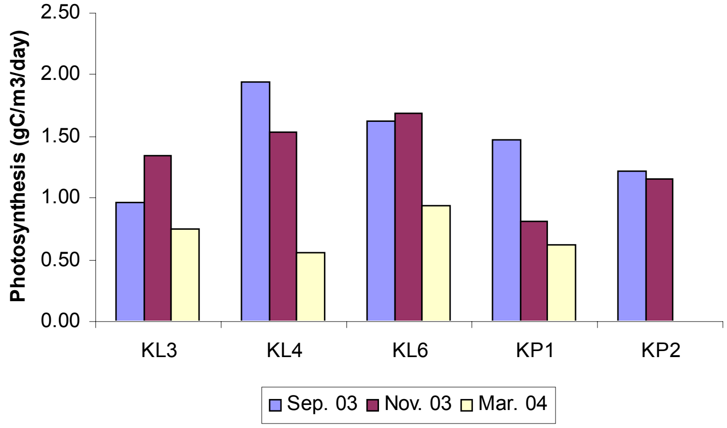
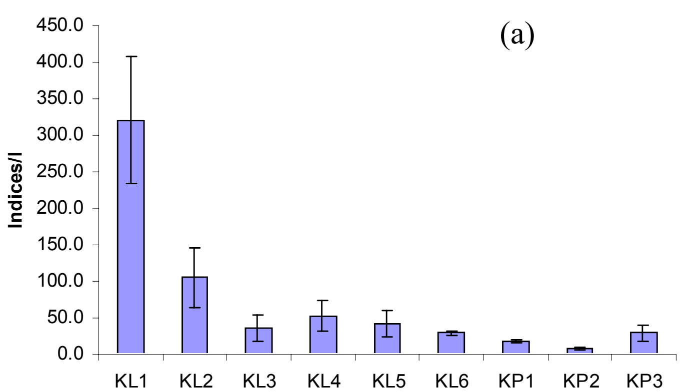


Figure 15 – Phytoplankton photosynthesis in littoral and pelagic stations during September 2003, November 2003 and Mach 2004 Is this based on optimal rate of photosynthesis OR a mean rate over euphotic depth; integral photosynthesis might give a different picture with more transparent stations supporting photosynthesis over a greater depth.

Zooplankton

The littoral stations such as KL1 and KL2 recorded higher zooplankton densities compared with other stations. This observation was made within and between months. There were spatial and temporal variation in abundance, distribution and diversity. Taking into consideration the mean densities for each station over the sampling period, KL1 recorded the highest density of 320.6±86.6 ind./l (Fig. 16a). Densities decreased progressively towards the main lake with the deepest station KP2 (57m) recording the lowest mean density (7.3±2.0 ind./l). Were these results based on tow over the depth of the station. Integral zooplankton i.e. numbers per square meter might look more similar among the stations



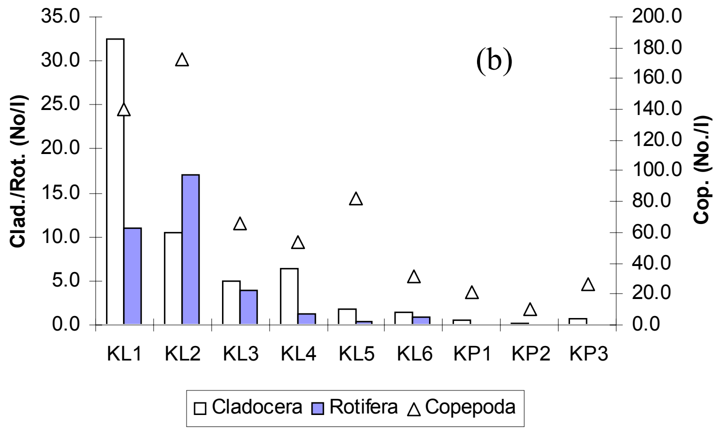


Figure 16 – Spatial variation of zooplankton abundance in the lake (a) all the groups (b) different groups

Copepoda dominated the zooplankton community in all the stations with percentages ranging from 73-97.5%. Their densities also followed the trend shown by the total zooplankton densities (general decrease from the littoral to the pelagic waters). Cyclopoida occurred in higher proportions compared to Calanoida, although relatively higher proportions of the latter were recorded at deeper pelagic stations e.g. in the month of August 2001 (KP1 27.04%, KP2 42.79% KP3, 28.51%).

Cladocera were identified to species levels with seven species recorded. Their densities decreased generally towards the open lake (Fig. 16b). While KL1 recorded the highest cladoceran mean density (32.5±16.6 ind.l^{-1}), the main lake stations recorded very low densities. *Moina micrura*, *Bosmina longirostris*, *Ceriodaphnia cornuta, Diaphanosoma exiscum* had a wide distribution throughout the lake. KP1, KP2 and KP3 were dominated by *Daphnia longispina.*

Rotifers were the most diverse group. Twenty-four species were identified. Their densities decreased progressively from KL1 to KP2. Rotifers occurred in very low densities in March and April.

Results for samples taken at various depths indicate that zooplankters usually occupy the lower water column during the day light period. The copepod nauplii however tend to occupy the uppermost waters during the day. Different zooplankters migrate through the water column at different rates and are therefore found at different depths at different time of the day. *Thermocyclops neglectus* was the most dominant copepod and zooplankter though its density varied in time and space. Other cyclopoid copepods were *T.emini*, *T.incisus, Tropocyclops confinnis; T.tenellus and Mesocyclops* spp. Calanoid copepods were represented by two species i.e.*Thermodiaptomus galeboides* and *Tropodiaptomus stuhlmani*. The former being dominant offshore while the latter inshore.

DISCUSSION

The difference in physico-chemical environment between the littoral and pelagic (deep offshore) stations can be attributed to a number of factors including, depth of mixing as well as availability of nutrients and light; surface inflows from the lake catchment with transported sediment, nutrients and other pollution loading and mode and extent of exchange between the two lake zones (Gikuma-Njuru & Hecky 2005). The difference between the Nyanza Gulf and the main Lake environments has been attributed to the oxygenation of the waters, influence of rivers and surface runoff input into the gulf (Gikuma-Njuru and Hecky 2005) and the limited exchange of the gulf with the main lake (Calamari et al 1995).

The shallow depth in the gulf (Fig. 1) allows for wind induced mixing and hence keeping the gulf well oxygenated throughout the year as opposed to the deeper pelagic stations which mix to the bottom only seasonally due to seasonal stratification (Gikuma-Njuru and Hecky 2005). High redox potential, associated with oxygenated conditions, keep PO_4–P firmly bond to bottom sediments and hence reducing its availability in the water column, which can explain the lower PO_4-P concentration in the gulf compared to the main lake (Fig. 7) despite high pollution input through riverine inflows and surface runoff (Lung'aiya et al 2001; Gikuma-Njuru & Hecky 2005). Higher PO_4 –P and to a lesser extent NO_3 –N in the main lake compared to the gulf can also be attributed to low nutrient demand by phytoplankton, whose growth in the main Lake Victoria has been found to be limited by light availability (Mugidde 1993; Guildford et al 2003; Mugidde et al 2003). The deep mixing depth (up to 30m) in the main lake causes algal cells to spend more time in darkness and therefore imposing light limitation to algal growth (Guildford & Hecky 2000; Mugidde et al 2003). In the gulf, where productivity is high, light limitation of algal growth maybe as a result of self shading (Gikuma-Njuru & Hecky 2005) or due to inorganic sediment from the high riverine input and re-suspension of bottom sediments in the shallow gulf. The apparent negative correlation between PO_4–P and Chlorophyll (Fig 12a) may be as a result of high demand for PO_4-P by phytoplankton in the less light limited and high productive littoral stations (Guildford et al 2000).

One of the drastic changes that have taken place in the past 4 decades in the Lake Victoria is the depletion of DRSi concentration in the water column, which is reported to have reduced 10-fold from that reported by Talling (1966) (Hecky 1993). The DRSi concentrations in the main lake are below those reported by Talling (1966) but in the gulf they are within the Talling range 4.0 – 4.5mg/l (Fig 7; Table 4). Riverine input into the gulf and less demand for Si, due to low diatom assemblage in the gulf, can in part account for these higher levels of DRSi in the gulf compared to the main lake, where diatoms are more (Lung'aiya et al 2000).

Talling (1966) reported phytoplankton biomass (chlorophyll) values of 1.2-5.5µg/l in the pelagic waters which is less than the values measured during the present study (Fig 8) in the pelagic stations, confirming the reported changes in phytoplankton biomass in the past four decades (Kling et al 2001; Hecky 1993). The dominance of Cyanobecteria in lake, during the present study, is consistent with observations made by other scientists (e.g. Ochumba and Kibaara 1989; Lung'aiya et al 2000) and in line with the reported changes of phytoplankton assemblage from diatom dominated to blue green dominated population (Hecky 1993; Lehman & Branstrator 1993; Kling et al 2001). The dominance of Cyanobacteria in the lake present water quality challenges as this algal group is bloom forming and has species which are known to produce phycotoxins, which can both cause fish kills and compromise drinking water quality (Hummert et al, 2001; Kling et al 2001; Krienitz et al, 2001). The occurrence, in mid 2004, of a large algal bloom in Kisumu Bay, which lead to the closure of the Prisons Department water treatment works for a number of days, is a good example of negative impact of algal blooms on water quality. Although this occurrence was thought to be as a result of reduced lake levels, due to long dry spell at the time, continued nutrient enrichment of the lake will probably increase the frequency and severity of such occurrences especially in the littoral hotspot areas (LVEMP 2002).

The ratio between N and P can be used to indicate the phytoplankton nutrient status in a water body. After analyzing nutrient data from both fresh and marine sources, Guildford and Hecky (2000) found out that in cases where TN:TP ratio was <20 phytoplankton was consistently nitrogen limited and in cases where the ratio was >50 phytoplankton was consistently phosphorus limited. The N:P ratio in the lake (Fig 9) shows that the Nyanza Gulf is consistently phosphorus limited whereas the main lake can be either nitrogen or phosphorus depending on the prevailing physico-chemical and nutrient status. Under nitrogen limited conditions, phytoplankton species with the ability to fix inorganic dinitrogen from the atmosphere, normally has an advantage over the other species and therefore dominate (Guildford et al 2003; Mugidde et al 2003). Measurement of N-fixation rates in the northern part of Lake Victoria has shown the N-fixation rate in the pelagic waters varies seasonally with high rates recorded during the stratified season and at shallow stations, when mixing depth is shallow (Mugidde et al 2003). Lung'aiya et al (2000) reported dominance of *Microcystis*, a non N-fixing algal species, in the Nyanza Gulf, which agrees with the predictions from the N:P values in this study. Since the gulf as a whole is P limited, continued P input to this semi-closed part of the lake will result in increased algal blooms and increased eutrophication and therefore negatively affecting the water quality. Dominance of N-fixing heterocystous blue green algal species has already been reported for some near shore areas with high pollution input (Krienitz 2002). Therefore necessary steps should be taken to reduce phosphorus input into the gulf and other inshore areas.

Using the OECD boundary values (Table 3), the main lake can be categorized as eutrophic as per chlorophyll and Secchi depth transparency values, whereas the mean TP concentration in the main lake and in the gulf puts the two lake zones in the hypereutrophic category. The gulf can be considered hypereutrophic considering the Secchi depth transparency values. The high TP in the main lake can be associated to low phosphorus demand due to light limitation whereas the low transparency in the gulf can mainly be as a result of both inorganic suspended sediments from inflowing rivers and the elevated phytoplankton biomass. Light can also restrict the full utilization of available nutrients with the Gulf (Njuru-Gikuma and Hecky 2005).

Table 3. OECD boundary values for fixed trophic classification system (extracted from Mason (1997))

Trophic Category	*TP*	*mean Chl*	*max Chl*	*mean Secchi*	*minimum Secchi*
Ultraoligotrophic	<4.0	<1.0	<2.5	>12.0	>6
Oligotrophic	<10.0	<2.5	<8.0	>6.0	>3.0
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

Explanation of terms:
TP = mean in-lake total phosphorus concentration (ug/l);
mean Chl = mean annual chlorophyll a concentration in surface waters (ug/l);
maximum Chl = peak annual chlorophyll a concentration in surface waters;
mean secchi = mean annual Secchi depth transparency (m)

Phytoplankton biomass can be controlled not only by nutrient and light availability but by zooplankton grazing (Lehman & Branstrator 1993; Guildford et al 2003) and it is possible that the lower phytoplankton biomass in KL1 compared to other eastern gulf stations (KL2 and KL3) may be as a result of zooplankton grazing since the station had the highest zooplankton abundance (Fig 16a & b). Zooplankton plays an important role in nutrient recycling in the lake water column and in some lakes they control the availability of dissolved nutrients through secretion (Carpenter et al., 1985). Zooplankton as secondary producers are important agents in transferring energy to the higher levels of the food web as they are important food source for fish (Cooke et al 1986). The high fish biomass in the gulf compared to the main lake (Personal observation during trawling) may be associated with higher algal and zooplankton biomass in the gulf compared to the main lake (Akiyama et al 1977). However low water transparency in the gulf can reduce the ability of the fish to catch the prey and hence affect fish abundance (Balirwa et al 2005). Poor visibility can also make the fish more susceptible to gill netting.

CONCLUSIONS AND RECOMMENDATIONS

The Kenyan part of Lake Victoria consists of two zones, the Nyanza Gulf and the main lake, with different physico-chemical and water quality characteristics.

- Although the main lake has higher SRP concentration than the Nyanza Gulf, the gulf has higher plankton biomass than the pelagic zone, which maybe as a result of light limitation of algal growth in deeper pelagic areas due to deeper mixing depth.
- Increased phosphorus input into the gulf will lead to N-limited phytoplankton growth resulting in dominance of bloom forming heterocystous N-fixing blue green algal species and therefore compromising water quality
- Management of phosphorus loading into the Nyanza Gulf and other inshore areas should be given a priority in order to stem further deterioration of water quality and restore aquatic environment health
- Studies should be conducted on the rates of nitrogen fixation in the Kenyan waters and its importance on nutrient balance. The influence of sediments on the availability of phosphorus in the water column and especially in gulf should be studied and quantified.

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CHAPTER 10

Eutrophication of Lake Victoria, Kenya: *lessons for Water quality management*

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INTRODUCTION

During the last 4 decades, the East African Lake Victoria has undergone major water quality and biological changes, which have threatened the long-term sustainable utilization of lake resources and have attracted local and international attention (World Bank, 1996).

The introduction in the 1950s and early 1960s of the exotic Nile Perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) has lead to a dramatic loss of the native cichlid species (Witte et al 1992). The phytoplankton species composition in the lake has changed from one dominated by large diatoms, mainly *Melosira* and *Stephanodiscus* (Talling 1966) to that presently dominated by cyanobacteria (blue green algae) (Ochumaba and Kibaara 1989; Mugidde 1993; Lung'aiya et al 2000; Kling et al 2001) and primary productivity and chlorophyll have increased 2-fold and 8 to 10-fold respectively (Mugidde 1992, 1993). Other reported changes to the lake are decline in the euphotic zone SRSi, more thermally stable water column, leading to more regularly anoxic deep waters and an increase in SRP in the water column (Hecky 1993; Lehman & Branstrator 1993).

The bulk of limnological studies on Lake Victoria has been done in the northern part of the lake (Ugandan waters), from UFFRO (FIRRI) research center where European and other local and international scientists were based from the early colonial days (Worthington 1930) and it is only in the mid-1980s that the Kenyan waters (to the northeast of the lake) started receiving scientific attention possibly due to the visible water quality changes caused by increased algal blooms (Ochumba & Kibaara 1989) and massive fish kills (Ochumba 1990). A group of national scientists under the Kenya Academy of Sciences, undertook an extensive limnological sampling of the Kenyan waters in 1985 (Lake Victoria, Kenya baseline survey; unpublished report) and since then several researchers have reported on the phytoplankton, zooplankton, nutrients, physical limnology, food web structure and pollution of the Kenyan Lake Victoria (Ochumba & Kibaara 1989; Mavuti & Litterick 1991; Calamari et al 1995; Ochumba 1996; Lung'aiya et al 2000; Lung'aiya & Sitoki 2001; Campbell et al 2003[1], 2003[2] and Gikuma-Njuru & Hecky 2005).

In the past five years, scientists from the three east African countries of Kenya, Tanzania and Uganda have been undertaking extensive lake-wide water quality studies in order to establish the current water quality status, identify and quantify limnological changes and predict possible future water quality changes in relation to the human activities in the catchment. These studies aimed at enhancing sustainable management and exploitation of Lake Victoria resources for economic well-being of the riparian communities.

This paper reports on the major limnological and water quality findings in Lake Victoria, Kenya and offers suggestions on sustainable management of lake water quality.

MATERIALS AND METHODS

Study Area

The Kenyan waters of Lake Victoria lie around the equator between 0^0 13' N/0^0 55'S and 33^0 56'E/ 34^0 45'E at an altitude of 1134 m asl and cover an area of 3600 Km^2 (approximately 6% of the whole lake) of which 1400 Km^2 comprises the Nyanza Gulf (Fig 1). It has a catchment area of 49000 Km^2, which is drained by 5 major rivers (Nzoia, Yala, Nyando, Sondu, and Kuja) through which it contributes approximately 30% of total riverine inflow into Lake Victoria (LVEMP 2002). The catchment falls in some of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centers including Kisumu (approx. 0.5m population). Increased agricultural and municipal input into the lake has continued to endanger the environmental health of the lake and continue to raise concern (Chege, 1995).

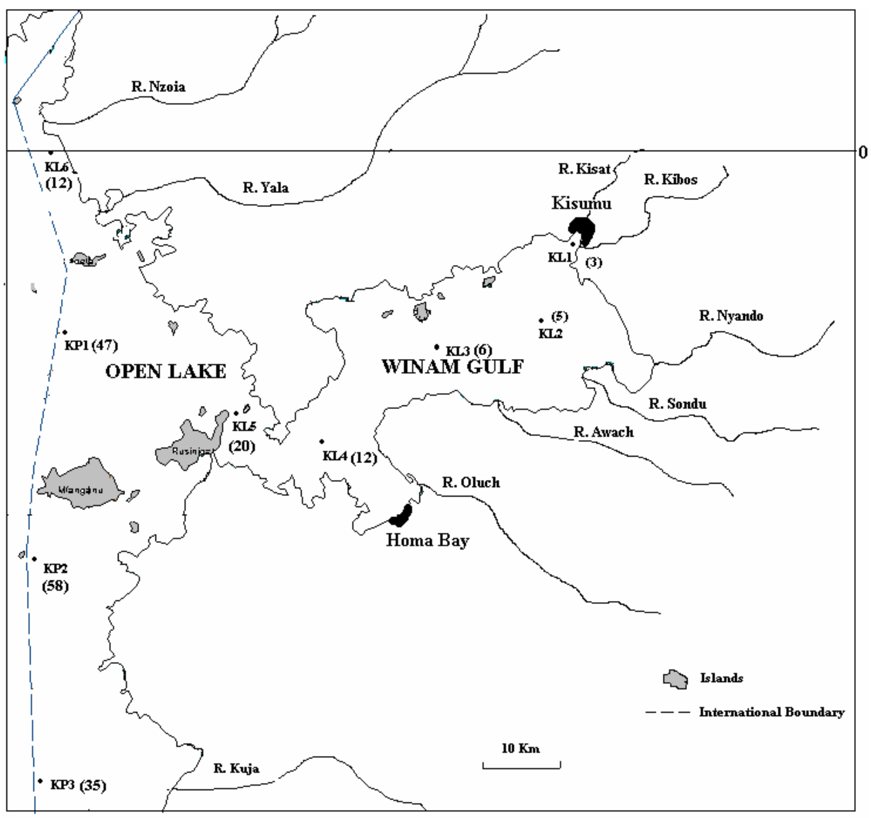


Figure 1 – Lake Victoria, Kenya showing sampling stations, KL1-6 (littoral) and KP1-3 (pelagic). Values in parenthesis beside the stations are station depth (m)

Between December 2000 and March 2005, 9 in-lake stations (6 inshore and 3 offshore) were sampled a total of 15 times, for the analysis of nutrients (orthophosphate (PO_4-P), total phosphorus (TP), dissolved organic phosphorus

(DOP), nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_3-N), total nitrogen (TN), dissolved organic nitrogen (DON), dissolved reactive silica (SiO_2-Si), particulate biogenic silica (PBSi) and total particulate carbon (TPC)), algal biomass and species composition, zooplankton abundance and species composition, and TSS. In-situ measurements of pH, temperature, conductivity, dissolved oxygen, turbidity and transparency (secchi depth) were done at each station and primary productivity assays were also carried out.

Sampling stations were selected to fall within the lake-wide transects established by the three countries of Kenya, Tanzania and Uganda, and were categorized according to depth and distance from the shore as littoral (<20m deep and <5km from the shore) and pelagic (>20m deep and > 5km from the shore) (Fig 1). Five littoral stations were within the Nyanza Gulf (KL1-5) and one was in the northeastern part of the main lake (KL6) and the three pelagic stations were all in the main lake (KP1 – KP3) (Fig 1).

Field sampling and laboratory analysis

Water samples were collected at different depths; at the surface, Secchi depth, photic depth, mid and 1m above bottom, using a 2-l Van Dorn sampler and immediately filtered on board through 0.45μm GFF filter paper for analysis of chlorophyll and TSS in the residue and dissolved nutrients in the filtrate. Water samples for analysis of phytoplankton species composition and zooplankton abundance were immediately preserved using Lugol's iodine and formalin, respectively. Primary productivity assays were incubated at different depths in light and dark bottles and the oxygen concentration was analysed using the Winkler titration method. Samples were kept under ice during transportation to the Kisumu, Ministry of Water and Irrigation, laboratory where analysis was immediately done.

In the laboratory, samples were analysed using specrophotometric methods as outlined in APHA (1995). Soluble reactive phosphate (PO_4-P) was analysed using the ascorbic acid method, nitrate-nitrogen (NO_3-N) using cadmium reduction and diazoic complex method and silica (SiO_2-Si) using heteropoly blue method. For the analysis of particulate biogenic silica (PBSi), an appropriate sample volume was filtered through 0.2μm membrane filter and the contents digested using wet alkaline method (2ml of 0.5M NaOH added and heated in oven for 15 minutes at 85^{o}C) to release the bound silica, which was then analysed as silica (SiO_2-Si). Samples for the analysis of total and total dissolved (filtered through 0.45μm GFF filter) nutrients were digested and analysed as outlined in APHA (1995). TP and DOP were analysed as PO_4-P whereas TN and DON was analysed as NO_3-N.

TSS samples (pre-weighed filter paper and residue) were dried in an oven for 24 hours at 105^{o}C and after weighing, the samples were combusted in a furnace for

30 minutes at 550°C to get loss on ignition (LOI) weight, which was multiplied by 0.4 (the estimated dry weight ratio of carbon in algae) to get total particulate carbon (TPC) content. Algal biomass (chlorophyll) was extracted from the filter residues using 90% ethanol and analysed spectrophotometrically according to the Witzel and Likens (1991) method.

In-situ measurements of pH, temperature, conductivity, turbidity and DO were carried out using a Hydrolab Surveyor 4a multi-probe with a depth sensor.

RESULTS

Physico-chemical Status

There were differences in physico-chemical parameters between the gulf and the main lake. Conductivity was higher in the gulf than in the main lake, showing a decreasing trend from 161.8µS/cm (KL1) to 98.2µS/cm (KP2) (Fig. 2). KL6 within the lake proper had an average value of 101.1µS/cm which was considerably lower than other littoral stations. Figure 3 shows average euphotic pH and chlorophyll values for all the stations. pH values in the littoral stations were higher than in the pelagic stations and followed the same trend as chlorophyll (Fig 3).

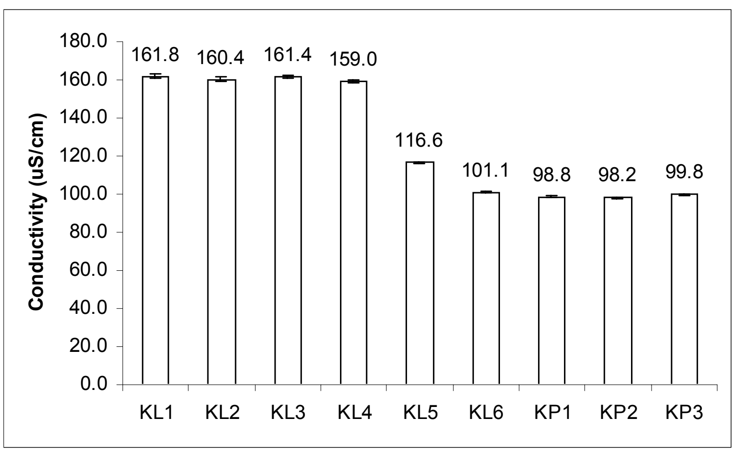


Figure 2. Average electrical conductivity (EC) in the littoral and pelagic stations

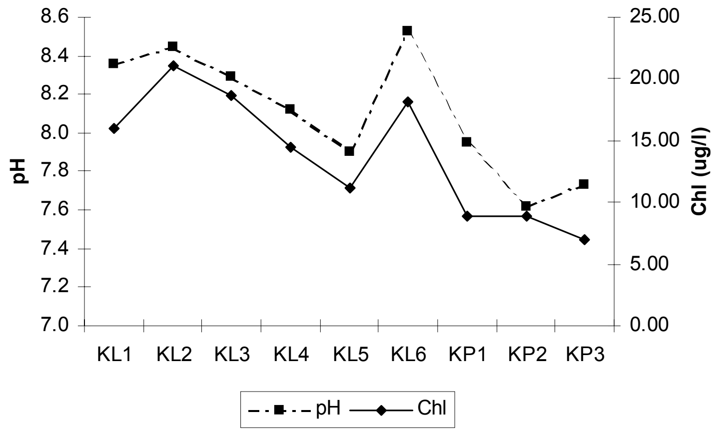
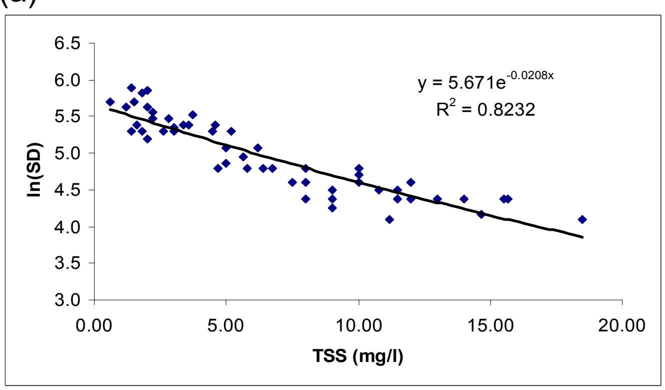


Figure 3 – Spatial variation of chlorophyll and pH in the lake

Water transparency (Secchi depth) was higher in the pelagic stations (2 - 3.5m) than in the littoral stations (0.4 – 1.6m) and varied exponentially with TSS and chlorophyll (Fig. 4 a and b). In the shallow littoral stations (<20m), dissolved oxygen was higher throughout the water column (>5mg/l) than in the deep pelagic stations, where it reduced with depth and was anoxic below 30m during stratification period (January-March and August-November) (Fig 5). Water temperature was higher in the gulf than in the pelagic stations, both for the whole column and for the mixed layer (Fig 6).

(a)



(b)

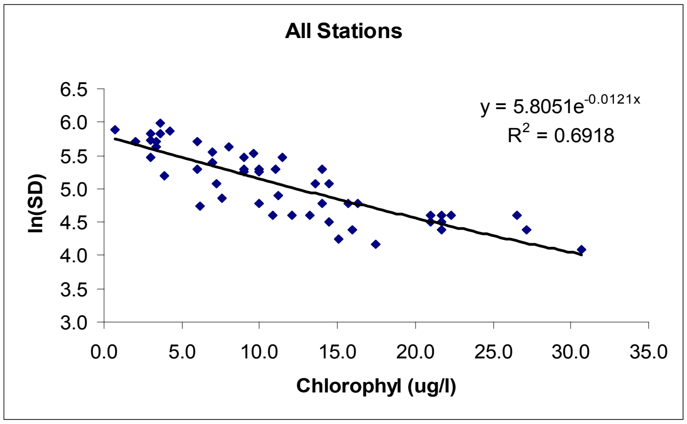


Figure 4 – Relationship between water transparency (Secchi depth) and TSS (a) and Chlorophyll (b) in the lake (all stations i.e. KL and KP)

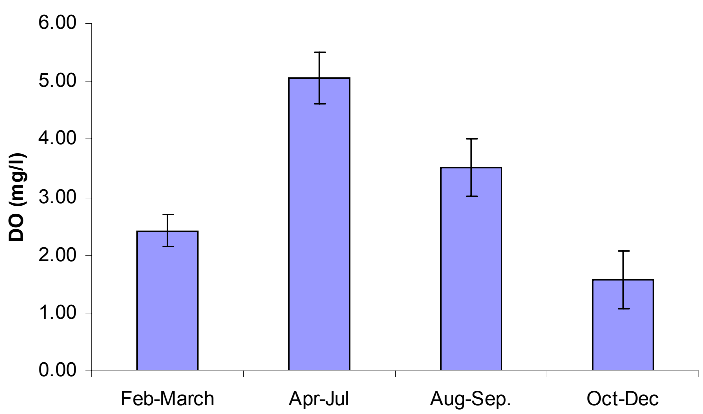


Figure 5 – Seasonal dissolved oxygen in the pelagic stations for depth >40m

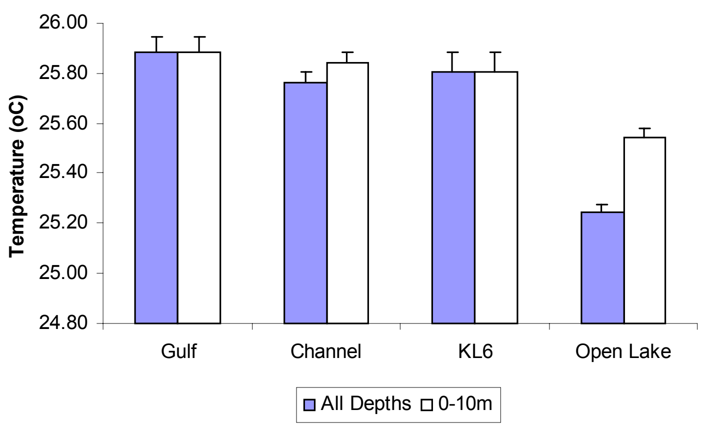


Figure 6 – Mean water temperature in the lake (Gulf, Rusinga Channel and main lake) for all depth and for 0-10m

Dissolved Nutrients

The main lake (including the littoral station KL6) had higher PO_4-P than in the gulf with KP1 having the highest average value of 56.5 µg PO_4-P/l and KL2 having the lowest value of 19.4 µg-PO_4-P/l. KP1 and KL2 also had the lowest and the highest average phytoplankton biomass respectively (Fig. 7). Spatial analysis of NO_3-N concentration revealed three zones with similar concentration; eastern gulf stations (KL1-3), the two stations along the Rusinga channel and the pelagic stations (KP1-3). KL4 and KL5 had relatively high NO_3-N concentrations (90.8 and 88.9 µg/l respectively) and KL3 had the lowest concentration (27.4 µg/l). SiO_2-Si average concentration decreased along the gulf from 4.51mg/l (KL2) to 1.28 mg/l (KL5) and the values in the main lake ranged between 0.6 mg/l (KP3) and 0.84 mg/l (KL6) (Fig. 7).

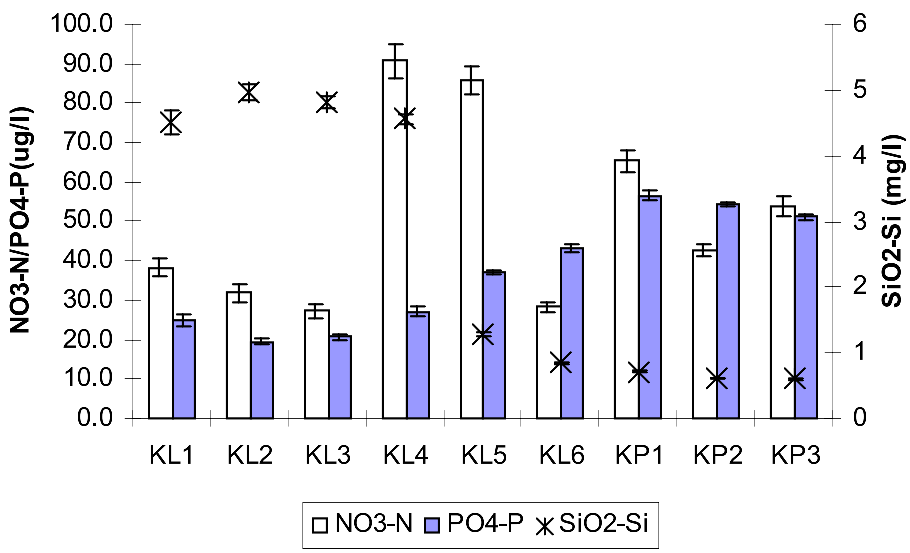


Figure 7 – Spatial variation of dissolved nutrients (PO_4-P, NO_3-N and SiO_2-Si) in the lake

Total, Total Dissolved and Particulate Nutrients

Total nitrogen and total phosphorus showed opposite spatial variation along the gulf into the main lake with TP being higher in the main lake than in the gulf, whereas TN was higher in the gulf than in the main lake (Figure 8). Particulate biogenic silica PBSi varied between 0.1 to 0.9 mg/l and showed no particular spatial variation between the littoral and pelagic stations. DOP ranged between 0.022 and 0.046 mg/l and was higher in the main lake than in the gulf but DON was higher in the gulf than in the main lake and had values ranging between 0.34 and 0.47 mg/l. The average TN:TP ratios ranged between 40 (KP2) and 80.8 (KL4) and were on average higher in the gulf than in the main lake (Fig 9). The values for all the gulf stations were within the zone where P can be limiting to algal growth (>50) whereas the main lake value were in the intermediate area where either P or N can be limiting (20 to 50).

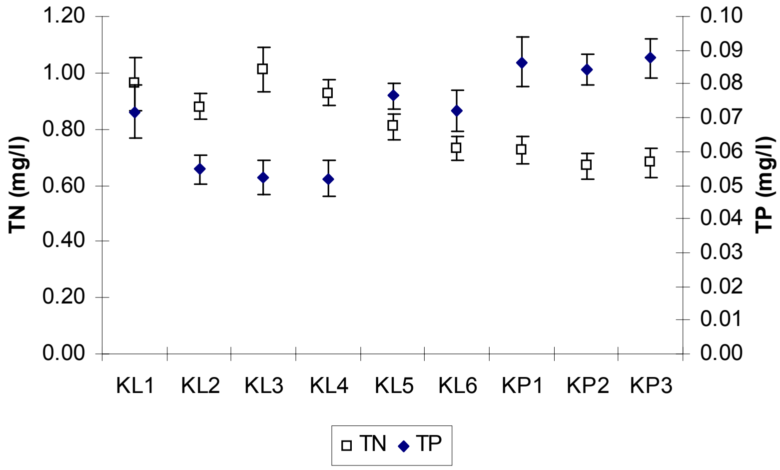


Figure 8 – Spatial variation of TN and TP

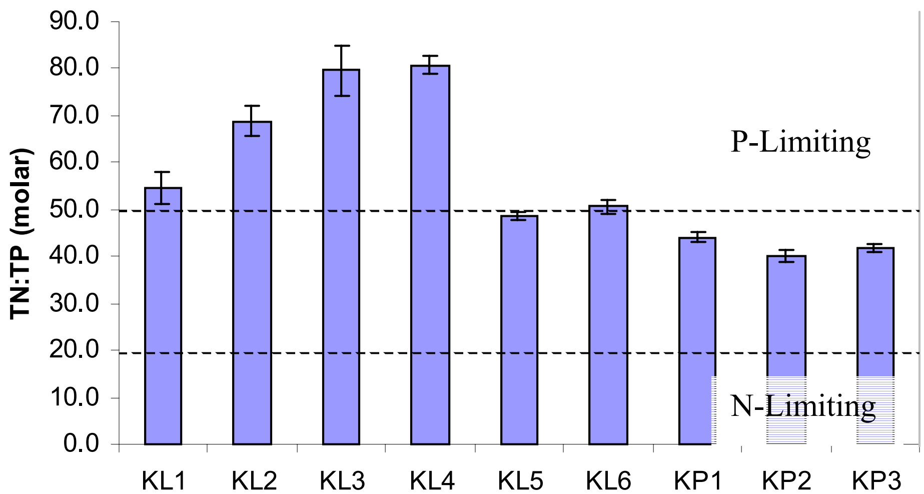


Figure 9 – TN:TP (molar) for the gulf . The ratios above which P can be limiting to the algal growth and below which N is limiting is indicated by the doted line Explain where the lines come from --reference

Phytoplankton biomass, abundance and productivity

Biomass

Phytoplankton biomass (chlorophyll) showed a reducing trend along the gulf into the main lake with the highest average value of 21.1µg/l (KL2) and lowest value of 6.9µg/l (KP3). KL6, a littoral station in the main lake, had an average value of 18.18 (Fig. 8). A comparison of 4 seasons, Jan-March (dry and long stratification); April-July (cool and mixing); August-September (short stratification) and November-December (short mixing) showed the maximum biomass in the gulf and the in the main lake to be that of August-October (29.6µg/l and 15.8µg/l respectively) but in KL6, the littoral station in the main lake, it was that of November-December (31.4 μg/l) (Fig 10). Chlorophyll showed a negative variation with PO_4-P and IN (inorganic nitrogen compounds), but varied randomly with SiO_2-Si (Fig 11 a, b and c).

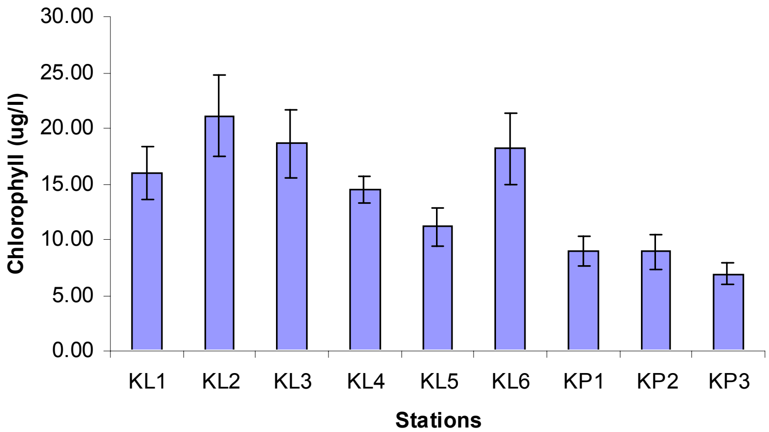


Figure 10 – Spatial variation of phytoplankton biomass (chlorophyll) in the lake

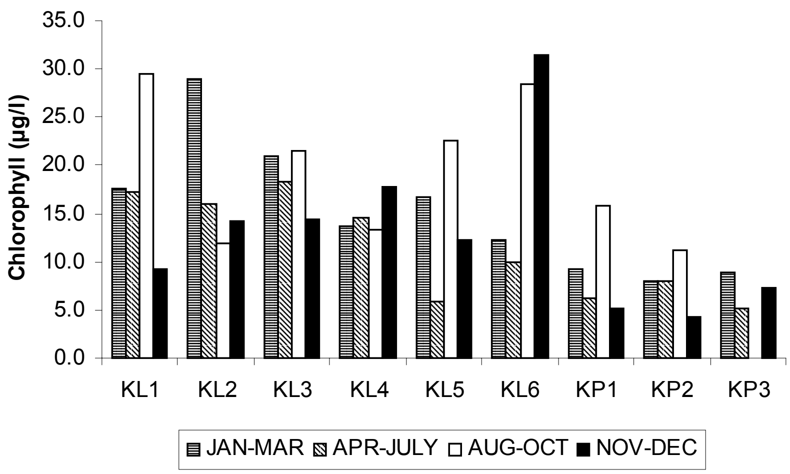


Figure 11 – Seasonal variation of phytoplankton biomass (chlorophyll) in the lake

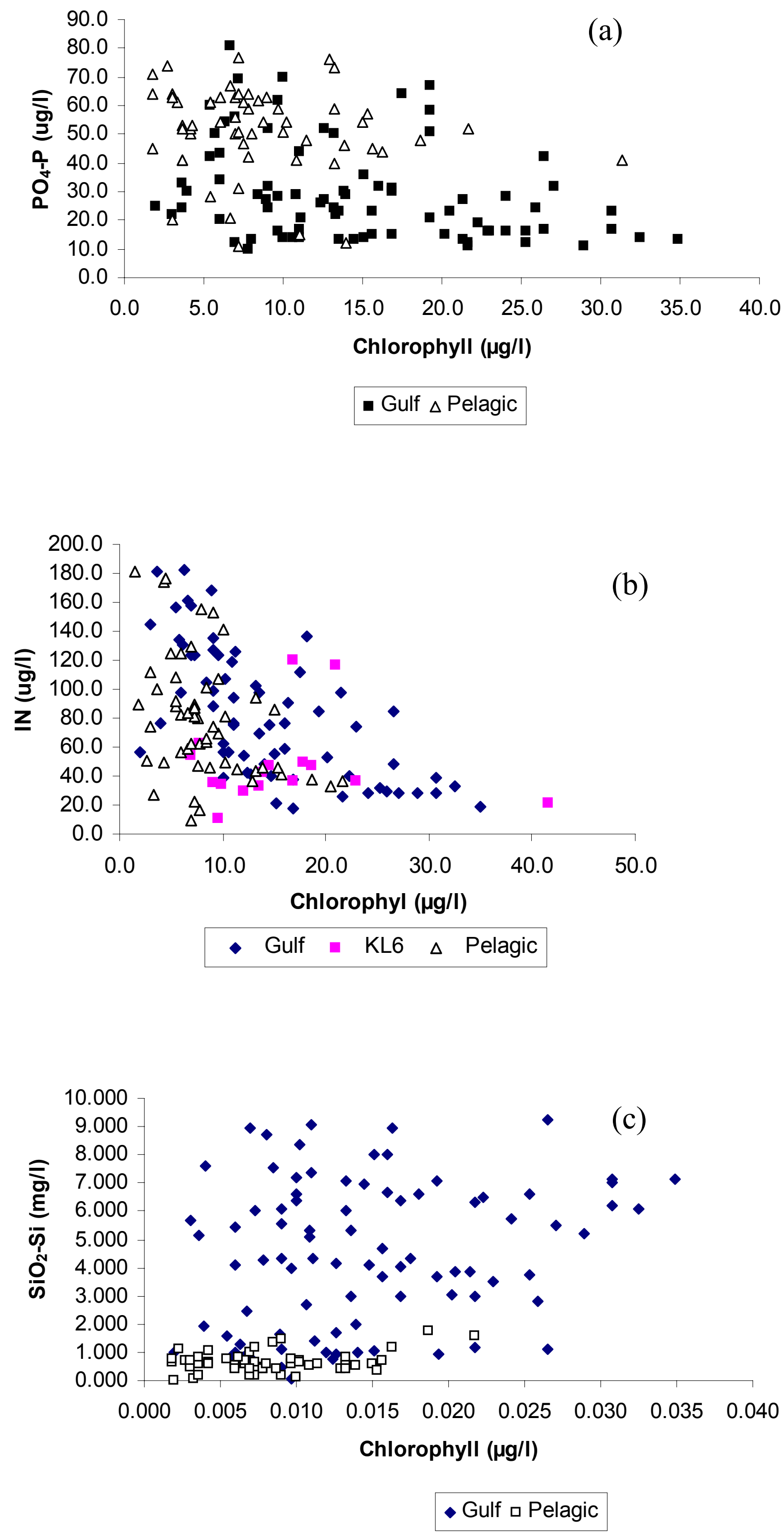


Figure 12 – Variation of phytoplankton biomass (chlorophyll) with (a) PO_4-P (b) NO_3-N and (c) SiO_2-Si

Phytoplankton biomass (estimated as chlorophyll) is photosynthetic and so produces oxygen and consumes carbon dioxide thus increasing pH in the illuminated upper water column but at greater depths beyond the depth of adequate light for photosynthesis algal biomass will consume oxygen and lower pH. So these parameters interact with light availability (time of day) over depth. In Figure 13, the depth profile of chlorophyll, DO and pH for KP2 (September 2003, 10:30am) is presented. Chlorophyll had a maximum value of 13.9µg/l at about 3m depth but decreased to 5.4 µg/l at 50m. pH increased with chlorophyll in the upper depth (0-5m) and DO decreased with depth from 5m depth (7.4 to 3.2 mg/l).

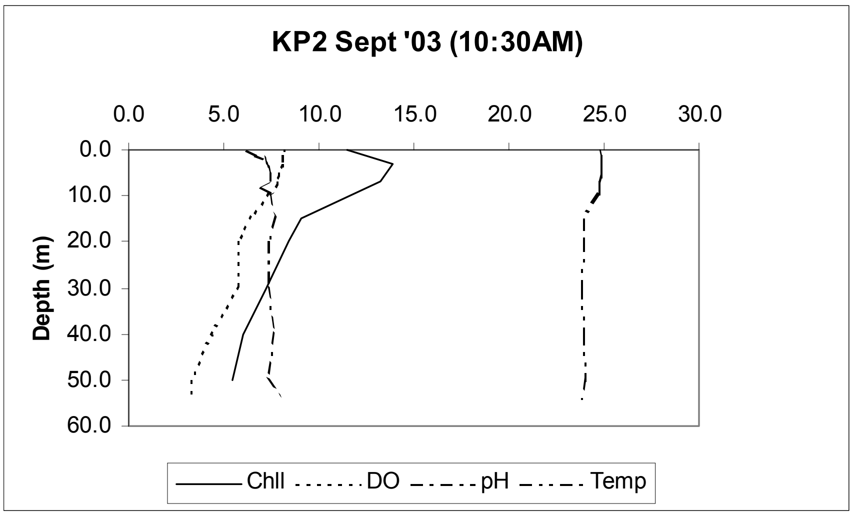


Figure 13 – Depth variation of chlorophyll, DO, temperature and pH in KP2 on September 2003, 10:30am

Species composition and abundance

In both littoral and pelagic areas, Cyanobacteria was the most abundant, contributing between 45 and 65% of the total phytoplankton abundance and diatoms contributed between 20 and 40% of total abundance, with the main lake having higher relative diatom abundance than the gulf (Fig 14 a and b). In Tables 1 and 2, the three most abundant species and the relative abundance for each station for November 2003 and March 2004 are presented. There was a difference between the two months indicating inter-seasonal variation in algal species composition and abundance. Phytoplankton abundance was higher in the gulf than in the main lake and followed a similar spatial pattern with phytoplankton biomass (chlorophyll) (Fig. 8).

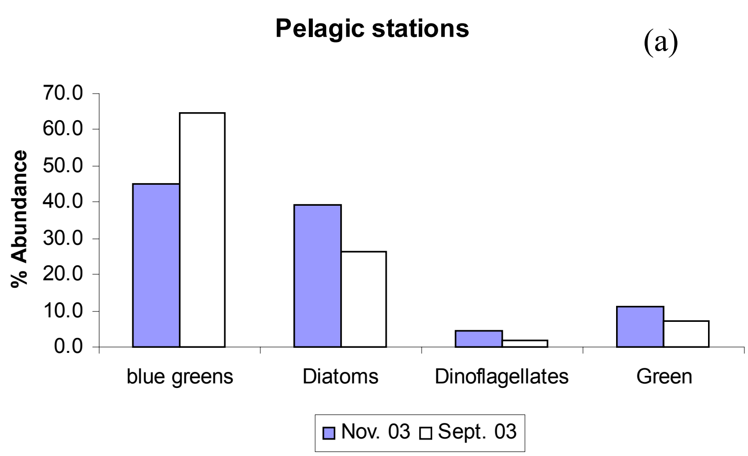
Table 1 – Spatial variation of dominant phytoplankton species and their abundance for March 2004

Station	Species	Cells/ml	% of Total
KL1	Cylindriospermopsis africana	1025.8	23.4
	Chrooccocus sp.	567.5	12.9
	Cyclotella sp.	327.4	7.5
KL2	Cymbella sp.	763.9	25.9
	Pseudoanabeana sp.	261.9	8.9
	Chroococcus limnetica	240.1	8.1
KL3	Chrooccocus sp.	763.9	15.2
	Planktolyngbya contrata	567.5	11.3
	Cylindriospermopsis africana	392.9	7.8
KL4	Cylindriospermopsis africana	720.2	15.9
	Aphanocapsa rivularis	436.5	9.6
	Synedra cunningtonii	371.0	8.2
KL5	Nitzschia acicularis	349.2	13.8
	Synedra cunningtonii	349.2	13.8
	Closterium sp.	261.9	10.3
KL6	Chrooccocus sp.	763.9	18.3
	Cylindriospermopsis africana	480.2	11.5
	Synedra cunningtonii	436.5	10.5
KP1	Synedra cunningtonii	261.9	14.8
	Planktolyngbya tallingii	240.1	13.6
	Cyclotella sp.	152.8	8.6
KP2	Planktolyngbya circumcreta	196.4	12.0
	Planktolyngbya limnetica	174.6	10.7
	Closterium sp.	109.1	6.7
KP3	Nitzschia acicularis	240.1	22.9
	Planktolyngbya limnetica	218.3	20.8
	Synedra cunningtonii	131.0	12.5

Table 2 – Spatial variation of phytoplankton species composition and abundance for November 2003.

Station	Species	Cells/ml	% of Total
KL1	Merismopedia tennuissima	196	13.8
	Aphanocapsa sp	153	10.8
	Crucigenia tetrapedia	131	9.2
KL2	Aulacosira nyassensis	284	26.0
	Merismopedia tennuissima	196	18.0
	Planktolyngbya tallingii	109	10.0
KL3	Merismopedia tennuissima	196	16.7
	Pediastrum duplex	131	11.1
	Aulacosira nyanssensis	87	7.4

KL4	Microcystis aeruginosa	153	14.0
	Cymbella sp	131	12.0
	Nitzshia acicularis	109	10.0
KL5	Nitzschia acicularis	458	29.2
	Microcystis aeruginosa	153	9.7
	Merismopedia tennuissima	131	8.3
KL6	Nitzschia acicularis	1004	39.7
	Cylindrospermopsis africana	196	7.8
	Anabaena sporoides	153	6.0
KP1	Nitzshia acicularis	306	13.2
	Chroococcus sp	240	10.4
	Coelomoron pasillus	218	9.4
KP2	Anabaena sporoides	153	17.1
	Closterium kuzingii	131	14.6
	Cylindrospermpsis africana	131	14.6
KP3	Nitzschia acicularis	327	33.3
	Anabaena sporoides	131	13.3
	Cymbella sp	131	13.3



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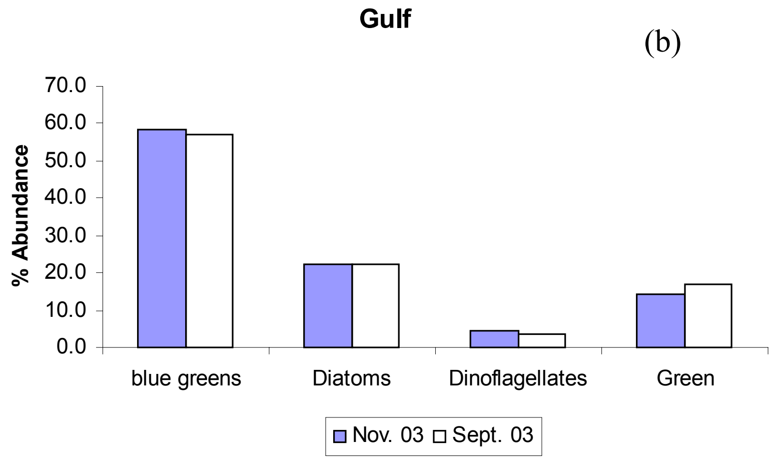

Figure 14 – Abundance of different phytoplankton groups in the (a) pelagic stations and (b) gulf stations

Productivity

Primary productivity rate measured as phytoplankton photosynthesis in the lake ranged between 0.56 and 1.94gC/m^3/day and showed seasonal variation within and between stations (Fig. 15).

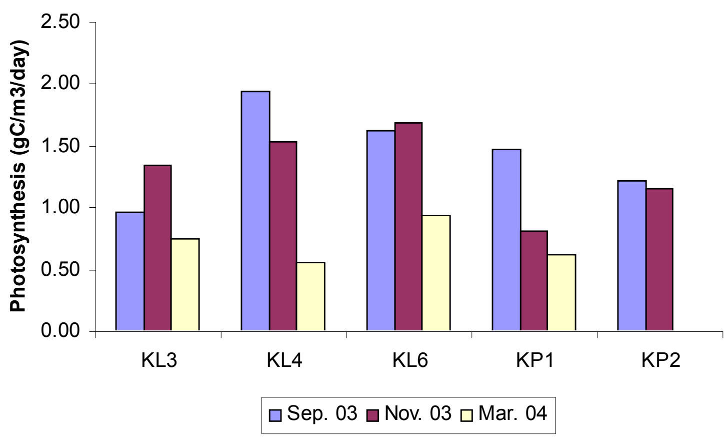

Figure 15 – Phytoplankton photosynthesis in littoral and pelagic stations during September 2003, November 2003 and Mach 2004 Is this based on optimal rate of photosynthesis OR a mean rate over euphotic depth; integral photosynthesis might give a different picture with more transparent stations supporting photosynthesis over a greater depth.

Zooplankton

The littoral stations such as KL1 and KL2 recorded higher zooplankton densities compared with other stations. This observation was made within and between months. There were spatial and temporal variation in abundance, distribution and diversity. Taking into consideration the mean densities for each station over the sampling period, KL1 recorded the highest density of 320.6±86.6 ind./l (Fig. 16a). Densities decreased progressively towards the main lake with the deepest station KP2 (57m) recording the lowest mean density (7.3±2.0 ind./l). Were these results based on tow over the depth of the station. Integral zooplankton i.e. numbers per square meter might look more similar among the stations

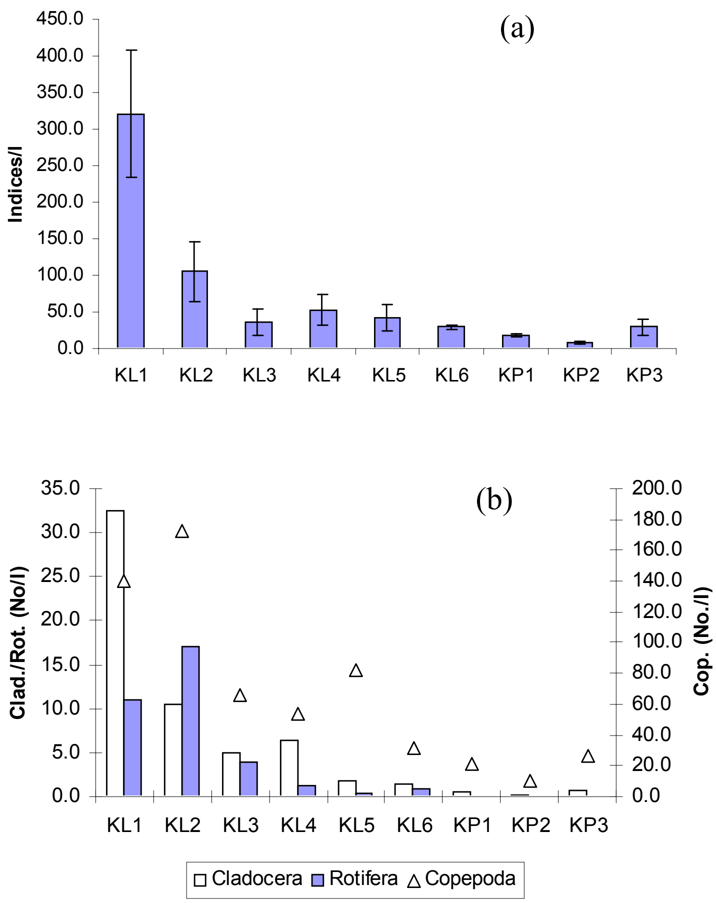

Figure 16 – Spatial variation of zooplankton abundance in the lake (a) all the groups (b) different groups

Copepoda dominated the zooplankton community in all the stations with percentages ranging from 73-97.5%. Their densities also followed the trend shown by the total zooplankton densities (general decrease from the littoral to the pelagic waters). Cyclopoida occurred in higher proportions compared to Calanoida, although relatively higher proportions of the latter were recorded at deeper pelagic stations e.g. in the month of August 2001 (KP1 27.04%, KP2 42.79% KP3, 28.51%).

Cladocera were identified to species levels with seven species recorded. Their densities decreased generally towards the open lake (Fig. 16b). While KL1 recorded the highest cladoceran mean density (32.5±16.6 ind.l^{-1}), the main lake stations recorded very low densities. *Moina micrura*, *Bosmina longirostris*, *Ceriodaphnia cornuta, Diaphanosoma exiscum* had a wide distribution throughout the lake. KP1, KP2 and KP3 were dominated by *Daphnia longispina.*

Rotifers were the most diverse group. Twenty-four species were identified. Their densities decreased progressively from KL1 to KP2. Rotifers occurred in very low densities in March and April.

Results for samples taken at various depths indicate that zooplankters usually occupy the lower water column during the day light period. The copepod nauplii however tend to occupy the uppermost waters during the day. Different zooplankters migrate through the water column at different rates and are therefore found at different depths at different time of the day. *Thermocyclops neglectus* was the most dominant copepod and zooplankter though its density varied in time and space. Other cyclopoid copepods were *T.emini*, *T.incisus, Tropocyclops confinnis; T.tenellus and Mesocyclops* spp. Calanoid copepods were represented by two species i.e.*Thermodiaptomus galeboides* and *Tropodiaptomus stuhlmani*. The former being dominant offshore while the latter inshore.

DISCUSSION

The difference in physico-chemical environment between the littoral and pelagic (deep offshore) stations can be attributed to a number of factors including, depth of mixing as well as availability of nutrients and light; surface inflows from the lake catchment with transported sediment, nutrients and other pollution loading and mode and extent of exchange between the two lake zones (Gikuma-Njuru & Hecky 2005). The difference between the Nyanza Gulf and the main Lake environments has been attributed to the oxygenation of the waters, influence of rivers and surface runoff input into the gulf (Gikuma-Njuru and Hecky 2005) and the limited exchange of the gulf with the main lake (Calamari et al 1995).

The shallow depth in the gulf (Fig. 1) allows for wind induced mixing and hence keeping the gulf well oxygenated throughout the year as opposed to the deeper pelagic stations which mix to the bottom only seasonally due to seasonal stratification (Gikuma-Njuru and Hecky 2005). High redox potential, associated with oxygenated conditions, keep PO_4–P firmly bond to bottom sediments and hence reducing its availability in the water column, which can explain the lower PO_4-P concentration in the gulf compared to the main lake (Fig. 7) despite high pollution input through riverine inflows and surface runoff (Lung'aiya et al 2001; Gikuma-Njuru & Hecky 2005). Higher PO_4 –P and to a lesser extent NO_3 –N in the main lake compared to the gulf can also be attributed to low nutrient demand by phytoplankton, whose growth in the main Lake Victoria has been found to be limited by light availability (Mugidde 1993; Guildford et al 2003; Mugidde et al 2003). The deep mixing depth (up to 30m) in the main lake causes algal cells to spend more time in darkness and therefore imposing light limitation to algal growth (Guildford & Hecky 2000; Mugidde et al 2003). In the gulf, where productivity is high, light limitation of algal growth maybe as a result of self shading (Gikuma-Njuru & Hecky 2005) or due to inorganic sediment from the high riverine input and re-suspension of bottom sediments in the shallow gulf. The apparent negative correlation between PO_4–P and Chlorophyll (Fig 12a) may be as a result of high demand for PO_4-P by phytoplankton in the less light limited and high productive littoral stations (Guildford et al 2000).

One of the drastic changes that have taken place in the past 4 decades in the Lake Victoria is the depletion of DRSi concentration in the water column, which is reported to have reduced 10-fold from that reported by Talling (1966) (Hecky 1993). The DRSi concentrations in the main lake are below those reported by Talling (1966) but in the gulf they are within the Talling range 4.0 – 4.5mg/l (Fig 7; Table 4). Riverine input into the gulf and less demand for Si, due to low diatom assemblage in the gulf, can in part account for these higher levels of DRSi in the gulf compared to the main lake, where diatoms are more (Lung'aiya et al 2000).

Talling (1966) reported phytoplankton biomass (chlorophyll) values of 1.2-5.5µg/l in the pelagic waters which is less than the values measured during the present study (Fig 8) in the pelagic stations, confirming the reported changes in phytoplankton biomass in the past four decades (Kling et al 2001; Hecky 1993). The dominance of Cyanobecteria in lake, during the present study, is consistent with observations made by other scientists (e.g. Ochumba and Kibaara 1989; Lung'aiya et al 2000) and in line with the reported changes of phytoplankton assemblage from diatom dominated to blue green dominated population (Hecky 1993; Lehman & Branstrator 1993; Kling et al 2001). The dominance of Cyanobacteria in the lake present water quality challenges as this algal group is bloom forming and has species which are known to produce phycotoxins, which can both cause fish kills and compromise drinking water quality (Hummert et al, 2001; Kling et al 2001; Krienitz et al, 2001). The occurrence, in mid 2004, of a large algal bloom in Kisumu Bay, which lead to the closure of the Prisons Department water treatment works for a number of days, is a good example of negative impact of algal blooms on water quality. Although this occurrence was thought to be as a result of reduced lake levels, due to long dry spell at the time, continued nutrient enrichment of the lake will probably increase the frequency and severity of such occurrences especially in the littoral hotspot areas (LVEMP 2002).

The ratio between N and P can be used to indicate the phytoplankton nutrient status in a water body. After analyzing nutrient data from both fresh and marine sources, Guildford and Hecky (2000) found out that in cases where TN:TP ratio was <20 phytoplankton was consistently nitrogen limited and in cases where the ratio was >50 phytoplankton was consistently phosphorus limited. The N:P ratio in the lake (Fig 9) shows that the Nyanza Gulf is consistently phosphorus limited whereas the main lake can be either nitrogen or phosphorus depending on the prevailing physico-chemical and nutrient status. Under nitrogen limited conditions, phytoplankton species with the ability to fix inorganic dinitrogen from the atmosphere, normally has an advantage over the other species and therefore dominate (Guildford et al 2003; Mugidde et al 2003). Measurement of N-fixation rates in the northern part of Lake Victoria has shown the N-fixation rate in the pelagic waters varies seasonally with high rates recorded during the stratified season and at shallow stations, when mixing depth is shallow (Mugidde et al 2003). Lung'aiya et al (2000) reported dominance of *Microcystis*, a non N-fixing algal species, in the Nyanza Gulf, which agrees with the predictions from the N:P values in this study. Since the gulf as a whole is P limited, continued P input to this semi-closed part of the lake will result in increased algal blooms and increased eutrophication and therefore negatively affecting the water quality. Dominance of N-fixing heterocystous blue green algal species has already been reported for some near shore areas with high pollution input (Krienitz 2002). Therefore necessary steps should be taken to reduce phosphorus input into the gulf and other inshore areas.

Using the OECD boundary values (Table 3), the main lake can be categorized as eutrophic as per chlorophyll and Secchi depth transparency values, whereas the mean TP concentration in the main lake and in the gulf puts the two lake zones in the hypereutrophic category. The gulf can be considered hypereutrophic considering the Secchi depth transparency values. The high TP in the main lake can be associated to low phosphorus demand due to light limitation whereas the low transparency in the gulf can mainly be as a result of both inorganic suspended sediments from inflowing rivers and the elevated phytoplankton biomass. Light can also restrict the full utilization of available nutrients with the Gulf (Njuru-Gikuma and Hecky 2005).

Table 3. OECD boundary values for fixed trophic classification system (extracted from Mason (1997))

Trophic Category	*TP*	*mean Chl*	*max Chl*	*mean Secchi*	*minimum Secchi*
Ultraoligotrophic	<4.0	<1.0	<2.5	>12.0	>6
Oligotrophic	<10.0	<2.5	<8.0	>6.0	>3.0
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

Explanation of terms:
TP = mean in-lake total phosphorus concentration (ug/l);
mean Chl = mean annual chlorophyll a concentration in surface waters (ug/l);
maximum Chl = peak annual chlorophyll a concentration in surface waters;

mean secchi = mean annual Secchi depth transparency (m)

Phytoplankton biomass can be controlled not only by nutrient and light availability but by zooplankton grazing (Lehman & Branstrator 1993; Guildford et al 2003) and it is possible that the lower phytoplankton biomass in KL1 compared to other eastern gulf stations (KL2 and KL3) may be as a result of zooplankton grazing since the station had the highest zooplankton abundance (Fig 16a & b). Zooplankton plays an important role in nutrient recycling in the lake water column and in some lakes they control the availability of dissolved nutrients through secretion (Carpenter et al., 1985). Zooplankton as secondary producers are important agents in transferring energy to the higher levels of the food web as they are important food source for fish (Cooke et al 1986). The high fish biomass in the gulf compared to the main lake (Personal observation during trawling) may be associated with higher algal and zooplankton biomass in the gulf compared to the main lake (Akiyama et al 1977). However low water transparency in the gulf can reduce the ability of the fish to catch the prey and hence affect fish abundance (Balirwa et al 2005). Poor visibility can also make the fish more susceptible to gill netting.

CONCLUSIONS AND RECOMMENDATIONS

The Kenyan part of Lake Victoria consists of two zones, the Nyanza Gulf and the main lake, with different physico-chemical and water quality characteristics.

- Although the main lake has higher SRP concentration than the Nyanza Gulf, the gulf has higher plankton biomass than the pelagic zone, which maybe as a result of light limitation of algal growth in deeper pelagic areas due to deeper mixing depth.
- Increased phosphorus input into the gulf will lead to N-limited phytoplankton growth resulting in dominance of bloom forming heterocystous N-fixing blue green algal species and therefore compromising water quality
- Management of phosphorus loading into the Nyanza Gulf and other inshore areas should be given a priority in order to stem further deterioration of water quality and restore aquatic environment health
- Studies should be conducted on the rates of nitrogen fixation in the Kenyan waters and its importance on nutrient balance. The influence of sediments on the availability of phosphorus in the water column and especially in gulf should be studied and quantified.

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CHAPTER 11

Pesticides and Heavy Metals Contamination in the Lake Victoria Basin, Kenya

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Introduction

In recent years, concentration of pesticides, heavy metals and other pollutants in the environment have been major causes of concern due to their toxic effects. These compounds can be toxic to humans and also to aquatic life because they interfere with enzyme and endrocrine action as well as other physiological functions.

PESTICIDES

Pesticide use in Kenya has been on increase and their imports have increased dramatically over years (Table 7) check the numbering of tables and figures in this and other sections citations should be in order of occurrence i.e. table 1 should be cited first etc. This widespread use of pesticides has helped the country to boost its economy by controlling the agricultural pests and vector-borne diseases in livestock (Kaine, 1976). For instance, tremendous growth of the Kenyan tea industry and subsequent increase in exports has been attributed to the use of herbicides (Caleb, 1989). Unfortunately, some of these chemicals are toxic and have deleterious effects on human health and the environment. The US-Environment Protection Agency (EPA) has estimated that between 10,000 and 20,000 physically diagnosed pesticide illness and injuries occur among agricultural workers per year in developing countries relative to the amount of pesticides used (Vorley and Keeney, 1998). This is probably due to lack of understanding on the proper handling and application by users. Studies by Ritter, 1990 has shown that high concentration of pesticides occur in the soil environment from spillage during pesticide mixing, loading, rinsing at the dealership and sprayer fill sites and by direct pumping into soil, disposal sites, ditches and ponds. In the sugarcane plantations, insecticides are sprayed on the nursery stalks and surrounding soils in the planting furrow and/or placed as a continuous deep layer by positioning the application nozzles behind the plough

(Novaretti et al., 1991). Pesticide use therefore requires a thorough knowledge of their properties and behaviour in the matrices in which they are applied since their residues in the environment are found in various complex matrices albeit at low concentrations (Megersa, 2000).
Pesticide pollution of waterways has been a long-standing problem particularly in areas of intensive agricultural activity such as the Lake Victoria region (Thompson et al., 1977). Because of their persistence in aqueous and sedimentary media, the organochlorine pesticide residues has been of most pressing concern.

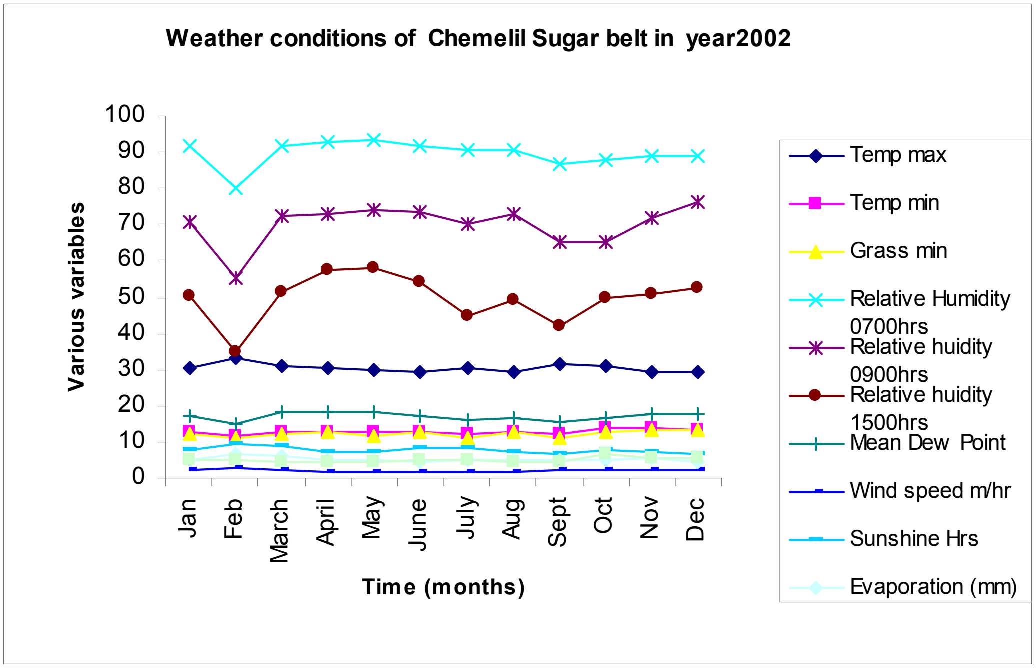
A more recent development related to the international action to protect human health and the environment, is the convention on 12 persistent organic pollutants (POPs) reached in Durban, South Africa in 2000. The targeted POPs were DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, hexachlorobenzene (BHC), mirex, toxaphene, polychlorinated biphenyls, dioxins and furans. Despite the official ban of these pesticides in Kenya, they are still available in the market, and are being detected in the environment (Wandiga et al. 2000). Currently, some organochlorine compounds such as heptachlor is allowed for the treatment of power and telephone wire posts to prevent termite damage, lindane is a traditional component of lotions, creams, and shampoos for the control of lice and mites in humans and in veterinarian products (Sparovek et al. 2001). However, the environmental fate of these pesticides has become an issue in Kenya and has been receiving more attention than ever before due to international residue limit requirements in food, drinking water supplies as well as in export products such as fish, fruits and horticultural produce (Wandiga et al. 2001). Everaats et al. (1996) analyzed sediments from the Kenyan coast and found α-BHC, γ-BHC and diedrin in concentrations of 7.1-62.2ng/g, 7.3-53.2ng/g and 37ng/g of organic carbon (OC), respectively. DDT, ß-BHC, dieldrin and heptachlor epoxide have been detected in breast milk of Kenyan women (Wandiga and Mutere 1988). The main route of exposure to the respondents was attributed to oral intake through vegetables, beef, contaminated water, and dairy milk containing the residues (Kanja 1988). DDT and other organochlorine pesticides have been shown to affect reproduction of various test animals (Hayes 1982).

Study Area

River Nyando where the study on persistent pesticides compounds was conducted has a total length of 170 Km and a catchment area of 3450 Km^2.
Nyando drainage basin consists of four main sub-catchment areas namely Nyando-Nandi, Nyando-Kericho, Nyando-Kano and Awach-Kano. These areas form the main agricultural and industrial zones in the Nyando drainage basin. The agricultural activities in this basin involve the use of fertilizers and pesticides that have been identified as some of the major sources of pollution into Lake Victoria.

Climate

Mean annual rainfall ranges 1000mm-1600mm, decreasing with elevation from the highlands to the Kano plains as does mean annual temperaturew that range 18^0c-26^0c.



The figure **a**. shows weather conditions in the fields during field studies 2002.

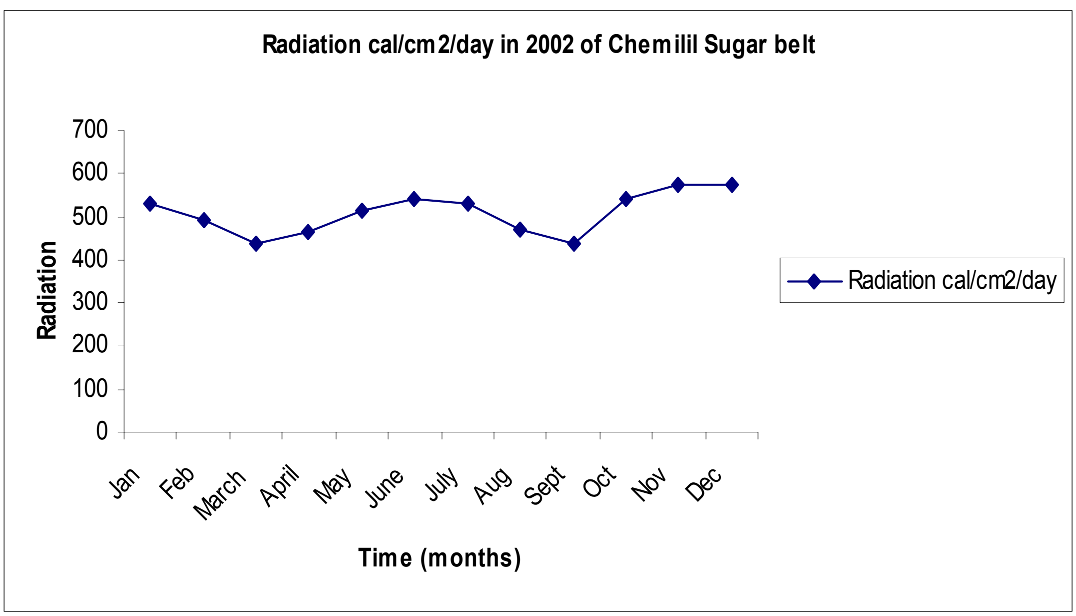


Figure b. Mean daily radiation during field studies in 2002

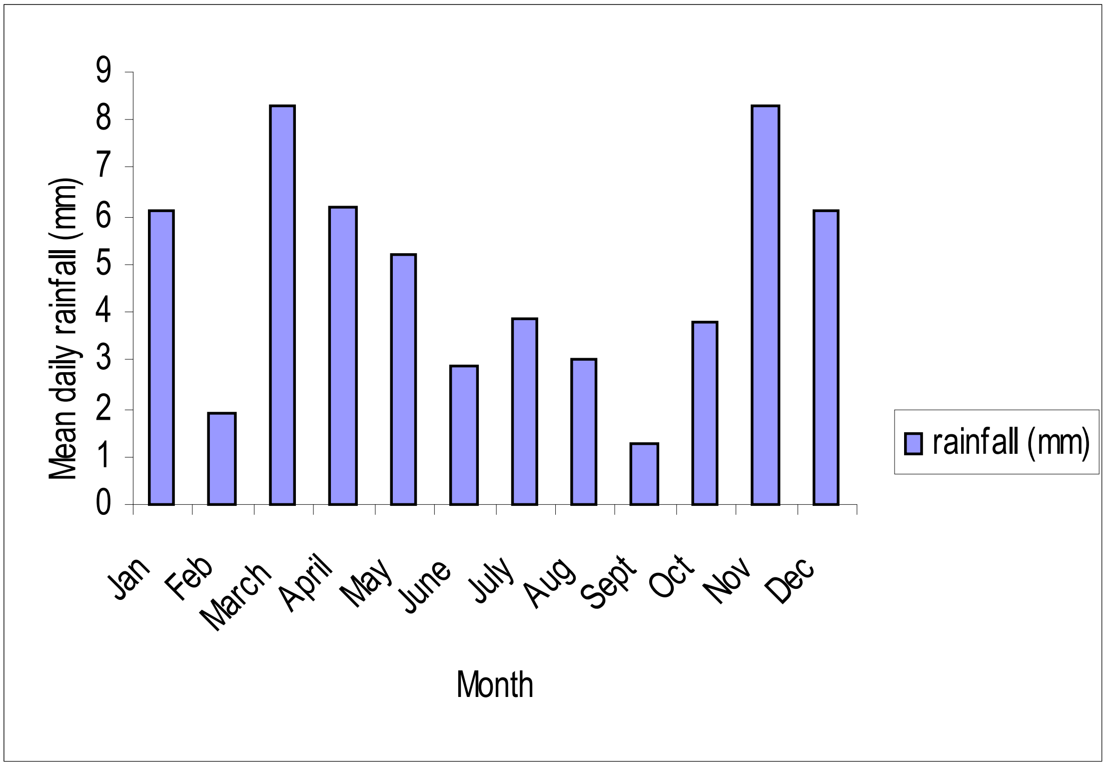


Figure c. Mean daily rainfall during field studies in 2002

Soils

The dominant soils in the highlands zone include Nitisols,Phaeozems, Luvisols and Cambisols. These soils are well drained deep and dark reddish brown sandy clay loam to clay. In the lowlands the dominant soils include Vertisols, Gleysols, Planosols, and Fluvisols. The Vertisols and Planosols are poorly drained, deep and of sandy clay to clay texture. The Gleysols of Nyando are very poorly drained, very deep clay soils with acid humic topsoils.
The soil was characterized as clay with the following properties, OC 2.07%, pH 6.08, clay content 68%, sand content 28%, silt content 12%, N 0.19%, P 80ppm, Na 0.95%, K 1.85%, Ca 10.5%, Mg 4.95%, Mn 0.51%, Fe 226.96% and electrical conductivity (EC) 0.62µS/cm.

Heavy Metals
Lake Victoria the second largest fresh lake in the world serves as a sink of industrial effluents from a few industries located in the urban centres situated a long the lake shores and its drainage systems, e.g. Kisumu Town has high density of automobiles, heavy and light industries. Most of these industrial

wastes, sewage, and surface run-offs composed of oils from garages; ”Jua Kali” sheds etc. end up in lake Victoria. In addition major rivers feeding lake Victoria such as Nzoia, Kuja, Nyando, Sondu Miriu, Migori and Yala traverse through industrial and agricultural zones, e.g Nzoia receives effluents from Webuye Paper Mills, Nyando transports effluents from East African Sugar Company and Agro-Chemical and Food Company Limited, Kuja receives coffee factory effluents from Kisii highlands, Sondu Miriu receives effluents from tea factories in Kericho highlands etc.

The heavy metals are also transported into receiving waters through industrial effluents, sewages and storm water from major cities and agricultural farms.
Heavy metals” generally include those metals of atomic weights greater than that of Sodium. The concept of toxicity is associated with these terms and is applied to include the elements:- Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se Mo, Ag, Cd, Sn, Te, Hg, and Pb.

Some elements such as Fe, Cu,Zn,Mn,Co,Mo,Se,Cr,Ni,Si,F and V are believed to be essential for plant and animal life. But heavy metals, such as Mercury, Lead, Cadmium, and Arsenic, although useful in industrial and agricultural technology, can be highly toxic to human life and have been found to be associated with a variety of diseases in man. Lead affects blood cells resulting to low haemoglobin levels and hence causes anaemia, (WHO 1972) and it inhibits enzymes. Cadmium disrupts the normal functioning of enzymea through inhibition and in human beings cadmium accumulates in ovaries, kidneys and liver hence result to kidney and liver damage. In Japan people suffered from a deadly disease known as”itai-itai” a syndrome of Cd toxicigty. Methyl mercury and its derivatives are very toxic to living organisms. They damage all tissues, including the brain. In 1953-1960 industries around Minamata Bay, Japan emptied methyl mercury into the Bay causing 111 deaths from contaminated fish. Mercury becomes an environmental contaminant because of many of its uses as algacide, used to clean vats in paper mills and then washed into neighbouring bodies of water, thermometer,fungicides and in small scale gold mining operations.In Nyanza Province of western Kenya mercury is used to amalgamate gold at Macalder (T.C Davies and Nyambok*)*. Inorganic mercury compounds are methylated by bacteria in aquatic environments and thereby there toxicity and their biomagnification is increased.

Despite the relatively low concentrations of the trace metals their ability to bio-accumulate through the food chain is emphasized. It is for this reason that the levels of lead found in fish and which is most likely came from leaded gasoline used by boats, is of critical concern. Similar concern holds for mercury that is used in gold extraction and whose level has been detected in 5-10 kg Nile perch fish muscle at a concentration of 200ng/g *(Campbell et al. 2000).*

Objectives

The main objective of the study was to generate information on the levels of pesticide residue levels in soil, sediments and water from river Nyando catchment area, where various pesticides are used for agricultural production.
The data generated will form the basis for future surveillance program on pesticides residues within the Lake Victoria catchment area and in policy formulation on the level of POPS in the environment .

On heavy metals the research was conducted in order to establish levels of trace metals in receiving waters and the muscles of aquatic organisms (fish), which may be hazardous to human health at high concentrations through food chain. In addition the research aims to determine whether the sources of pollutants can be related to industries, urban centres and increasing land use activities within the lake basin.

MATERIALS AND METHODS

Organochlorine Compounds

This study was undertaken to analyze soil, sediments and water from river Nyando catchment area, soil samples were taken from the sugar belt in Kenya, where 2260 hectares of land have been devoted to the cultivation of sugarcane for over 40 years. In this study organochlorine compounds were particularly targeted because they are banned and they are illegally being used.

Water and sediment samples were collected from designated sites within the Nyando system and analyzed for the presence of organochlorine compounds.
The location of the Chemelil sugar belt where the study was carried out lies within 34^{o} 50’ 49” E - 35^{o} 35’ 41” E longitude and 0^{o} 4’ 55” N – 0^{o} 20’ 11” S latitude. Fields where pesticides are heavily used for the control of many different pests were selected according to the time when the pesticides were last applied. Four fields were identified as having received pesticide applications 2 months, 6 months, 12 months and 60 months ago, respectively. Three different sampling points were randomly selected within each field. A soil core was dug and soil scooped down to the depth of 30cm, mixed thoroughly before a sub-sample of approximately 500g was taken in a black polythene bag. The soil samples were air-dried, homogenized and crushed in a mortar with a pestle and then sieved through a 2-mm pore sieve in the laboratory.

Water and sediment samples were taken from the rivers, which drain the Nyando basin and were considered to be directly receiving the surface run-offs from the sugar belt and from other adjacent farming areas. Water and sediment samples were collected in 2.5litre amber bottles and black polyethene papers resctively, by taking several composites across the rivers. Where rivers were deep, a dinghy boat was used or a grab sample was taken from a strategic position and considered to be representative sample. Soil sampling from the sugar cane fields was done twice, in May and October 2002. Rainfall in the area is s well distributed throughout the year. Sampling from the river was done twice , in the months of October 2002 and August 2004. All samples awaiting analysis were kept in the refrigerator at -4°C. General-purpose reagent (GPR) grade hexane, acetone, methanol and dichlomethane solvents were all triple-distilled in all-glass apparatus before use. Florisil and Na_2SO_4 used were heated up to 100°C before they were kept in dessicators to cool. The Whatman #1 filter papers used for extraction of soil sediment samples were pre-soxhlet extracted in extraction solvent for 24 hours and kept in desiccators.

A sub-sample of 30g of air-dried and homogenized sieved soil and sediments was taken in replicas of three and mixed with equivalent weight of Na_2SO_4 to dry the soil. The dried soil and sediments was placed in a pre-extracted filter paper and soxhlet-extracted for 24 hours in 150 ml of triple distilled acetone:hexane(1:1) mixture. The extract was rotary evaporated to 10ml. The 10-ml extract was cleaned up by eluting the extract through a column packed with 10g of activated florisil and topped with Na_2SO_4 to a height of 2 cm. The extract was eluted through the column at a rate of 5ml/min. Elution was done using 200ml of 6%, 15% and 50% of diethyl ether in hexane in that order. The extract was reduced to just dryness and then reconstituted in 5ml of HPLC grade hexane.

Two litres of the water sample was measured by measuring cylinder and transferred into a 2.5-litre separatory funnel. 100ml of triple distilled methylene chloride was added to the water sample in the separatory funnel. 50g of Na_2SO_4 were added to the separatory funnel to salt out the pesticide into the organic phase. The separatory funnel was tightly corked and vigorously shaken for three minutes with periodic venting to prevent pressure build up by methylene chloride. The contents in the funnel were allowed to stand for ten minutes so that the two phases could separate. The organic phase was passed through a Na_2SO_4 column to remove water and then collected in a round-bottomed flask. Another portion of 100ml of methylene chloride was added to the extracted water in the separatory funnel and the process repeated. The extraction was done three times. The dry organic phase was rotary evaporated to dryness, reconstituted in 5ml of HPLC grade hexane before it was analyzed by GC. 1 µl was taken from the 5ml extract and injected into the Varian Chrompack CP-3800 GC under the conditions specified. Column: CP-SIL 8CB-15m, 0.25 mm (ID), 0.25 µm film; sample size: 1 µl split 1:20; detector: ECD at 300°C; column temp: 150°C held for one minute changed to 200°C at 4°C/min then to 300°C at 4.5°C/min, flow pressure was 30 Psi of the nitrogen gas as the carrier gas and injector temperature at 250°C. External standard calibration was used to determine peak areas from the samples. The following organochlorine pesticides were analyzed in both water and soil samples heptachlor, heptachlor epoxide, aldrin, dieldrin, endrin, lindane, endosulfan, α-BHC and ß-BHC. Recovery studies were carried out by spiking soil and water standard samples with 0.01 ppm of the pesticide standards. The percentage recoveries for the pesticides ranged from 84-119% and 84-94% from soil and water, respectively. The concentrations in the samples were corrected according to the percentage recovery for each pesticide. The residue concentrations in water and soil samples were expressed in ppm

Heavy Metals

For analysis of heavy metals, water was collected from wastewater treatment facilities, rivers within the lake basin and fish from Kisumu bay of Winam Gulf.
Fish were collected from three sampling points within Kisumu Bay of Winam Gulf during the period of December 1999 to February 2000. The fish was bought from small scale fishermen by the assistance of the Kenya Marine and Fisheries Research Institute (KMFRI) personnel, fish was sorted out according to species, sex, size, fork length and body weight. Fish was deep-frozen at -10$^{o}{}_{C}$ in sealed plastic bags with labeled nametags prior to analysis.Three species of fish were sampled,Nile perch (*Lates niloticus*), Tilapia (O*reochromis niloticus*) and Mud-fish We should really have a species name here. The fork length ranged from 35-50 cm, body weight from 800-1000 grams and the mass of the fillet used was 10 grams.

The deep-frozen fish was left to thaw to 4^{o} C at room temperature for easy cutting. The fillet was cut near the gills across the body, along the ventral edge from the gill to tail. The skin was peeled off, taking care not to contaminate the fillet, and then the fillet was homogenized in a blender and transferred into a clean borosilicate petri dish that had been weighed empty.
The Petri dish was again weighed with homogenate and weight noted.

The accurately weighed 10 ± 0.1 g of fish fillet was placed in the digesting tubes of the block digester, the organic matter was broken down by the use of the wet-oxidation method at 60^{o}C-140^{0}C and oxidation of the organic matter allowed to proceed for 2-4 hours. A mixture of concentrated nitric acid and sulphuric acid and 30% V/V hydrogen peroxide were used in the digestion of organic matter. The colourless homogenous solution was cooled and quantitatively transferred into 50 ml volumetric flask and made up to the mark using distilled water.

The digest was filtered through a filter paper previously soaked in 10% V/V nitric acid and rinsed with distilled water. The filtrate was kept in 50ml -100ml plastic containers and later analyzed using Atomic Absorption spectrophotometer (AAS) – CTA -2000 model.(UNEP/WHO 1989).
Water samples were collected from point sources and rivers within the lake Victoria drainage basin during the period of November 1999 to October 2004. The samples were collected in 100-200 ml polyethylene containers and they were preserved by addition of 2mls of concentrated nitric acid in a litre of sample. The samples were stored at 4^{0}C prior to analysis. 50ml of water was mixed with 10ml concentrated nitric acid and boiled in a block digester until turbidity and colour were clear.

For the heavily polluted water such as water from river Kisat and effluents from factories such as Webuye Pan Paper factory, A.C.F.C. Muhoroni and municipal sewage wastes a mixture of 10 ml conc. nitric acid and 5 ml conc. sulphuric acid was used.The digest was made up to the mark of 50 ml volumetric flask using distilled/deionized water. The digest was filtered through a filter paper previously soaked in 10% v/v Nitric acid and rinsed with deionized water and final filtrate kept in 50-100 ml plastic containers ready for heavy metals analysis using Atomic Absorption spectrophotometer (AAS) – CTA -2000 model. (UNEP/WHO 1989).

RESULTS

Table 1: Concentration of organochlorine compounds in the soil from fields in May 2002. Explain retention time is it necessary to the table

		Conc. (ppm) in soil			
Pesticide	Rentention time (min)	2 months	6 months	12 months	60 months
α-BHC	2.47	3.758	0.939	0.681	0.434
β-BHC	3.04	5.022	0.308	0.273	0.25
Lindane	3.65	2.579	1.283	1.27	1.294
Heptachlor	4.52	7.924	0.396	0.482	0.317
Aldrin	5.39	4.088	0.861	0.811	0.534
Heptachlore	6.64	3.522	0.283	0.25	0.243
Endosulfan	7.76	1.242	0.513	1.891	1.552
Dieldrin	8.66	3.512	0.542	0.568	0.473
Endrin	9.37	4.693	0.142	0.052	0.31
Methoxychlor	15.1	1.026	0.049	0.022	0.475

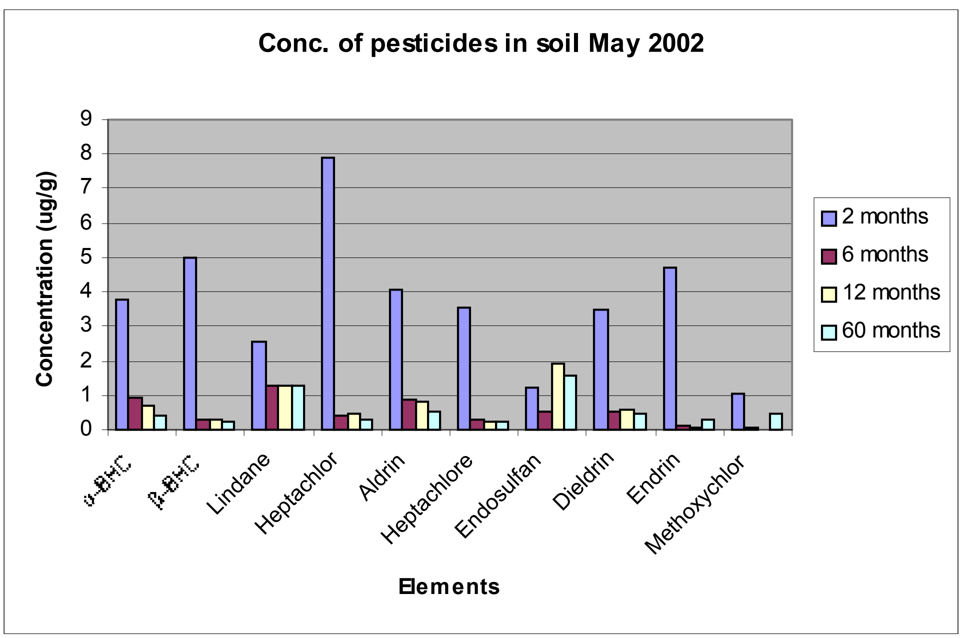


Fig.1. Temporal variation of pesticide concentrations in soil in May 2002 with different times from last treatment.

Table 2. Concentration of Organochlorine compounds in the soil from fields in October 2002

		Conc. (ppm) in soil			
Pesticide	Rentention time (min)	2 months	6 months	12 months	60 months
α-BHC	2.47	75.201	70.673	55.71	50.62
β-BHC	3.04	8.223	8.65	4.658	2,.546
Lindane	3.65	44.217	10.631	8.976	6.612
Heptachlor	4.52	2.048	1.886	0.837	2.147
Aldrin	5.39	0.417	0.503	0.505	0.884
Heptachlore	6.64	0.447	0.386	0.433	0.534
Endosulfan	7.76	0.501	1.152	0.245	0.782
Dieldrin	8.66	0.641	0.919	0.813	1.446
Endrin	9.37	0.43	0.66	0.534	1.361
Methoxychlor	15.1	0.224	1.578	0.332	1.513

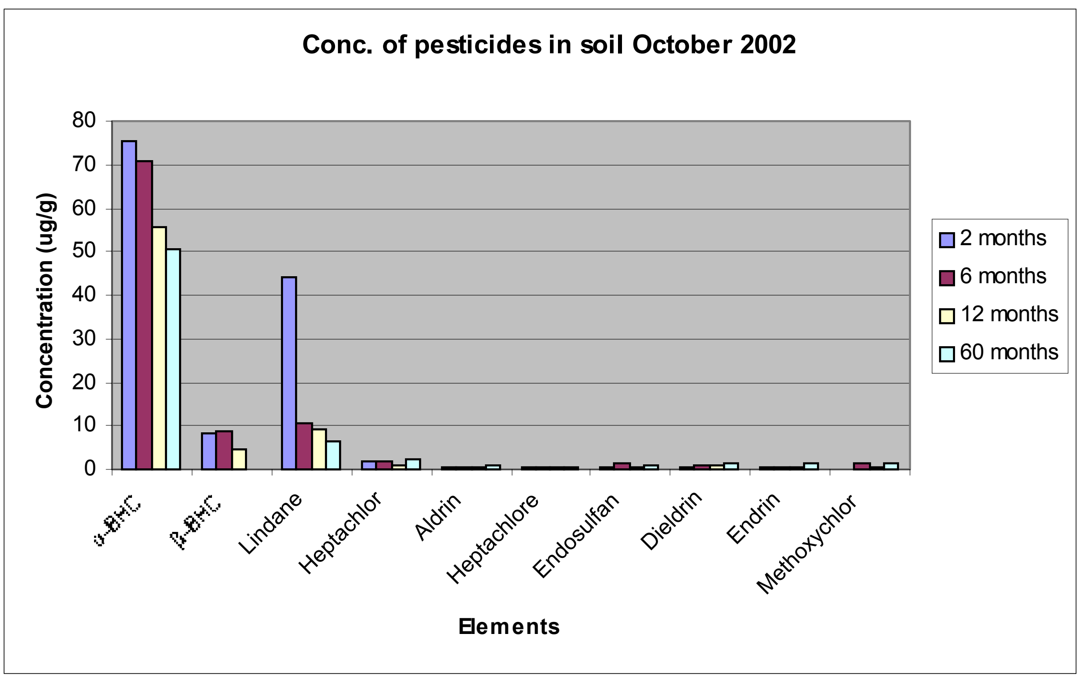


Fig 2. Variation of pesticide concentrations in soil from fields with different times since last pesticide treatments in October 2002. Are these the same fields as Fig.1? If so say so

Table 3 Concentrations of Organochlorine compounds in water from different sampling points

Pesticide	Mbogo 1GB6A	Nyando 1GD7	Nyando 1GD3	Nyando 1GD2	Kedowa	Ahero channel	Ainamotua 1GB3
α-BHC	0.379	0.211	0.182	0.176	0.691	0.251	0.113
β-BHC	0.046	0.0112	0.0095	0.0091	0.035	0.014	0.0073
Lindane	1.24	0.0433	0.039	0.034	0.095	0.104	0.027
Heptachlor	0.07	0.0102	0.0086	0.0062	0.07	0.011	0.0063
Aldrin	0.089	0.0083	0.0046	0.0033	0.089	0.0055	0.0034
Heptachlore	0.0048	0.0029	0.0034	0.0024	0.0048	0.0036	0.0027
Endosulfan	N/D	0.0101	N/D	N/D	N/D	N/D	N/D
Dieldrin	0.096	0.0052	0.0018	0.0011	0.096	0.096	0.0024
Endrin	0.031	0.0011	0.0011	N/D	0.031	0.031	0.0004
Methoxychlor	0.022	N/D	N/D	N/D	N/D	0.0404	N/D

N/D = denotes not detectable.

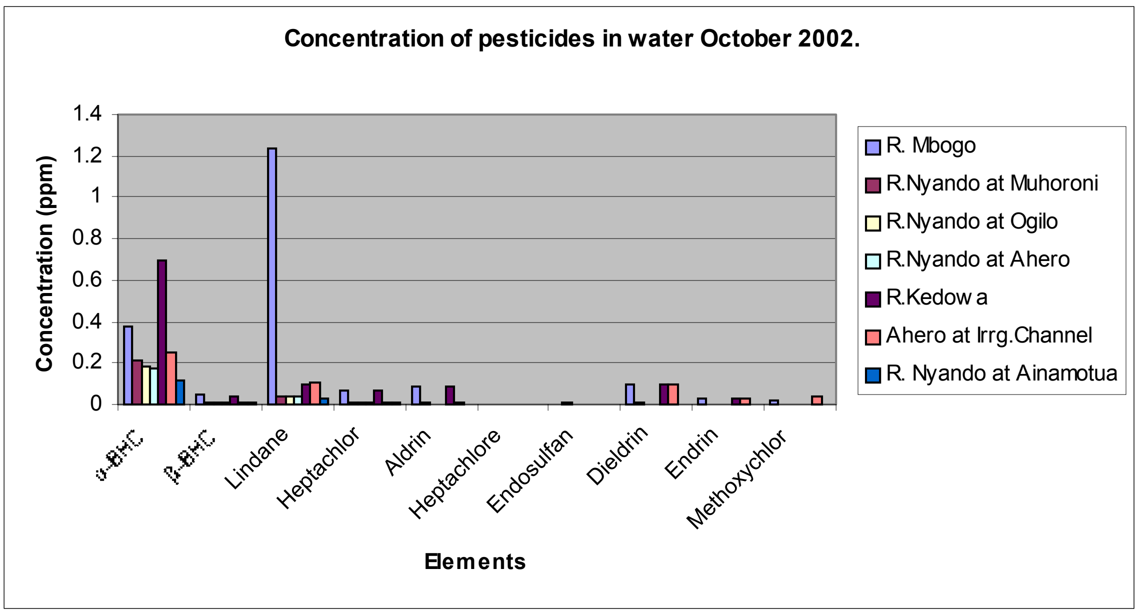


Fig 3. Variation in concentration of pesticides in water samples from different Sampling stations in October 2002

Table 4: Concentrations of Organochlorine compounds in water from different sampling points August 2004.

Station	α-BHC	β-BHC	Lindane	Aldrin	Dieldrin	Endrin	Heptachlor	Heptachlor e	Methoxychlor	Endosulfan
Kedowa	0.86	0.04	0.1	0.15	0.12	0.04	0.06	0.05	0	0.01

Pararget	0.22	0.21	0.05	0.08	0.09	0.06	0.05	0.03	0.04	0.07
Mbogo 1GB6A	0.41	0.05	0.8	0.13	0.07	0.04	0.05	0.05	0.03	0.002
Ainamutua 1GB3	0.12	0.02	0.01	0.07	0.01	0.03	0.004	0.095	0.005	0.003
Nyando at 1GD3	0.15	0.01	0.025	0.098	0.005	0.007	0.085	0.05	0.001	0.001
Nyando Dyke	0.13	0.007	0.03	0.065	0.002	0.003	0.068	0.02	0	0

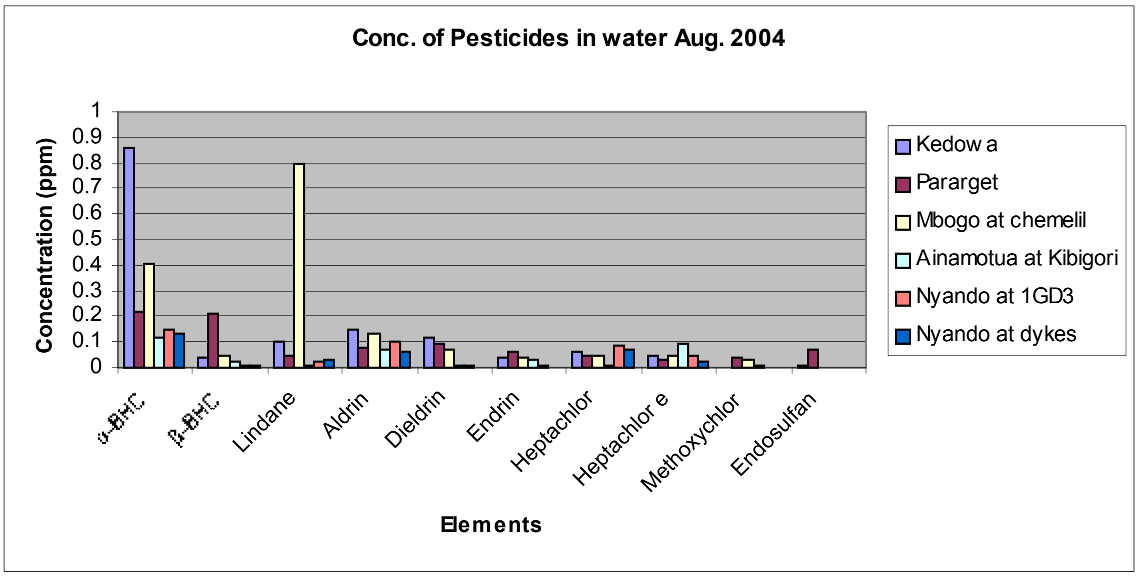


Fig 4: Concentration of pesticides in water samples from different Sampling stations in August 2004

Table 5: Concentrations of Organochlorine compounds in sediments from different sampling points of river Nyando in August 2004.

Station	α-BHC	β-BHC	Lindane	Aldrin	Dieldrin	Endrin	Heptachlor	Heptachlore	Mathoxychlor	Endosulfan
Kedowa	6.15	4.5	4.13	2.35	1.15	0.87	1.89	0.99	0.055	0.07
Pararget	2.58	2.32	2.5	1.35	0.98	1.15	1.65	0.85	1.35	0.19
Mbogo 1GB6A	5.26	2.5	2.15	1.55	1.66	1.56	1.85	0.85	0.95	0.01
Ainamutua 1GB3	4.22	3.01	1.5	1.25	0.09	1.5	0.98	2.5	0.85	0.05
Nyando at 1GD3	3.52	2.75	3.05	1.15	0.085	1.2	2.65	1	0.05	0.0095
Nyando Dyke	3.15	2.75	3.5	1	0.07	0.07	2	0.45	0.03	0.05

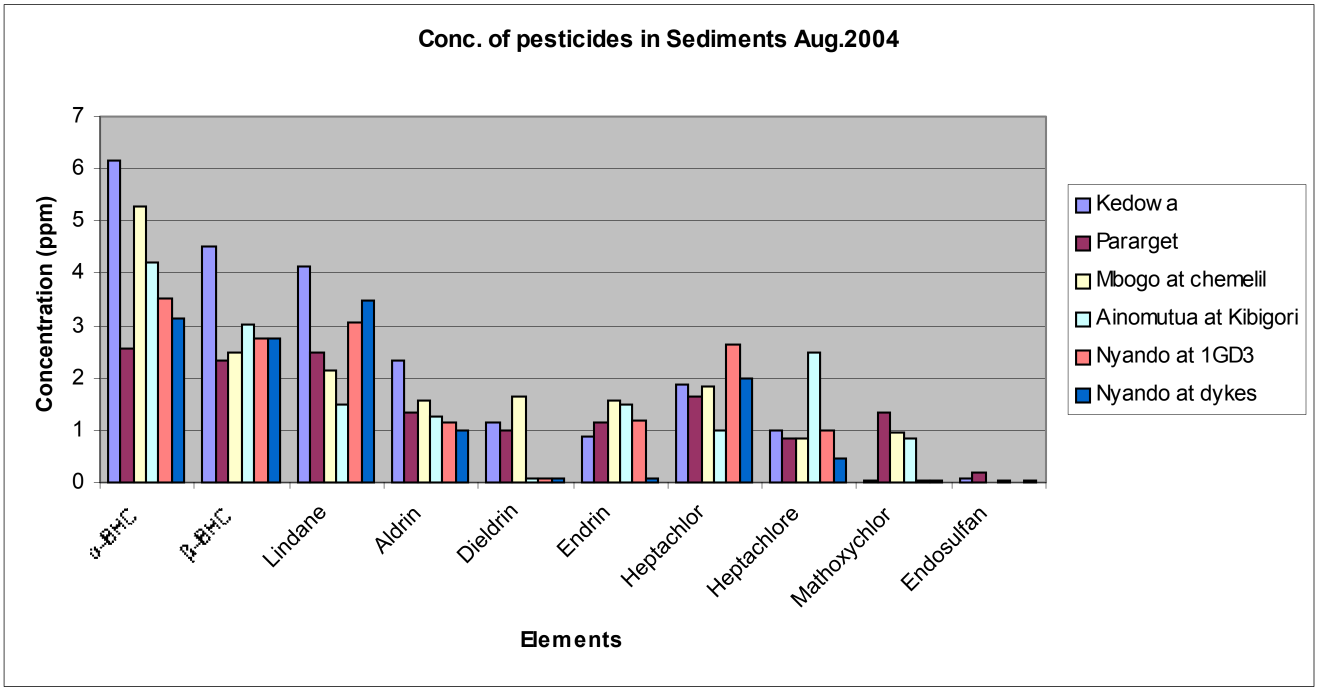


Fig 5: Concentration of pesticides in sediment samples from different sampling stations of river Nyando in August 2004 (there should be a map of all these sampling sited. Where are they located I assume they are ordered in a downstream manner but I cannot assess the meaning without understanding the drainage network.

Table 6: Concentrations of heavy metals in wastewater from various facilities in major towns.Why are some data put in bold

Date	Station		Cd	Cu	Fe	Pb	Mn	Zn	Cr	Co	Ni
6/11/2003	Bungoma Muni.	RE	0.00	0.00	**0.02**	0.00	0.14	0.55	**0.14**	0.00	0.00
6/11/2003	Bungoma Muni.	FE	0.00	0.03	**0.75**	0.00	0.07	0.10	**0.02**	0.00	0.00
18/10/2004	Busia Muni.	RE	0.00	0.02	**4.60**	0.00	0.25	0.25	0.05	0.29	0.30
18/10/2004	Busia Muni.	FE	0.00	0.69	**2.50**	0.00	0.00	0.40	0.00	0.29	0.36
18/10/2004	Chepkoilel campus	RE	0.00	0.00	0.60	0.00	0.08	0.00	0.00	0.00	0.00
18/10/2004	Chepkoilel campus	FE	0.00	0.00	0.33	0.00	0.22	0.00	0.00	0.00	0.00
6/11/2003	Eldoret Muni. Ponds	RE	0.00	0.00	0.00	**0.05**	0.05	0.87	0.24	0.00	0.01
6/11/2003	Eldoret Muni-ponds	FE	0.00	0.18	0.01	**0.11**	0.05	0.11	0.00	0.01	0.00
18/10/2004	Eldoret New& (STN)	RE	0.00	0.00	2.16	0.00	0.40	0.10	0.15	0.00	0.00
18/10/2004	Eldoret New& (STN)	FE	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00
6/11/2003	Homa Bay Muni.	RE	0.00	0.10	0.03	**0.01**	0.05	0.26	0.16	0.01	0.00
6/11/2003	Homa Bay Muni.	FE	0.01	0.19	0.02	**0.13**	0.03	0.24	0.09	0.01	0.05
6/11/2003	Kakamega Muni.	RE	**0.01**	0.00	0.53	0.00	0.28	0.08	0.06	0.00	0.00
6/11/2003	Kakamega Muni.	FE	**0.00**	0.00	0.00	0.10	0.04	0.80	0.18	0.00	0.00
18/10/2004	Kakamega(shi)-	RE	0.00	0.09	9.44	0.00	0.22	0.35	0.05	0.26	0.23
18/10/2004	Kakamega(shi)-	FE	0.00	0.02	0.73	0.00	0.07	0.00	0.00	0.23	0.22
18/10/2004	Kapsabet-	RE	0.00	0.00	5.00	0.00	0.44	0.20	**5.00**	0.00	0.00
18/10/2004	Kapsabet-	FE	0.00	0.00	0.00	0.00	0.11	0.00	**0.00**	0.00	0.00
18/10/2004	Kericho Muni.	RE	0.00	0.03	**12.7**	0.00	0.47	0.00	0.00	0.00	0.00
18/10/2004	Kericho Muni.	FE	0.00	0.00	**0.15**	0.00	0.08	0.00	0.08	0.00	0.02
18/10/2004	Kisumu Conv. STW-	RE	0.00	0.00	5.84	**0.05**	0.86	0.25	0.05	0.46	0.00
18/10/2004	Kisumu Conv. STW-	FE	0.00	0.03	4.13	**0.05**	0.40	0.20	0.00	0.48	0.00
18/10/2004	Kisumu Ponds	RE	0.00	0.01	**11.00**	0.00	0.99	0.65	0.00	0.40	0.45
18/10/2004	Kisumu Ponds	FE	0.00	0.00	**1.38**	0.00	0.00	0.00	0.00	0.47	0.48
6/11/2003	Kisii Muni.	RE	0.00	0.03	0.00	0.00	0.08	1.06	**0.24**	0.00	0.01
6/11/2003	Kisii Muni.	FE	0.00	0.00	0.00	0.04	0.03	0.40	**0.00**	0.00	0.00
6/11/2003	Kitale Muni.	RE	0.00	0.00	0.63	0.00	0.26	0.00	0.06	0.00	0.00
6/11/2003	Kitale Muni.	FE	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
18/10/2004	Kitale Matisi-	RE	0.00	0.00	0.84	0.00	0.13	0.00	0.00	0.00	0.00
18/10/2004	Kitale Matisi-	FE	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.17	0.02
18/10/2004	Moi Main Campus	RE	0.00	0.00	1.90	0.05	0.02	0.05	0.00	0.55	0.00
18/10/2004	Moi Main Campus	FE	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.54	0.00
18/10/2004	Mumias Artisan-	RE	0.00	0.00	0.25	0.05	0.00	0.00	0.00	0.39	0.40
18/10/2004	Mumias Artisan-	FE	0.00	0.00	0.65	0.00	0.00	0.00	0.05	0.39	0.47
18/10/2004	Mumias Central-	RE	0.00	0.09	1.94	0.10	0.00	0.05	0.00	0.46	0.38
18/10/2004	Mumias Central-	FE	0.00	0.02	0.38	0.05	0.00	0.00	0.00	0.43	0.38
18/10/2004	Mumias muni-	RE	0.00	0.07	8.33	0.05	0.45	0.55	0.05	0.34	0.81
18/10/2004	Mumias muni-	FE	0.00	0.07	8.34	0.15	0.54	0.25	0.05	0.40	0.32
6/11/2003	Sony Sugar	FE	0.00	0.00	0.03	0.01	0.02	0.27	0.16	0.01	0.00
6/11/2003	Sony Sugar	RE	0.01	0.00	0.02	0.07	0.03	0.88	0.18	0.00	0.01
6/11/2003	St. Joseph Hosp.	RE	0.00	0.10	0.03	0.00	0.04	0.37	0.06	0.01	0.01
18/10/2004	Webuye Muni.-	RE	0.00	0.00	**0.35**	0.00	0.00	0.10	0.00	**0.27**	0.30
18/10/2004	Webuye Muni.	FE	0.00	0.03	**0.07**	0.00	0.06	0.00	0.00	**0.19**	0.05
18/10/2004	Webuye Paper	FE	0.00	0.02	0.83	0.05	0.08	0.05	0.05	0.13	0.08

Key: RE = Raw Effluent,
FE = Final Effluent

Table 7: Show Concentrations of heavy metals in water from various rivers in the lake basin (Nov.2003-April 2004). Should give limit of detection (LOD) not zero as a value

Date	Station	Cd	Cu	Fe	Pb	Mn	Zn	Cr	Co	Ni
6/11/2003	R. Nzoia at Rwambua	0	0	1.36	0	0	0	0.01	0	0
6/11/2003	R.Sio at Mundika	0.02	0	1.15	0	0	0.03	0.02	0	0
6/11/2003	R.Awach Seme	0	0	0.33	0	0	0	0.01	0	0
6/11/2003	R.Yala at Kadenge	0.02	0	1.36	0	0	0	0.02	0	0
8/4/2004	R.Awach Kibuon	0	0	5.7	0.14	0	0	0	0	0
8/4/2004	R.Kuja-Migori at Wathonger	0	0	5	0.24	0	0	0	0	0
8/4/2004	R.Mara at Bridge	0	0	0.9	0.33	0	0	0	0	0
8/4/2004	R.Miriu at Nyakwere	0	0	0.6	0.14	0	0	0	0	0
8/4/2004	R.Nyando at Ogilo	0	0	2.7	0.42	0	0	0	0	0

Table 8: Explain sample code

Kisumu Bay- Heavy Metals Concentration (ppm) in Fish Muscle and Water

Station	Sample	Pb	Cd	Ni	Fe	Cu
Dunga	T	1.3	0.12	1.67	0.72	0.05
Dunga	NP	1.22	0.09	1.18	1.03	0.04
Dunga	MF	1.36	0.11	1.6	0.85	0.05
Hippo Point	T	1.37	0.12	1.77	0.99	0.05
Hippo Point	NP	1.32	0.11	1.63	0.22	0.04
Hippo Point	MF	1.5	0.15	2	1	0.08
Police Pier	MF	1.68	0.12	1.41	0.8	0.12
Otonglo Point	MF	0.12	0.02	0.03	1.45	0.02
Dunga Point	W	0.15	0.01	0.09	0.7	0.01
Hippo point	W	0.23	0.006	0.08	1.04	0.01
Shell-Power	W	0.19	0.007	0.07	5.6	0.014
police Pier	W	0.13	0.02	0.02	1.5	0.014
Otonglo Point	W	0.09	0.01	0.07	0.15	0
Kisat River	W	1.21	0.08	1.04	5.73	0.05

Table 9: Mean Concetration of heavy metals in water and fish muscle from Kisumu bay of Winam Explain units for fish and water the sample code in this caption

Gulf

Station	Sample	Pb	Cd	Ni	Fe	Cu
Ksm Bay	Mud Fish	1.17	0.10	1.26	1.03	0.07
Ksm Bay	Nile Perch	1.27	0.10	1.41	0.63	0.04
Ksm Bay	Tilapia	1.34	0.12	1.72	0.86	0.05
Ksm Bay	Lake Water	0.16	0.01	0.07	1.80	0.01

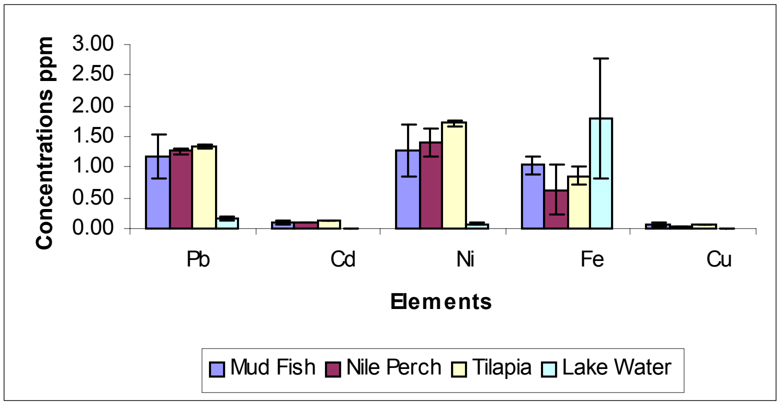


Fig. 6: Concentrations of heavy metals in water and fish muscle from Kisumu bay of Winam

Gulf (199-2000)

Table 10: Chemical composition of the bed load sediments from major rivers in the lake Victoria basin. Check these numbers some cannot be correct for example column on % Na2O and zero for percent SiO2 which means no sand in this sample and I don't know what it could be this table is likely not necessary to this chapter

Date	Station	SiO_2 %	Al_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	TiO_2 %	MnO %	Fe_2O_3 %
8/4/2004	Awach Kibuon-S	0	19.4	4.2	13	822	49	60.5	17.4	9
6/11/2003	Awach Seme-S	88.5	10.23	0.82	0.44	1.86	1.43	0.61	0.12	6.1
8/4/2004	Kuja-Migori-Watho.	0	3	1.75	4	262	28.8	70.7	3.1	0
8/4/2004	Mara-Bridge-S	0.02	20.8	6.65	8	720	71.6	69.1	23.5	14
8/4/2004	Miriu-Nyakwere-S	0	12.7	3.71	14	465	52.3	158.9	9.7	9
8/4/2004	Nyando-Ogilo-S	0.03	16.6	2.87	15	623	52.3	71	12.6	9
6/11/2003	Nzoia-Rwambua-S	92.2	4.62	0.81	0.2	1.34	1.79	0.29	0.02	1.33
6/11/2003	Sio-Mundika-S	90.7	4.19	0.73	0.26	1.02	1.43	0.51	0.03	1.39
6/11/2003	Yala-Kadenge-S	80.6	12.97	0.25	1.46	1.36	1.55	1.14	0.18	8.93

DISCUSSION

The present study revealed high (how do you define high?) concentrations of the organochlorine compounds in the soil samples from different fields in the sugar belt (Table 1 and Fig.1).

Even in the field where the pesticides were applied five years ago, measurable or high high concentrations of the compounds were still detected (Table 1 and Fig.1).

Their continued use in the agricultural sector although illegal as far as the Kenya Government policy is concerned, has been attributed to their availability at low costs, low mammalian toxicity and their broad-spectrum bioactivity for a long duration (Wandiga et al. 2002a). Although low in mammalian direct toxicity some bioaccumulate and can disrupt physiological functions in aquatic organism as well as humans

All the ten compounds were still in the soil after five years with the highest concentration of endosulfan (1.552±0.512ppm) followed by lindane (1.294±0.346ppm). Heptachlor concentration was the least (0.243±0.032ppm) in the soil after five years. This true in May but not in October see figs. 1 and 2

The high concentration of endosulfan in soil is of great concern because of its extreme toxicity to fish and aquatic invertebrates (Gonzalez et al. 2003). Studies have shown that organochlorine pesticides such as the cyclodiene, heptachlor, aldrin, endrin, and dieldrin are the most persistent and were found to persist in field crop soils for long periods of time, with long half-lives of disappearance ranging from 0.3-2.8 years in temperate soils (Wandiga 1995). The adsorption of the compounds by soil, which was influenced by diverse factors such as organic matter content, soil type, and physical-chemical properties of pesticides, that is, vapor pressure, water solubility, and the n-octanol-water partition coefficient (K_{ow}), played a role in the persistence of the compounds in soil (Cheng 1990). The results (table 1 and figure 1) showed that aldrin and heptachlor were in higher concentrations than their metabolically formed analogues, dieldrin and heptachlor epoxide, respectively. Studies by other researchers have also shown that aldrin and heptachlor were in higher concentrations than their converted products (Barlas 2002; Barlas 1999; Ayas et al. 1997). Ratios of DDE/DDT, α-BHC/lindane, dieldrin/aldrin and heptachlor e/heptachlor in soil are often used as indicators of recent DDT, lindane (γ-BHC), aldrin and heptachlor inputs into the environment, with low ratios, particularly <1, indicating recent input (Gonzalez et al. 2003).

For α-BHC, it appears the compound is applied directly in the soil and does not necessarily originate from the degradation of lindane. This is further supported by the data presented in table 2, where the concentration of α-BHC was abnormally high.

From table 2 and fig. 2 it was revealed that pesticides had just been applied to the fields a month before. Comparing the data with one obtained from the previous sampling (table 1), it was clear that α-BHC had been applied to all fields, including the one which had not received pesticides in the last five years and was still idle and overgrown with vegetation during the second sampling. Need to clarify that these are **same** fields in October and May with an intervening treatment of pesticides. This is somewhat confusing as it is now
The other compounds that were applied to all fields but in lower quantities than α-BHC were ß-BHC and lindane. The remaining compounds heptachlor, aldrin, heptachlor epoxide, endosulfan, dieldrin, endrin and methoxychlor did not seem to have been applied especially to the field designated as "2 months" in the previous sampling. This was supported by concentrations of these compounds that were lower than the concentrations obtained in the previous sampling.

In the five months after the previous sampling, rain could have influenced the dissipation of the compounds from soil through surface run-off, leaching and evaporation, resulting in lower concentrations than those obtained in the previous sampling. Concentrations of these compounds were generally higher than in the previous sampling from other fields, implying that these compounds could have been applied to the fields prior to second sampling.

Figures 3,4 &5 and Tables 3,4 &5 show results of analysis of water samples from different sampling sites. These sites receive surface run-offs from the fields in the sugar belt, maize, wheat, coffee, tea and rice growing areas. Most of the pesticides were detected in all the sampling sites except endosulfan, which was only detected on R. Nyando at Muhoroni, pararget???,Mbogo and methoxychlor on Ahero channel, pararget and river Mbogo. High concentrations of α-BHC were recorded in all the samples from the seven sites. With exception of the sample from river Kedowa with a high concentration of α-BHC (0.691ppm), the other six sites had an average concentration of 0.219±0.091ppm. River Mbogo recorded the highest concentration of lindane (1.240ppm). There was good correlation between the concentrations of the three isomers α-BHC, ß-BHC and lindane in the soil and in the surface water (table 2 and fig. 3). The pesticides reached the surface water through surface run-off. Although high concentrations of the α-BHC, ß-BHC and lindane were detected in the fields when the surface waters were analyzed, the corresponding concentrations of pesticides detected in water were low due to their low water solubility and their high values of log K_{ow} and log $K_{oc.}$ These factors, coupled with high clay content (60%) and OC (2.07%) in the soil increased the adsorption of the pesticides in the soil thus reducing their rate of transportation through surface run-offs (Diaz et al. 1995). The concentrations of the compounds such as α-BHC, ß-BHC and lindane were still above the U.S. Environmental Protection Agency (EPA) limits for drinking water of between 0.001 and 0.002 ppm (ATSDR 2002).

The distance between the fields and the various sampling sites along the rivers increased from river Mbogo to river Nyando at Ahero bridge. The concentrations of the pesticides at these sites also decreased as one moved farther away from the fields (Figures 3, 4 & 5).

The decrease in concentrations of the pesticides in water as the distance of sampling sites increased from the fields was due to the adsorption of the pesticides by soil, which reduced the movement of the pesticides to the surface. These compounds have also been detected in water,sediment, weeds and aquatic organisms (fish) samples collected from inland lakes of Baringo, Naivasha, Nakuru and Victoria in Kenya in previous studies (Wandiga et al. 2002b).

\According to Madadi V. O. and Wandiga S.O. 2004 water, sediment, weeds and fish samples collected from river Sio, river Nzoia, Sio Port Beach and Marenga Beach indicated the presence of organochlorine pesticides (α – HCH, β –HCH, γ

- HCH, p,p' –DDT, o,p'-DDE, p,p'-DDD, α – Endosulfan, Endosulfan sulphate, β-Endosulfan, Aldrin, Dieldrin, Endrin, Heptachlor, Heptachlor e, Methoxychlor) . The detected levels in sediment were considerably higher than those found in water. The weeds exhibited higher concentration of pesticides than that found in the water but lower than that in the sediments. The pesticides residues in the muscle of *Tilapia zilli* showed a wide variation with a mean much higher than in water and weeds but lower than in sediments.

Table 6 indicates the levels of heavy metals in the raw and final effluents from wastewater treatment facilities in the major towns within the lake basin. The concentration of the trace metals appears reduced in most final effluents, which shows some that some facilities are effective, but abnormal cases appears on lead where most final effluents have higher concentrations than raw effluents, which might be associated with type of equipment and materials being used in the treatment.

Table 7, shows the concentrations of heavy metals in water from various rivers in the lake basin, iron is found in samples from all rivers and others rivers show presence of lead, chromium, zinc and cadmium, which is attributed to the contribution of wastes from the urban centres situated along the drainage basin.

Table 8 &9 and fig. 6 the obtained levels of lead, cadmium, iron, nickel and copper in fish fillet, lake water and river water were in the average range of 0.12-1.68 ppm, 0.09-0.19ppm and 1.21ppm respectively. These levels are within the acceptable regulatory limits in Kenya, 10ppm for marine and fresh water fish, animal products and 5ppm recommended by the WHO. The values are similar to values of lead obtained by Hoene 1983, 0.32-0.35ppm for Tilapia muscles, Onyari 1987 0.41-0.67 ppm for Tilapia muscle, using similar methods.

For water samples WHO recommended values range 0.05-0.1ppm for drinking water. Comparing values obtained by Shitsama 1999 0.12-0.45ppm. Meaning is unclear which levels of yours are you comparing with Shitsama ???The determined levels of lead show reasonable increase. This may be due to dramatic increase of industries in the urban centres within the lake basin, which results to industrial waste and municipal waste discharge directly into the receiving waters, automobile exhaust fumes, and oil spillage.

The cadmium values in fish are within the acceptable current regulatory limits for cadmium in seafoods 2.00ppm wet-weight in USA and Australia, and 1.0 ppm in New Zealand. For water samples the values are slightly above the acceptable limits recommended by WHO (0.005- 0.01mg/l) for drinking water.
Compared with the values obtained by Onyari 1987, 0.04-0.07 ppm fish muscles, Shitsama 1999,0.69-1.94ppm fish muscles and 0.01-0.02ppm for water and Alala 1981 0.0ppm surface run-offs from garages. **Make this a sentence(s) and make sure its meaing is clear –I could not follow your thoughts here**

The values of Nickel in fish muscle, lake water and river water were in the range, 0.03-2.0 ppm, 0.02-0.09ppm,no range here1.04ppm respectively. The values obtained in fish muscles and lake water are relatively low and hence should pose no dangers to the consumers and the aquatic organisms. The results obtained from River Kisat are high due to industrial and municipal wastes being discharged into the river directly or indirectly from Kisumu Town.

The obtained levels of iron in fish muscle, lake water and river water were in the range, 0.22-1.45ppm, 0.15-5.60ppm and 5.73ppm respectively and can be compared to WHO recommended values 0.1-1.0 ppm for drinking water, and the maximum permissible level in fruit juice is about 15 ppm.

Levels of copper in fish fillet, lake water and river water were in the range 0.02-0.12 ppm, 0.0-0.014ppm, 0.05ppm respectively. The WHO recommended values for drinking water range 0.05-1.5 ppm. So the obtained values in water and fish muscle are within the acceptable current advisory limits for protection of human health, but copper is known to be exceedingly toxic to aquatic biota even as low as 0.025 ppm.

Delete table and this reference-not necessary to discussion or chapter
Measurements of heavy metals like copper, zinc, manganese, iron, cadmium, lead and chromium have been carried out in various media of the lake by various researchers (Wandiga and Onyari, 1987; Onyari and Wandiga, 1989) and generally indicated that sediments have higher trace metal concentrations than water and other living organisms in the lake. However levels in sediments how do levels in sediments relate to drinking water guidelines do you mean in water are above those recommended by WHO guidelines for drinking water, 1996/98. The WHO guidelines levels for drinking water require the concentration of the metals to be 0.003 ppm for cadmium, 0.01 ppm , lead, 0.05 ppm, chromium, 0.001 ppm for mercury, 0.4 ppmfor manganese and 2 ppm for copper (WHO 2004). So how do these relate to your concentrations???

CONCLUSIONS

The present study has shown that banned organochlorine pesticide compounds are still being used in the catchments.

There were high concentrations of the compounds in soil where they are directly applied. They were also detected in water and sediments from rivers which drain through the farming areas, and that their concentration in water was influenced by their concentration in soil and sediments and rain played a major role in the transportation process through surface run-offs. Their presence in the soil for up to five years since last application shows that the pesticides also persist in tropical soil conditions.

It has been observed that most farmers are unaware of the safe use and handling practices for the agro-chemicals being used in the catchment, which results in some injuries and illness.

The amount of pollutant loads and the type of pollutants depend on the origin and land use activities in the particular river catchment.

Deforestation, poor agricultural practices, over-stocking and gracing have all contributed to massive soil erosion and there are serious surface run-off problems that bring the soils and associated pollutants to the lake.

Pollution from heavy metals especially lead, cadmium, and mercury is a serious problem that needs considerable attention and monitoring as these compounds can be toxic in low concentrations**.**

Obtained levels of lead, cadmium, nickel, iron and copper in fish muscle from Kisumu Bay of lake Victoria are within the acceptable limits of the Kenyan and international standards for marine and fresh water animal products.
The levels of the heavy metals in water were lower than the levels found in fish muscle, which shows the accumulative concentrations of the heavy metals in fish muscle. Need to cite studes of Campbell et al in regards to Hg in fish in Winam Gulf and risks associated with Hg. See references I have added to your list
River Kisat has relatively higher values than lake water and this is attributed to the fact that River Kisat serves as a sink for industrial and sewage waste from Kisumu Town.

The levels of trace elements in the industrial and domestic effluents apparently show that most final effluents have lower concentrations after treatment.

The major driving force behind water quality deterioration is population increase.

RECOMMENDATIONS

There is a need to apply a mixture of command and control laws on importation and enforcement of regulations as well as market forces to effect change. Some market price adjustment for fertilizers and pesticides will introduce their conservative use and discourage use of banned pesticides.

Sensitization of farmers on the safe use of agro-chemicals in the catchment will enhance proper and appropriate usage of agro-chemicals in the farms.
Use of lead free petrol should be regulated and enforced by the relevant Governments and law enforcement bodies.

The environmental law (EMCA) should be properly enforced to ensure that no direct disposal of industrial and municipal wastes into the receiving waters and wastewater standards should be put in place.

Review of land tenure system in the catchments is an essential first step to the restoration activities of the lake. Ownership will encourage farmers to adopt best practices to improve their land and keep it contaminant free.

Reorganization of the rural villages into self –supporting, well serviced utilities in urban centres will free land for cultivation that can be properly planned and managed.

Enforcement of laws governing agriculture, forest, land and water conservation will lead to sediment and nutrient load reduction. Most of the heavy metals with the exception of Hg are brought into the lake in association with sediments.

The planning of urban and rural centres will lead to the provision of waste treatment plants, potable water, electricity, roads and other utilities. Once utilities are provided there should be sufficient financial resources to ensure maintenance of installed infrastructures are operational at all times.

Operation and maintenance systems should be strengthened. The quality of our environment cannot be maintained if utilities are non-functioning. Hence sufficient resources need to be budgeted each year for operations and maintenance, so that all municipal waste treatment plants that are in disrepair are, made to function and trained staff should be engaged to ensure their continued service.

Market forces should be put in place to reward or penalize the offenders and enforcement of the polluter pays principle is an incentive to ensure that profits are not wasted in paying taxes and fines.

Establishment of institutions that will encourage stake-holders participation in conservation and management of resources at the village, local, national and regional levels is essential for the Lake Victoria resources utilization.

Because Lake Victoria is a shared resource, the East African Community should play a stronger role in regional policy coordination and at the national levels the respective riparian government should show both political will and policy direction in establishing policies that engage the public in enforcing existing rules and regulations and where deficient, making new ones; and establishing policies that use existing markets.

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APPENDIX

Table 1:Agricultural land use in the Lake Victoria Catchment.

CROP	**AREA (ha)**	**%**
Maize	550000	48.2
Beans	200000	17.5
Sugar	110000	9.6
Sorghum	60000	5.2
Cassava	40000	3.5
Bananas	35000	3.0
Tea	30000	2.6
Cotton	30000	2.6
Coffee	25000	2.2
Millet	25000	2.2
Sweet Potatoes	20000	1.7

Others	15000	1.3
TOTAL	1140000	100

Table 2:Livestock Production in the Lake Victoria Catchment.

LIVESTOCK	NUMBER
Cattle	5,000,000
Sheep and Goat	3,000,000
Poultry	11,000,000

Table3: Agro-chemicals used in the Lake Catchment.

Type of Culture	Fertilizers	Insecticides/ Acaricides	Fungicides	Herbicides
Maize	• CAN • DAP • NPK • UREA (Nitrate)			
Rice	• DAP • CAN	• Furadan • Carbofuran		
Tea	• CAN • ASN • NPK 25:5:S • NPK 20:20:0 • NPK 26:6:12 • FOLIAF	• Fenitrothiom • Dimethoate • Diazinon • Karate	• Copper-Zinc Spray • Dithane M45(Mancozeb) • Marshal • Milraz(metalaxyl&propinep) • Ridomil(metalaxyl)	• Round up(Glyphosate) • Touch Down • Gramoxone(Paraquat) • Afalon • 2-4D Amine (72%)

	EEDS • UREA			
Sugar Cane	• NPK • CAN • UREA		•	• Round UP • Diuron • Nata • Kombi
Coffee	• NPK 20:20:0 • NPK! 7:17:0	• Diazinon • Dasis • Fenitrothiom • Fenthiom	• Copper Nordox • Kocide 101 • Dithane • Antracol • Copper-Oxychloride	• Round Up
Horticulture	• DAP	• Diazinon • Ambush • Doom Powder • Karate • Dimethoate	• Dithane Super • Milruz • Ridomyl • Mithane Super • Acrobat • Antracol • Sancozeb • Samcozide	
Cattle		ACARICIDES • -Tritix • -Delnav • -Steladone • -Almatix	•	

SOURCE:- Farmers and DALEO Offices- Nandi, Kericho and Nyando Districts

KEY: **DAP** = Diammonium Phosphate (NH4) 2HPO4 **TSP** = Triple Superphosphate

NPK = Nitrogen Phosphate potassium **SSP** = Single Superphosphate

CAN = Calcium ammonium phosphate **ASN** = Ammonium Sulphate nitrate

Table 4. Main Agrochemical Use and the Recommended Rates.

AGROCHEMICAL	CROPS USED ON	RATES AND REMARKS
Urea-Fertilizer	Sugar and occasionally Rice	50-100 kg top dressing, used in splits
CAN-Fertilizer	All Crops	50-120 kg per top dressing, used in splits
DAP and NPK-Fertilizer	All Crops	75-150 kg per ha. Basal application
Karate*	Tomatoes, Kales, Cotton	750-1000 litres per ha.
Milraz	Tomatoes	30-50 gm/20 litres
Dithane M45/ Mancozeb	Tomatoes	30-50 gm/20 litres
Actellic Supper	Cereals-Maize + Sorghum	100gm per 90 kg bag on storage pests
Dimethoate	Vegetables, fruit trees, tobacco	25-50mls/20lts, 0.75-1.5 litre per ha. In a number of trade names.
Ridomil	Tomatoes	180gm/20 litres, 500-1000 gm per ha.
Milthane	Tomatoes	180gm/20 litres, 500-1000 gm/ha.
Furadan 5G	Rice and Hort.nursery	1-1.5 kg per ha.
Kocide	Coffee	2-2.5 kg per ha.

Dipterex	Maize and sorghum	1 kg per ha.
Linulon	Sugarcane	Herbicide upto 5 kg per ha.
Round up	Sugarcane	Herbicide upto 3- 5 kg per ha.

SOURCE: District Agriculture Office Nyando (NYD/SUP/VOL.I/98).

Table 5.Annual Crop Production and amount of Pesticides and Fertilizers used in Kericho District.

Crop	**Area (ha)**	**Fertilizers(Tons)**	**Pesticides (Tons)**
Maize	32,000	5,000	650
Beans	16,000	1,200	450
F/millet	2,000	15	Nil
Sorghum	1,700	10	Nil
Wheat	70	10	5
Irish Potatoes	500	100	15
Sweet Potatoes	80	Nil	Nil
Horticultural Crops	2,300	1,000	850
Tea (KTDA)	5,200	1,400	150
Coffee	3,000	400	300
Sugarcane	3,100	500	30
Prethrum	400	80	Nil
TOTAL	**66,350**	**9,715**	**2,450**

Table 6 : Agrochemicals used by Chemelil Sugar Company.

Chemicals **Fertilizer (Kgs)**	**Nucleus Estate**	**Out growers**	**Nandi Out growers Company**	**Chemelil Out growers Company**	**TOTAL**
Urea(46%N)	230,000	211,600	32,500	132,650	606,750
CAN(26%N)	490,000	155,150	26,550	132,200	803,900
NPK 23:23:0	100,000	180,150	40,000	43,650	363,800
NPK 17:17:0	100,000	8,050	**-**	**-**	108,050
Herbicides (Litres)					
Round-Up	1,030	18,000	325	180.5	19,536
Sencor	978	3600	400	400	5378
TCA	3000	15,000	1000	2,000	21,000
Velpar	600	400	-	-	1000

Gesapax Combi	1500	4,918	213	1119.5	21250.5
Actril(D.S.)	300	1,000	73	257	1630
Diuron	-	-	122	-	122
Insecticides (Litres)					
Confidor	20	-	-	-	20

Table 7: Annual use of pesticides in Nandi District.

Enterprise	**Level of Adoption %**	**Area Ha**	Annual Pesticide Amounts Used in Kilograms			
			Fungicides	**Insecticides/Acaricides**	**Herbicides**	**TOTAL**
Maize		64,500	0	60,000	10,000	70,000
Beans	5	12,560	1,300	0	0	1,300
Brassicas	50	1,200	2,400	9,600	0	12,000
Sugarcane	80	9,500	0	0	30,000	30,000
Coffee	80	1,100	3,300	5,300	5,300	13,000
Floriculture	80	5	400	300	10	710
French beans	80	70	500	500	0	1,000
Irish potato	60	300	2,200	0	0	2,300
Passion fruit	80	10	200	100	0	300
Tea	80	25,000	0	0	96,000	200,000
Tomato	70	360	6,000	3,000	0	9,000
Livestock		0	0	(120,000)	0	120,000
TOTALs		**114,605**	**16,300**	**198,800**	**141,310**	**460,510**

Table8: Quantities of pesticides imported [tonnes] into Kenya

YEAR	**Insecticides / Acaricides**	**Herbicides**	**Fungicides**	**Others**	**TOTAL**
2002	57.1	11.4	28.4	3.1	100
2001	52.5	7.6	22.9	17.0	100
2000	50.6	13.7	32.4	3.3	100
1999	47.0	10.3	35.5	7.2	100
1998	38.4	16.7	43.6	1.2	100
1997	48.4	12.5	34.4	4.7	100
1996	47.7	13.2	35.6	3.5	100

1995	39.8	17.6	38.4	4.2	100
1994	37.8	22.3	33.7	6.6	100
1993	35.5	22.6	36.6	5.3	100
1992	39.0	17.7	35.4	7.9	100
1991	32.9	23.9	36.4	6.8	100
1990	40.4	24.7	26.3	8.6	100
1989	28.8	21.4	45.5	4.3	100
1988	24.0	21.9	49.8	4.3	100
1987	24.6	23.4	48.2	3.8	100
1986	23.2	20.9	48.6	7.3	100

Table 9: List of banned or restricted pesticides in Kenya.

No	Pesticide	Use	Status
1	Dibromochloropropane	Soil fumigant	Banned
2	Ethylene dibromide	Soil fumigant	Banned
3	2,4,5,-T	Herbicide	Banned
4	Chlordimeform	Insecticide	Banned Banned
5	Mixture of isomers of Hexachlorocyclohexane (HCH)	Insecticide	Banned
6	Lindane {pure γ-BHC (HCH) }	Insecticide	Restricted use for seed dressing only
7	Chlordane	Insecticide	Banned
8	Heptachlor	Insecticide	Banned
9	Endrin	Insecticide	Banned
10	Aldrin	Insecticide	Restricted for termite control in building industry

			building industry
11	Dieldrin	Insecticide	Restricted for termite control in building industry
12	Toxaphene (Camphechlor)	Insecticide	Banned
13	DDT	Insecticide	Restricted use to Public Health only for mosquito control in mosquito breeding grounds, banned for agriculture use
14	Captafol	Fungicide	Banned –1989
15	Parathion methyl/ Parathion ethyl	Insecticide	Banned- 1988
16	Daminozide (Alar)	Plant growth regulator for use on fruits	Voluntarily withdrawn by the company
17	Cyhexatin(Plictran)	Acaricide	Voluntarily withdrawn by the company

Nos. 1-13 banned in ***1986***

SOURCE-Pest Control Products Board BOX 14733, Nairobi, Kenya.

CHAPTER 12

Study on Water Quality and Human Health in the Lake Victoria basin, Kenya

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Background

Water is one of the most important resources for man's survival. In recognition of this fact, and in order to fight diseases which was one of the three cardinal problems identified at independence as being the hindrance to the development of this nation, the Government of Kenya instituted Water Supply and Sanitation Programmes in various parts of the country to bring water closer to people and improve the their health. The National Water Master Plan, launched in 1974, had the express aim of ensuring that potable water was made available, at a reasonable distance, to all households by the year 2000 through the establishment of water supply schemes, sinking of boreholes, construction of catchment dams and construction of conveyance infrastructure in the forms of pipes and furrows.

It has been generally believed that human health has a close relationship with water quality, but not enough studies have been done to quantitatively relate the two. When the LVEMP was conceived, one the problems cited was increase of diarrhoeal diseases in the riparian communities, thought to be due to deteriorating water quality. It therefore became necessary to study the effect of water quality on human health within the Lake Victoria basin. However, after a few ears of project implementation, there was still limited knowledge of the water quality in various parts of the Lake (particularly bays) and its relationship with human health. The direct or indirect measure for improving the livelihood of the inhabitants living in the Lake Region was a key goal for this project. It was therefore important to get an overview of what was known about the relationship between *water quality and human health,* with possible changes over time.

The main purpose of the Study was "*to review the relationship between water quality and human health in the Lake region and the effects that various mitigation measures may have*". This was to help make future projects to be more focused towards the main goal of improved standard of living for the inhabitants in the study area, through improved human health conditions.

This report contains findings and analysis from Kenya from the study on *Water Quality & Human Health* (give a reference) around Lake Victoria.

Study methodology

The main components of the Study comprised: desk review of relevant documents; collection of statistics on relevant water-related diseases and water quality parameters; meetings with relevant health and water institutions and stakeholders centrally; and visits to health centres, dispensaries and villages locally.The study thus tried to establish the water quality/human health relationship based on available data and information, and find out the aspects, which seem to have the largest impact. All the readily available data and written materials were collected.

The Study thus had a dual approach, a *quantitative* one (statistics and data for five consecutive years) and a *qualitative* one (interviews with stakeholders, field observations, etc.). In order to limit the human health parameters to a practical number, data for the following diseases were collected (considering those most relevant to the water-health relationship): diarrhoea, dysentery, typhoid, cholera, schistosomiasis (hereafter for simplicity reasons referred to as *bilharzia*), intestinal worms and skin infections.

The water quality data from the lake largely came form LVEMP studie, complemented by other institutions' data, which were scarcely available. The main water quality parameters assumed to have an impact on human health were compiled, like coliform bacteria, nutrients, suspended solids, etc.

It is widely known that several factors interact and jointly decide the human health conditions therefore evaluating water quality alone, as the only thing related to human health was not adequate. It therefore became necessary to also review the sanitary/waste disposal conditions in the study locations, in addition to the level of sensitisation/health education of the population.

Meeting with central authorities and key stakeholders

In order to collect as much overall and aggregated reference statistics as possible, relevant government institutions in Kisumu City (provincial and district offices) as well as field stations and local people, were visited in order to collect data and information on waterborne and water-related diseases, and to discuss the relative importance of water quality as related to human health. In addition, key institutional actors within water, sanitation and health were also visited in order to get the best overview of other past and ongoing activities within the sector. The intention was also to get the best impression, from the local professionals in the health centres and dispensaries, in addition to the villagers themselves, on which practical measures presumably had the highest effect locally on water- and sanitation-related health and why. Mainly shoreline locations in Nyanza Province (covering most of the lake area) were visited.

Water borne diseases

A number of infections can occur due to ingestion of water contaminated with pathogens or infested with parasites, being in contact with water infested with parasites, being close to water sources that support the life circle of disease vectors or absence of clean water for general use to wash away the disease. Such infections include diarrhoeal diseases, intestinal worms, bilharzia, malaria and skin diseases as well as eye infections. Ingestion of water contaminated by other chemicals that are introduced into water due to use by human near water bodies such as pesticides might cause poisoning due their toxic effect and concentration in the water body or bioaccumulation of some substances through food chain. Thus chemical quality of water is also an important aspect for human health. However, there may also be chemicals produced by plants in water such as algal toxins, which have effect on human internal organs and skin.

There are basically two relevant sources of water influencing the human health of the lakeshore population: the lake waters itself and the on-shore drinking water sources in the communities (rivers/streams, wells, boreholes and springs, where they exist). The rivers are used for similar activities as the lake and in many aspects with similar problems as lake waters. The interactions between large water bodies and human beings causing serious health impacts are mainly: swimming/bathing, drinking and eating (contaminated fish). The health implications could be many.

Main findings - Available health statistics, data and information

1. Nyanza Provincial Health Statistics

According to data from provincial health information services in Nyanza Province, the top five diseases only five are given??? In the table and following phrase causing the highest morbidity included Malaria, skin conditions, diarrhoea, intestinal worms and eye infections. Diarrhoea had been amongst the top five for many years. All of these diseases are incidentally water related, table #

Table # Water related diseases causing Morbidity in Nyanza Province in 2001 and 2002.

Diseases	**2001**			**2002**		
	Total cases	**% Total**	**Morbidity per 1000 population**	**Total cases**	**% Total**	**Morbidity per 1000 population**
Malaria	889,952	41	194	958,408	43	204
Skin condition	137,069	6	30	137,400	6	30
Diarrhoea	123,891	6	27	115,286	5	25
Intestinal worms	72,371	3	16	64,362	3	14
Eye infections	34,146	2	7	30,533	1	7

Source: Provincial Health Information System – Nyanza Province Health Annual Report, 2002[1]

A similar pattern is observed in the statistics of districts in Nyanza province, table ##. The districts, which mainly relied on untreated lake water, had problems with these diseases more than the districts, which had spring water sources, hence better quality.

Table ## Water related morbidity in districts in Nyanza Province, 2001

	% Of total for each district									
Disease	Kisumu	Homa Bay	Nyando	Kisii	Rachounyo	Nyamira	Kuria	Suba	Bondo	Siaya
Malaria	36	41	38	45	39	45	46	35	38	37
Skin condition	7	6	9	5	7	5	6	4	7	9
Diarrhoea	6	10	6	4	5	3	7	13	7	6
Intetinal worms	3	2	2	4	3	4	3	3	4	4
Eye infections	2	2	2	1	2	2	1	1	2	1

Source: Provincial Health Information System – Nyanza Province Health Annual Report, 2002

The tables above show the relative prevalence of diseases for the Nyanza Province in 2001 and 2002, and several districts in the province for the year 2001. The data generally show that highest prevalence of diarrhoea in 2001 was for the lakeshore districts with Suba District leading; whereas, Nyamira

[1] Before year 2000, the data went to Nairobi and is not available in Kisumu!

and Kisii districts, being inland district with a number of springs, had the lowest prevalence.

2. Data and Information from Health centres, Hospitals and Communities

Statistics for five consecutive years were collected from the Kisumu District hospital, Kombewa Sub-District Hospital (Kombewa Division), and Bodi Dispensary and Miranga Dispensary (both being under Kombewa Division). In addition, statistics from Nyalenda Health Centre and Pandpieri Catholic Health Centre under Kisumu Municipality (urban area) were collected. Asat Beach community (in Kombewa Division), and Dunga Beach landing site and Dunga Nursing Home/Hospital (in Kisumu Municipality) were visited and qualitative information collected.

The disease patterns in Kisumu district from 1998 indicate a big drop in all water related diseases from 1998 to 1999, Figure #a. This was reported to be after an outbreak of cholera in 1998 when a extensive flooding accompanied high water levels caused by El Nino rains (Fig. 11 in Chapter 3) and a lot of efforts were put in improving water quality for domestic use. This included disinfections of water sources by use of chemicals, such as chlorine compounds, boiling drinking water and campaign oin the importance of safe drinking water. (The data for 1998 includes Nyando district, as it was still part of Kisumu district.)

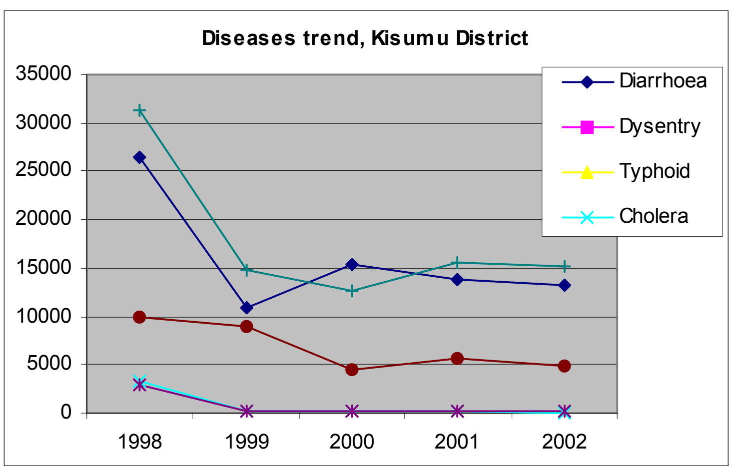

Figure #a Shows diseases trends in Kisumu district from 1998 to 2002

In the same period of time there was a big drop in cholera, with very few cases reported in 2000 and 2002. Bilharzia data has not been consistent with expectations however the big drop could be due to more awareness creation.

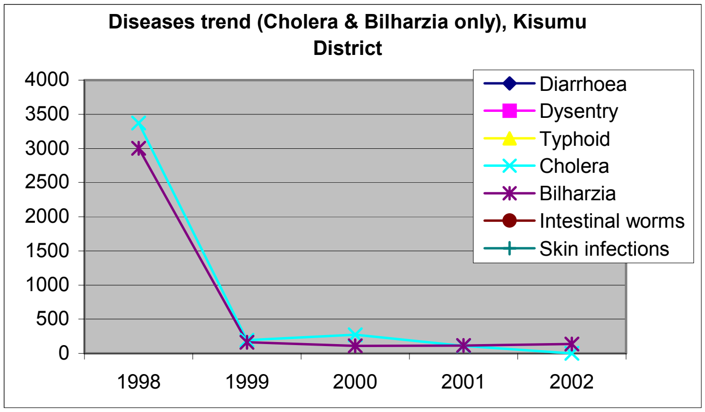

Figure #b Shows occurrence trends of Cholera and bilharzia in Kisumu district from 1998 to 2002

a) On-site observations/information given

The staff in *Kombewa Sub-District Health Centre* (covering around 100,000 people and eight dispensaries) claimed that the most prevalent diseases registered were diarrhoea, dysentery and typhoid, with a few cases of bilharzia (the reason was not known for low cases of bilharzia). Both diarrhoea and dysentery had been stable over the previous year, but the number of cases varied with the season (more cases in rainy season). After an outbreak of cholera in the division in the late -90s, sanitation facilities were improved, sensitisation were instigated and boreholes were sunk in Kadongo Village, where the inhabitants had only used raw river water. Even with new water supply, some people were reported to still use the river water out of old habits and taste of the water.

The health centre staff claimed that people at the Asat Beach used the lake water for drinking without any treatment. They also had no adequate toilet facilities and could easily contaminate the lake water. The staff suggested that increased sensitisation was required to change the habits.

The staff at the *Bodi Dispensary* (having a catchment population of around 12,000 in 4 main villages/8 communities of which three were along the lake) claimed that the most serious diseases after malaria and respiratory tract diseases were diarrhoea and intestinal worms, Figure #c. There were also cases of dysentery and typhoid. Diarrhoea and dysentery were somewhat decreasing due to health education (especially of school children), but had seasonal variations (highest in rainy season). Both skin diseases and intestinal worms were going down. There were few bilharzia cases and the trend was downwards. The last cholera case reported was in 2000. KWAHO had sunk six boreholes in the area, but some people still used the lake for drinking and washing. Plan International had also sunk a couple of boreholes and CARE had built pit latrines in schools, these were assumed to have contributed to the reduced number of diseases.

Kakowa Pharmacy Shop near the Bodi Dispensary was covering three villages. In addition to selling drugs, condoms, etc. they staff were also doing some diagnosis[2]. The sales of medicine were going up in the rainy season. The sales of medicine for diarrhoea and dysentery had slightly gone down, which was attributed to introduction of borehole water and health education. The pit latrines coverage in two of the villages was 30% and 17% respectively.

At *Asat Beach* (400 people at the landing site and 800 in the closest village, where Bodi Dispensary was the closest health facility), everybody was said to take water directly from the lake (as the nearest borehole was far away. The majority was said to boil the water before drinking starting from 1998, and consequently the diarrhoea cases had gone down. Also bilharzia and other diseases had gone down (a total reduction of diseases from 85% of the people infected, to 65%, was indicated by the Voluntary Health Worker). There had been several sensitisation campaigns at the Beach. There were a few latrines at the site and a Beach Committee set up under LVEMP, said that the prevalence of defecation on the beach had reduced. Claims of itching during some periods, particularly when the water looked greenish were reported at this beach. It was claimed that the neighbouring Bao Beach generally had a higher number of diarrhoeal and other diseases, and had cholera some two years earlier. Here, there had been no awareness campaigns and no sanitary improvements and hence water contamination.

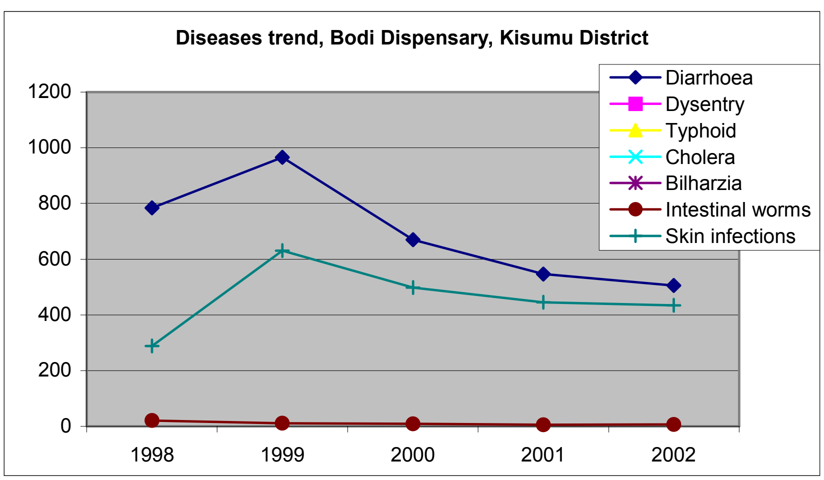

Figure #c Shows disease pattern in Bodi dispensary

[2] On staff was also working at the Bodi dispensary.

Miranga Dispensary (catchment of around 50,000, 9 villages) is located inland (close to a river) in Upper Kadongo area where there was a cholera outbreak following El Nino in 1998. The shoreline people did not visit this dispensary for treatment. Top diseases after malaria and respiratory tract diseases were skin diseases and diarrhoea cases (including dysentery and typhoid), Figure #d. As in other areas, people used the river for bathing, washing, and water supply. There had been a decrease in the number of diarrhoea cases in the past years due to the introduction of boreholes and sensitisation following the cholera outbreak. Therefore there were seasonal disease problems both in dry and rainy season. However, people were still depending on the river and roof catchment for water supply. KWAHO was working in the area to improve domestic water supply and sanitation and also conduct health education.

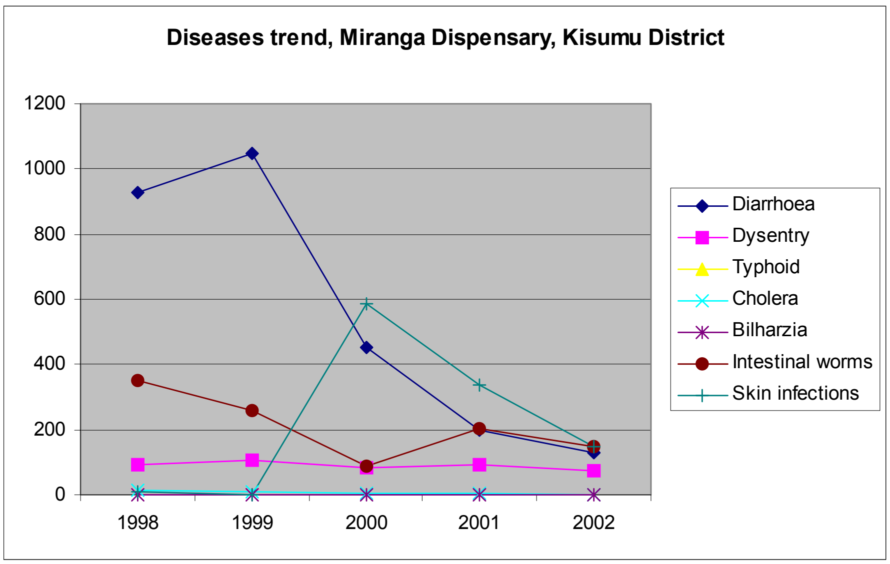

Figure #d Shows disease patterns for Miranga dispensary from 1998 to 2002

Water quality parameters by KWAHO from selected locations in the Bodi and Miranga Dispensaries catchments were made available to the study team. The samples were taken in January 1997, December 1997, August 1998, January 2001, December 2002 and June/July 2003, but not in all places at all times. Comparison therefore was difficult, and no substantial analysis of water quality versus human health could be undertaken based on these spot sampling (and thus, the water quality tables are not included in this report). In most samples, the number of total coliforms and faecal coliforms by far exceeded safe levels for the drinking water quality, thus unfit for human consumption without treatment. Water treatment was rare, however, so the sub-standard quality might have contributed to the statistics on disease cases (i.e. diarrhoea, dysentery, typhoid and cholera).

Assessment

From the above information and quantitative data for the five years' disease statistics for Kisumu District, Kombewa Sub-District Hospital, Bodi Dispensary and Miranga Dispensary as well as the total sales statistics for 2003 from Kakowa Pharmacy Shop and the diseases reported at the shop, the following observations were made:

The district statistics show that the number of diseases had been fairly steady since year 2000, with a small downward trend on diarrhoea (including dysentery and typhoid). The Kombewa Sub-District Hospital figure showed a reduction in diarrhoea from 2000 to 2001 (the two years with statistics), slightly contrary to the verbal information given by the staff. Bodi dispensary followed the small downward diarrhoea trend like the district as a whole, coinciding with the verbal information given at the dispensary and also in line with information given at Asat Beach. Miranga Dispensary showed a significant reduction in diarrhoea cases since 1999, and a small reduction of dysentery, coinciding with the verbal information. The district figure on intestinal worms was fairly steady since 2000, as had the figures from both Bodi and Miranga Dispensaries. Kombewa Hospital showed a significant reduction from 2000 to 2001.

The verbal information on medicine sales decrease at the Kakowa Pharmacy coincided with the downward statistic trend at the Bodi Dispensary. The phamacy's seasonal statistics showed a peak in skin infection in the rainy season, but low figures on other diseases. On the other hand, sales are highest in August when malaria was most prevalent.

Bodi Dispensary, having most of its catchment close to the lakeshore, had the highest prevalence of diarrhoea. The number of skin diseases in Bodi was significantly higher than the district average. This could be connected to the algal blooms as body itching during some seasons after use of lake water was reported at Asat beach. Algal toxins possibly caused this. LVEMP study data on transparency associated to agal blooms indicate very high growth in the study area including Asat beach, as seen in Figure ##. On the other hand, the prevalence of intestinal worms is lower in Bodi than in the Kombewa Hospital and Miranga Dispensary and the district average. The reason for this discrepancy between prevalence of diarrhoea and intestinal worms was not understood.

Eutrophication, Secchi depth transparency

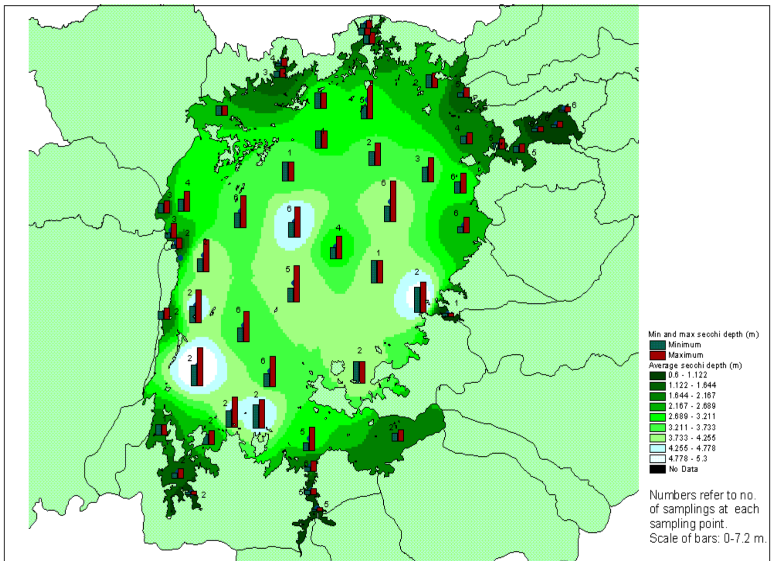

Figure ##. Shows Secchi disc transparency values as measured in the whole lake and which is as an indicator of algae concentration. Most algae are seen in the near shore areas, with heavy infestation in Winam gulf.

The study indicated that there were high algal biomasses, change of species composition and Cyanobacteria dominance (potentially toxin producing), which were serious concerns for water and fisheries managers and policy makers as well as to the lakeside communities who heavily depend on lake for fish food and drinking water, (LEVMP – Water Quality, 2002)

Qualitatively, from the discussion with the various stakeholders, it seems clear that only health education programmes were not sufficient to have a *significant* impact on the health of large groups of people. There was a slightly downward trend on diseases in the areas of study partly due to improved water infrastructure, latrines and special awareness campaigns, and the Asat Beach inhabitants firmly claimed a reduction of diseases after the latrines were built, formation of the Beach Committee, special sensitisation efforts undertaken and boiling of drinking water put in practice.

Therefore, in all the cases studied above it is evident that in each case there was a reduction of diseases occurance with improvement of water quality through provision of of safe water sources, e.g boreholes, wells and roof catchment, boiling or disinfections of unsafe waters and general awareness through health education and sanitation. The eutrophic conditions in the lake conversely were viewed as contributing to the degradation of lake water and its use.

There were few water quality data from the study area from LVEMP, and none for the shore itself as the LVEMP studies concentrated on the causes and sources of eutrophication in the lake and saples taken at certain in-lake spots. Drinking water parameters were not investigated due to the heavy workload involved, and the intention was that such should be analysed at a later stage. Higher Chlorophyll-a figures are generally expected closer to the shore than in the open waters. Chlorophyll contributes directly to turbidity and its association with higher bacteria loads and reduction in natural anti-microbial processes such as plankton grazing, exposure to uv light, and reduced organic substrates to sustain bacteria.

3. Kisumu Municipality

The situation in Kisumu municipality was not easy to understand, as there is generally a lot of mobility and patients do not necessarily seek for treatment in the nearest health facilities.

The staff in *Nyalenda Health Centre* (being the closest government centre to Dunga Beach with an estimated catchment of 36,000 people) claimed that the number of diarrhoea and dysentery case had decreased and that the number of typhoid cases had increased; however in the statistics the three are lumped together Figures ### and 4#. Diseases were mostly prevalent in the rainy season[3]. The staff had noted a clear reduction in disease cases from the Dunga Beach, since the new water supply at the landing site and the primary school was introduced in 2001. Around ¾ of the population in the Dunga area did not have a proper pit latrines. Since there was only one tap by the beach, people were also using the lake water. Otherwise, the lake was used for washing and bathing by “all people”, but bilharzia was claimed not to be prevalent. It was also said that migration was very low in Dunga area. Some patients from the health centres catchment obviously go directly to the district hospital in Kisumu Town, as the Health Centre in any case must refer more serious cases to the hospital. The relative statistics of the Health Centre from the catchment must therefore be carefully reviewed. The Pandipieri Catholic Health Centre, in the same area, is assumed by the Nyalenda staff to take around 75% of the patients in the catchment, with most of the rest going to Nyalenda.

[3] A quick calculation showed that in 2002, around 80% of the total annual patients had visited Health Centre by September.

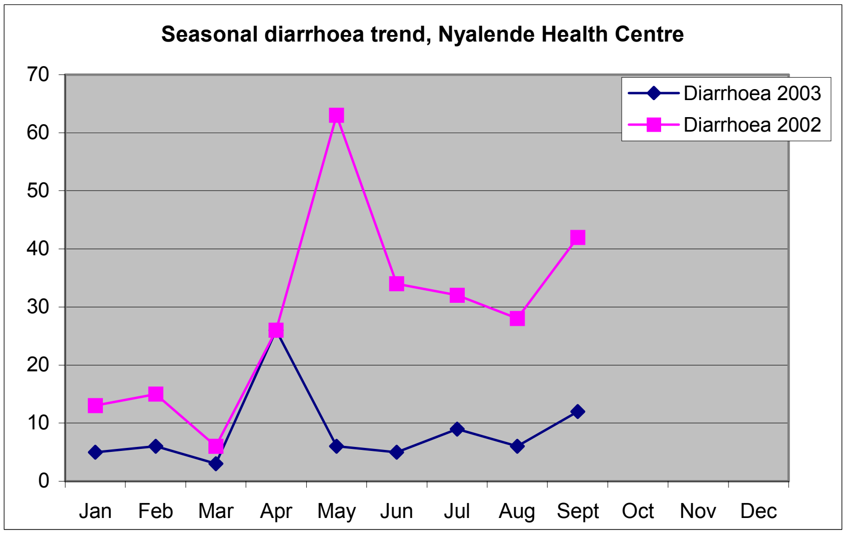

Figure ### Shows monthly variation of diarrheoea occurance as recorded at Nyalenda Health Centre in 2002 and 2003

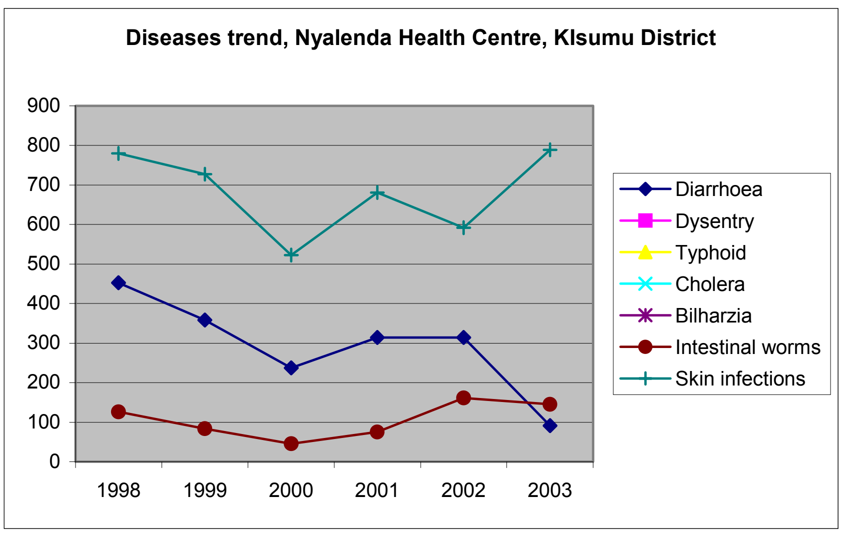

Figure 4# Shows diseases trends for Nyalenda Health Centre from 1998 to 2003

The *Dunga Hospital* is a private Nursing Home serving the immediate Dunga area estimated to 3000-4000 people in the catchment, in fact being part of the Nyalenda and the Pandipieri catchment. The most prevalent diseases reported in the hospital were malaria, diarrhoea, malnutrition (mostly fishermen) and HIV/AIDS, with most of the beds occupied by HIV/AIDS pateints. The number of diarrhoea cases had been stable with insignificant reduction the previous years, and bilharzia had been stable.

At *Dunga Beach,* the Beach Committee members interviewed claimed that the number of diseases had gone drastically down since 2001 when the new water supply at the landing site was completed. People also died of blood dysentery earlier, but not anymore. There had also been sensitisation amongst the fishermen, and no bathing in the lake at the landing site was allowed.

Assessment

Quantitatively: With reference to the five years' diseases statistics and seasonal diarrhoea trend for Nyalenda Health Centre, notably, the number of diarrhoea cases for the Nyalenda health centre was stable (reduction in 2003). The Kisumu district statistics had been stable for all diseases in the same period, with a small reduction in diarrhoea. This coincided well with the verbal information from the Nyalenda Health Centre and the Dunga Hospital.

The Dunga Beach was said to have had a significant decrease in the number of diarrhoea cases. The correlation between health centre statistics, district statistics and the verbal information given was fairly good and decrease in diseases with improvement of water quality could be related.

Qualitatively: There was clearly a positive effect from the improved water supply system and sensitisation campaign at Dunga Beach. The Beach Committee was keeping up a certain momentum and time would show whether this would last or if new health education campaigns would be required to keep up the awareness level. The impression from discussions with various stakeholders in Kisumu was that such campaigns must be repeated, or rather there must be a continuous pressure in the changes of sanitary and water supply habits.

Some coliform counts from selected spots, mainly in the Kisumu water supply system available indicated that the raw water intake near Dunga Beach showed both high total coliforms and E-coli, indicating faecal contamination. The water at this spot was not fit for human consumption without treatment, however water quality data was largely lacking from most areas.

4. Information from other programmes/projects

(i) Joint Evaluation of Three Water and Sanitation Projects in Nyanza Province

The evaluation of the donor-supported projects (The Netherlands, CARE and Finland) undertaken in 1999/2000 revealed among others "Reduced cases of diarrhoea and cholera following water and sanitation interventions". "Interventions on behaviour changes amongst school children were effective, as well as PRA and PHAST approaches. It was clearly recognised that inclusion of a sanitation and hygiene education component in the Finnish-supported project would have enhanced the benefits of the improved water supply".

(ii) Rapid Assessment of Water Supply and Sanitation Coverage in Migori and Kuria Districts

This Rapid Assessment undertaken by the Ministry of Health in collaboration with WHO in 1993 found out that "there was a direct relationship between the safety of water and water-related diseases commonly found and that there were seasonal variations of water-related diseases. Community sensitisation, amongst others on simple water treatment (i.e. boiling) and safe excreta disposal, and sense of ownership to facilities was found to be very important."

(iii) Impact on Safe Water System on Health in Rural Western Kenya (CARE)

This study, undertaken in 2000 in three districts in Nyanza Province, was indeed very relevant to the Water Quality-Human Health Study. CARE (Kenya) in 1998 initiated the WASEH (Water, Sanitation & Education for Health) programme in 77 communities, comprising construction of latrines, improved water supply and hygiene education campaigns. To provide safe potable water, the *Safe Water System* (SWS) was introduced, mainly comprising: behaviour change through hygiene education; water boiling, safe water storage in homes (jars/pots with lids); and water disinfection with 1% sodium hypochlorite ("Klorin").

Amongst the main findings from the study (covering 12 WASEH villages, 6 non-WASEH villages), was that the data on diarrhoea prevalence showed that the water quality interventions with Klorin had drastically reduced the number of diarrhoea cases during an 8-week period. These interactions improved the water quality in the house before drinking. The *sensitisation* resulted in the changes of household practices and thus improved drinking water quality. The interventions like hygiene education in combination with latrine construction had great impact on the health, as compared to the villages where no interventions made.

The study also showed that the non-sensitised households to a significant larger degree used unsafe surface water sources than the sensitised ones. In general, the risk of diarrhoea was lower in the intervention villages, the use of Klorin, latrines and rain- and borehole water were all associated with lower diarrhoea risk, and the reduction of diarrhoea risk is greater when interventions were combined.

(iv) Bilharzia Study in Kisumu Municipality

A study was undertaken in 1997-1998 as part of MSc thesis[4], presented in August 1999. The study investigated some key epidemiological factors connected to prevalence of bilharzia (schistosomiasis) transmission and other human water contact behaviour, and availability and attitudes towards basic sanitary facilities. Three sites were studied: the Car Wash site, the Kisumu Fishermen site, and the Kisian Beach. At all the sites sanitary conditions were poor, there were no latrines and clients used bushes near the shore for long and short calls. Thus, the water samples from all the three sites were highly contaminated with faecal streptococci (bush defecation and sewage contamination). The resulting pour water quality promoted the occurance of the disease.

It is estimated that through improvement in water quality, some of the main diseases can be reduced as shown in the tableXX below. These diseases depend on availability and quality of water used by the people.

Table XX Shows reduction of diseases through improvement of water quality.

Disease	**% Reduction**
Cholera	90
Typhoid fever	80
Diarrhoea	50
Trachoma	60
Sscaimasis	40
Scabies	80

Source: Walter J. Bray, 1984 Water and disease

Source ??

(Dr Abuodha, Confirm the source of this from Mr. Chebwek then include it as a reference. Note that I have not put the references because they remained there. If you can't get them then we will include them later)

Conclusion

Although water quality inevitably has an impact on human health, there are also other factors that contribute significantly to this. The other most

[4] Ms. Wilfridah Nafula Kahigi

prominent ones are: the sanitation/waste disposal practices in the communities, and the sensitisation/health education/awareness raising undertaken to change people's attitudes and practices related to the use of water and the sanitation. These three factors are closely inter-related and each one influences the others and it is difficult in most cases, where these three factors prevail, to single out *the one* having the largest impact on the human health. Indeed, these practices directly lead to degradation of local water resources and initiate a downward spiral of deteriorating water quality and human health. The nutrient enrichment cause by these practices also leads to wider spread eutrophication of waters that can affect other communities. However, improved sanitation lead to reduced water conatamination, hence improved water quality, and sensitisation lead to desire to use only safe water and maintain hygienic conditions. The inter-relationship was also confirmed by all actors in the health sector and has in fact been known for decades also by the water development professionals. These inter-relations were much focused during the International Water Decade in the 1980s.

The underlying factor in the region is however believed to be the *poverty*, which limited provision of safe drinking water supplies and construction of adequate sanitation facilities.

However, it clearly emerged in all areas studied that there were clear reductions in disease cases following improvement of water quality, sanitary conditions and sensitisation. It is therefore safely concluded that water quality has direct effect on human health.

Recommendations

1. It is recommended that more water quality data be collected to help in comparision of the same to the health statistics and come out with a good water quality-human health Inter-relationship. Such statistics would provide good guidance for the planning of LVEMP 2 and other programmes on where to concentrate the efforts in order to meet the needs population with the lowest standard of living.

2. The health data collection and storage and health institutions should be improved and be quality assured and consistent.

References:

Special acknowledgement to Mr. Tore Laugerud, Environmental Technical Adviser, Nordic Consulting Group (NCG) Norway, who participated in the collection of this data (together with the main aurthor of this paper) when he was hired by the World Bank to carry out a study on water quality and Human health.

NB: Dr. Abuodha, Mr Masongo has a CD by Mr. Tore on his report on water quality and human health. You can get additional data from there. I did not have any other information to add, though if I was in the office, I believe I could get more. You can improve this draft we'll make it better later.

CHAPTER 12

Environmental impacts of water quality change on beneficial uses of Lake Victoria

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Abstract

The Lake Victoria Basin (LVB) has become a focal point of development in Kenya, thereby attracting intensive multiple land use which has accelerated environmental degradation through siltation, water pollution and changes in flooding frequency. In addition, multi-sectoral uses of water have created competition among various water users without due regard to the need for ecological sustenance or the needs of downstream users. This pattern poses serious management problems.

The LVB is used as a source of food, energy, drinking and irrigation water, shelter, transport and as a repository for human, agricultural and industrial waste. With the population of the riparian communities growing at rates among the highest in the world, the multiple activities in the lake basin have increasingly come into conflict. This has contributed to rendering the lake environmentally unstable. The lake ecosystem has undergone substantial, and to some observers alarming changes, which have accelerated over the last three decades. Massive blooms of algae have developed, and come increasingly to be dominated by the potentially toxic blue-green variety. The distance at which a white disc is visible from the surface, (a transparency index measuring algal abundance or secchi depth), has declined from 5 m in the early 1930s to 1 m or less for most of the year in the early 2000s.

Water-borne diseases have increased in frequency. Water hyacinth, absent as late as 1989, has choked important waterways and landings. Overfishing and oxygen depletion at lower depths of the lake threaten the artisanal fisheries and biodiversity (over 200 indigenous species are believed to be facing possible extinction).

Scientists advance two main hypotheses for these extensive changes. First, the introduction of the Nile perch as an exotic species some 30 years ago has altered the food web structure; second, nutrient inputs from the adjoining catchments are causing eutrophication. Thus, although the lake and its fishery

show the evidence of the dramatic changes in the lake basin over the past century, the lake is not the source of the problem. The problem has arisen in the surrounding basins through polluting activities of humans activity and the demand for fish.

Introduction

Water quality expresses the suitability of water to sustain various uses of such as drinking water, water for agricultural and industrial use and nature conservation. The Lake Victoria natural water quality, mainly determined by the geology and hydrology of the Lake Victoria Basin (LVB) was relatively in its clean status prior to the 1960s (Talling, 1966), with low concentrations of chemical constituents. Presently, research shows that the lake is increasingly being polluted and the water quality has been deteriorating due to a wide range of water pollutants, especially nutrients (Hecky, 1993). This has been revealed through the analysis of various water quality parameters with the main aim of establishing the extent to which the lake Victoria water quality has changed over the years (especially after 1960's).

The water pollutants emanate from both point and non-point sources due to agricultural, urbanization and industry, which contribute to organic, inorganic and aesthetic pollution of water.

High pollution loads into the lake causes the influx of nutrients into the water (Hecky, 1993) and greatly contributing towards the decline of water quality. The impacts of water quality change are manifested through:

- High cost of water supply, as polluted water is expensive to treat;
- Environmental health effects with occurrence of waterborne diseases and chemical poisoning in humans and animals;
- Food web contamination threatening its use and sale;
- Loss of fish habitat;
- Inefficient food webs;
- Loss of biodiversity;
- Nuisance macrophyt growth.

Sedimentation

The humid tropical climate of the LVB in combination with the steep relief and slopes, and the presence of easily erodible volcanic soils in relation to intensive agriculture, results in tremendous soil erosion, and denudation rates are high. Soil erosion is a major problem in many river catchment areas. In fact, the total sediment load transported by many rivers is very high, particularly during the rainy season; some of which finally end up in the lake.

This has direct impact on the water quality and the life of aquatic ecosystems in the lake.

From historical records, Verschuren (2000) calculated that sediment yields from the catchment have increased dramatically since the beginning of the 19th century, corresponding with the colonial and post-colonial eras. His sediment core data indicates deposition rates of 1mm per year in offshore areas but rates can be much higher in river deltas.

The interplay between sediments and the overlying water of shallow lakes in particular, can have profound effects on the nature of the benthic and planktonic biota, nutrient fluxes and sediment transport. These processes may have impact on the performance of populations of potentially troublesome plants such as water hyacinth (*Eichornia crassipes*) and blue green algae, and animals such as Dipteran flies. The potential for sediments to retain or release nutrients and the potential for the currents to transport sediments have not been well studied. The pilot study on sedimentation during the final stages of LVEMP Phase I is therefore expected to determine rates of sedimentation, characterizing the sediments and assessing their potential for retaining or releasing nutrients such as phosphorous and nitrogen, and their capacity for harboring particular invertebrates under certain conditions occurring in the deltas of rivers and in Winam Gulf of Lake Victoria.

The river mouths and the Winam Gulf have been identified on the Kenyan part of the lake to be the major sediment recipients and transport routes into Lake Victoria. Similarly the river mouths and Winam Gulf receive the highest loads of nutrients and have high populations of benthic and planktonic biota. Additionally, they also receive certain other pollutants per unit water surface area and volume. This is attributed to high population concentration in the surrounding areas.

Land use impacts

In the past few decades, Lake Victoria basin has developed into one of the most intensely agricultural areas in Kenya. As the agricultural industry and settlements have mushroomed, it is likely that more pressure will be exerted to develop more farmlands. The river basins are highly diverse in morphology, geology and ecology. They combine lowlands, wetlands, highlands, escarpments, plateaus and the Rift Valley, giving an outstanding scenic variation. A few areas are still forested and support a rich variety of plants and animals.

Presently, about 40% of the Lake Victoria basin is under agriculture and the rest is under a mixture of unimproved pasture and natural vegetation. The human population has been expanding rapidly, resulting in increased agricultural and livestock activities. Some of these activities include clearing of forests in water catchment areas, biomass burning and overgrazing. The combined effect of these activities is increased soil erosion, pollution of the rivers and increased atmospheric deposition of nutrients.

Crop production is increasingly applying agro-chemicals, and substantial amounts of these agrochemicals have found their way into watercourses. Besides, some cultivation methods lack soil conservation and preventive measures; thus, they facilitate soil erosion, especially during the rainy season. Soil management is not helped by customs and traditions which favour large herds, irrespective of the land's carrying capacity. Overstocking of livestock has been increasing, resulting in overgrazing, which in turn leads to accelerated devegetation and soil erosion. This is accentuated by animal trampling which causes death and injury to vegetation; sometimes causing irreversible changes to the ecosystem.

The catchment landscape exhibits numerous physical and biological processes- some are rapid and conspicuous, yet others are subtle although their effect on the landscape is still profound. Added to these are the manifold activities of man (social processes), enhancing or counteracting the natural forces, or causing new processes. Pressure from the siting of towns, human settlements, agriculture, grazing of domestic stock, collection of building and fuelwood and in recent years, trampling by animals, have resulted in the modification or destruction of the catchment landscape and ecological features. The installation of the necessary conservation measures has not been recognized in the landscape so far. Also, the perpetual nuisance and economic losses on account of soil erosion in cultivated areas and settlements at many places require artificial soil fixation.

So far, no management strategies exist for physical planning, restoration, protection and conservation of catchment areas. In spite of numerous national conservation activities policy and environmental legislation, catchment areas have remained neglected for a long time for the benefit of mountain, coastal and wild terrestrial landscapes such as forests and game reserves. This is due to insufficient knowledge of the landscape processes and a lack of integration of available knowledge in planning. Further research is indispensable for catchment management. The investigations should entail mapping, measuring and modelling the relevant processes and their interactions, to evaluate the effects of the various activities and to present management and planning alternatives.

Effluent disposal

Water quality has deteriorated due to increase in eutrophication, especially in the Winam Gulf of Lake Victoria. The rivers have been polluted by agricultural runoff and by effluents from industries. For example, sediment, phosphates and nitrates input into the Winam Gulf have been very high and are considered the greatest threat to the lake water quality. These two elements are of particular interest since they exert limitation on the aquatic plant and animal life.

In addition, effluents discharged from urban centres in the basin are major sources of pollution to the rivers and the lake. Although a few major towns have sewage lagoons or conventional treatment facilities, the performance of these facilities are hampered by overloading and/or poor maintenance. Most other towns discharge untreated or partially treated effluents directly into the lake or through the rivers draining into it.

Likewise, most agro-based industries in the basin lack waste water treatment facilities and like the towns discharge their effluents directly into the lake or into the rivers feeding the lake. Unfortunately for the inhabitants of the basin, these rivers are the principal sources of their drinking water.

Flooding

Flooding is a recurring problem affecting the LVB. Nearly all rivers draining into the lake such as Sio, Yala, Nyando, Sondu-Miriu, Kuja-Migori and Mara, experience flash flooding in the lower reaches during the rainy season causing a lot of damage to crops, livestock, infrastructure and human settlements. In particular, the Kano Plains on the eastern shores of Winam Gulf are susceptible to annual flooding from River Nyando. Flooding also affects the low-lying lakeshore areas where clearing of vegetation has occurred, especially in Busia District's Budalangi Division. The floods in Budalang'i originate from heavy precipitation in the upper catchments of River Nzoia and River Yala, namely Mount Elgon and Cherengani Hills. During flash floods, Lake Victoria is slow in absorbing water, and there are back watger effects that causes inundation of the nearby floodplains.

A study by Mburu (2005), indicates that flooding in Budalangi dates back to the 1940s. The area has since then experienced major floods, which has led to construction of 32 km dykes to control floods; breaching of these dykes due to human activities on or in their vicinity has largely rendered them ineffective.

Mburu (2005) has examined the flooding impact on socio-cultural and economic activities in Budalangi, and proposes solutions that could be replicated elsewhere in flood-prone areas of the LVB. Flood control is therefore a priority concern because of its frequency and the magnitude of the damage to shelter and property, and human misery it causes. Some of the actions required to control floods include identification of the mechanisms and sources of flooding, land use practices that promote infiltration rather than runoff, community participation in flood control projects and proper planning of relief and emergency assistance. Such measures could become encouraged during LVEMP 2.

Table #: Matrix of environmental impacts of water quality change on beneficial uses of Lake Victoria

Effect / Cause	Sedimentation	Nutrient enrichment	Algal biomass	Oxygen depletion	Transparency values	Silicon concentrations	Toxicity	Acidity	Biodiversity loss	Inefficient food webs	Loss of fish habitats	Massive fish kills	Fish populations	Fishing efforts	Waterborne diseases	Macrophyte growth	Floods	Drinking water	Food availability	Lake area degradation	Ecosystem services	Economic value	Quality of life
Climate change																							
Biomass burning																							
Land degradation																							
Wetland conversion																							
Agrochemicals																							
Industrial loading																							
Unsewered (rural)																							
Sewered (municipal)																							
Direct discharge																							
Population growth																							
Overfishing																							
Species introductions																							
Normalized total score																							
Overall ranking																							

Eutrophication

Water quality has declined greatly in the past few decades, owing chiefly to eutrophication arising from increased inflow of nutrients into the lake. Nutrient inputs have increased two or three-fold since the turn of the century, mostly since 1950. Nutrient inflow into the lake from the Kenyan catchment area has been estimated at 20 kg m^{-2} a^{-1} of phosphorous and 400 kg of nitrogen m^{-2} a^{-1} (Ochumba et al., 1991)**Better to use LVEMP numbers. These as quoted are impossibly high**. Concentrations of phosphorous have risen markedly all over the lake and nitrogen has increased dramatically in shallower water because of N fixation by Cyanobacteria. This has resulted in a five-fold increase in algal biomass since 1960, and the shift in composition towards domination by blue-green algae. Eutrophication contributing to deoxygenation of the water, increased sickness for humans and animals drawing water from the lake, clogging of water intake filters, and increased chemical treatment costs for urban centres. Aside from the near-total loss of the deepwater fish species, the deoxygenation of the lake's bottom waters now poses a constant threat, even to fish in shallow portions of the lake, as periodic upwelling of hypoxic water causes massive fish kills. The increased nutrient loads have also spurred the water hyacinth infestations.

I would remove this highlighted text as it is repitive with the paragraph above. Eutrophication in the lake has led to algal blooms (O'Riordan, 1996; World Bank, 1996, Wangila, 1993; Ochumba et al., 1991). Algal blooms are associated with such adverse effects as fish deaths related to oxygen poisoning resulting from excessive oxygen levels during the day when algae photosynthesize; fish deaths from high CO_2 and low oxygen concentrations at night; low oxygen levels in deeper water columns leading to the deaths of benthos that are an important part of foodwebs; and depletion of oxygen because of the decomposition of the dead biomass of algae and phytoplankton. Severe pollution impacts on the Kenyan side of the lake are localized nearshore and coincide with spots of high algal bloom concentrations and fish deaths (Ochumba and Kibaara, 1989; Ochumba, 1990).

The nutrients represent a transfer of materials at an increasing rate from the terrestrial basin to the lake. Among others, these transfers comprise organic and inorganic suspended solids and dissolved nutrients carried by streams, terrestrial dust from wind erosion, inorganic compounds in the smoke produced by biomass burning (in cooking fires or forest burning), and direct additions along the lake shores of human and animal waste associated with domestic water use. Preliminary estimates (Chapter 4 and 5) suggest the increased nutrient inflows are coming largely from rural areas. Although the main causes of eutrophication are known, the rates of enrichment, its sources, and its numerous effects are not well quantified.

Since many of the farms in the area apply no fertilizers, or use very small quantities, there are not likely to be a major source of the nutrients, nor will they be until fertilizer application rates reach substantially higher levels than currently seen. Rather, nutrients may be released from soil particles washed or blown off the land surface by erosion, from burning woodfuels and from human and animal waste from areas surrounding the lake. From the urban areas, the main source is untreated sewage, which besides providing additional nutrients, also increases the disease risk from water pathogens. Thus the water quality problems of the lake arise in the watershed, not in the lake, and it is in the catchment that the solutions must be found.

Pollution

Generally, the quality of river water in the drainage basins is good. However, there have been cases of local pollution, particularly from industrial, agrochemicals and municipal discharges. Pollution has made a substantial contribution to ecological changes and general fishery decline in Lake Victoria. Evidence of increasing pollution is overwhelming (Ikiara, 1999). Thus compared to 1950s and 1960s, anoxia (lack of oxygen) now affects up to 50% of the entire lake bottom abd progressively shallower depths of the water are anoxic (Ochumba et al., 1991); Hecky et al. 1994; World Bank, 1996).

Additionally, phytoplankton productivity has increased considerably resulting into increasing algal biomass; the phytoplankton population is dominated by the toxic blue green-algae. According to World Bank (1996), there has been a two-fold increase in algal productivity, a four-fold increase in algal biomass and a three fold decline in water transparency since 1960s.Let us cite your own chapters on Aketch et al (1992) have reported high loads of nutrients from urban centres, agro-based industries and soil erosion. Heavy metals such as iron, manganese, zinc, copper, nickel, chromium, cadmium, and cobalt have also been reported Cite your own reports/chapters. Campbell (2003a; 2003b; 2004) has reported levels of mercury in water, fish, sediment, soil and humans. Although Hg concentrations in fish muscle were not high relative to North American Great Lakes THg concentrations in Victoria water were high relative to those in the northern Great Lakes, and she concluded that high values in water can mainly be attributed to biomass burning and soil erosion.

The sources of pollution in the Kenyan part of the lake are manifold but principally industrial, municipal and agricultural. The Kenyan catchment is the most developed and economically diversified on Lake Victoria and processes in are potentially of concern to the other riparian countries that share Lake Victoria. As the lake's catchment in Kenya holds 42% of the country's population and is drained by many rivers, agricultural, industrial and municipal wastes are washed into the lake through these rivers or runoff (Ochumba et al 1991). Several sugar and pulp and paper factories (Webuye pulp and paper factory, Nzoia sugar factory and Mumias sugar factory) discharge their waste into River Nzoia , one of the largest rivers draining into the lake; Chemelil sugar factory, Muhoroni sugar factory and Agrochemical factory discharge their wastewater into River Nyando. The wastewaters include suspended solids, colour, foam, organic matter, toxins such as resin acids and several other chemical substances (Wangila 1993). Through River Kuja, coffee-processing factories in Kisii and sugar factories in Migori discharge their wastes into the lake.

In addition to these factories, industries located in the towns surrounding the lake, notably Kisumu and Eldoret, also discharge their wastes either directly into the lake or into rivers draining into the lake. These industries include textile manufacturing, soap manufacturing, sisal factories, soft drink bottling, brewery, dairy industries, abattoirs, fish processing and wood based industries (Wangila, 1993; Ochumba et al., 1991). The towns surrounding the lake and its feeder rivers also pollute the lake ecosystem through the discharge of raw sewage into it.

Industrial and municipal discharges have varied adverse effects on the lake and the associated riverine ecosystems. Suspended solids reduce light penetration of the water and thus lead to anoxia, poor visibility of such species as Nile Perch and *Bagrus* that feed by light, impaired gill respiration due to clogging, and chocking of eggs resulting from adsorption of the solids and decomposition of the solids into nutrients leading to algal blooms.

Colour discharges into the lake and rivers may block out the penetration of light energy of some wavelengths and consequently lead to the disappearance of species that utilize light of these wavelengths. Foam accumulation may interfere with water mixing and thus oxygenation.

Toxins can kill fish, human beings, and animals directly. They can also lead to collapse of entire food webs, with disastrous effects on biodiversity, when they are bio-concentrated through the food chain. Probably the most recent dramatic effect of toxins in aquatic environment is exemplified by the Danube experience. On January 30, 2000 a tailings dam failure at the Aurul S.A. plant in Baia Mare, Romania, resulted in the release of 100, 000 m^3 of cyanide-contaminated liquid into the Lapus stream, tributary of the Somes, Szamos, Tisza, Theiss and Danube rivers, killing tones of fish in these rivers and poisoning the drinking water of more than 2, 000, 000 people in Hungary. Similar events would also devastate large areas of Lake Victoria and the risks of such events increases with basin development unless good environmental management practices are applied. Economic development is necessary but it cannot be at the cost of other users of the natural resource base including the valuable Lake Victoria fishery.

Atmospheric particulate and gaseous matter, largely from industries, is washed down by rain into water bodies as dilute acids such as nitric and sulphuric acids. These can acidify the dilute waters with serious corrosion-related injuries to fish and other organisms. Atmospheric deposition has been identified as a major source of nutrients input into the lake (LVEMP, 2002; Tamatamah, 2005). But the demand for nitrogen and sulphur compounds by the lake's biota keep concentrations low and the lake is not at risk of acidification. Organic and chemical discharges lead to excessive depletion of oxygen from the water bodies as they have high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Discharge of raw sewage into the water bodies not only increases the level of organic matter but also increases acidity due to production of carbon dioxide. BOD and COD inputs create greatest problems when discharged into confined deeper, stratified embayments where oxygen concentrations below the thermocline can be rapidly depleted. There contribution to the anoxia in the open lake is minor compared to the organic loading from algal growth.

Agricultural activities and land use changes are also important determinants of pollution in Lake Victoria (Aketch et al., 1992; Wandera, 1988; Wangila, 1993; World Bank, 1996; Ochumba et al., 1991; Okemwa, 1991). Production of coffee, tea, sugarcane, tobacco, cotton, pyrethrum, rice, maize, horticultural crops, and livestock are important agricultural enterprises in the areas surrounding the lake basin. The lake's catchment hosts Kenya's largest sugarcane growers and sugar processing factories, including Chemelil, Muhoroni, Mumias, Nzoia and South Nyanza Sugar Company (SONY). There is heavy use of inorganic fertilizers and other chemicals such as herbicides, insecticides and fungicides in these areas. There is also serious soil erosion owing to poor land use systems. Vegetation removal through cutting of trees for agricultural purposes, charcoal and firewood production has actually been cited as the most severe threat to the lake ecosystem by Hanking (1987). Heavy chemical use and soil erosion coupled with intense precipitation have led to runoffs loaded with sediment and nutrients especially phosphorous and nitrates finding their way into the lake, leading to serious eutrophication (see preceding section).

One key reason why pollution of rivers and the lake has not been controlled is lack of coordination among the many government institutions charged with the responsibility of water management. These include the ministries of Water and Irrigation, Health, Agriculture and Environment and Natural Resources. LVEMP1 has fostered greater cooperation and even some collaboration among these agencies, but proper environmental management will depend on even greater interactions among them.

Drinking Water Impairment – treatment cost.

The deterioration of water quality resulting from eutrophication is responsible for increased water treatment cost especially in urban centres around the lake as polluted water resources are more costly to treat for domestic purposes, industrial and other uses. Increased deterioration of water quality favours the emergence of algal blooms and the water hyacinth (see subsequent section). Algal blooms and water hyacinth are a manifestation of eutrophication in the lake Mugidde R. 1993). They clog water supply intakes and impart undesirable taste and odour to water for domestic and industrial uses (recently this happened in Kisumu water supply intake in July/August 2004 and March 2005 – inversion of algal blooms). Again this means increased cost of treatment of water resulting in an increased cost to consumers.

The clogging of the water supply intakes also makes it necessary to clean/replace the filter media (sand filters) in the water treatment works frequently. This is done at an extra cost, which again is transferred to the consumers.

Similarly the water hyacinth weed clogs the water pumps reducing the pumping capacity and increasing the pump breakdown. This results in extra maintenance and operating cost, still a heavier burden to the consumers.

It is usually not possible to adequately treat polluted water as the ions of chlorine used to disinfect water combines with organic matter to form chloramines, thus reducing available chlorine to effectively kill disease causing pathogens such as viruses, bacteria, protozoa, and worms. This may pose major outbreaks of diseases in the region, with consequent impacts on morbidity and mortality. To achieve effective disinfection more chlorine has to be used resulting in additional cost of water treatment.

Water Related Diseases

Water, even more than food, is such a basic human need and yet more people die each year from water borne illnesses. This is due to water quality degradation as a result of pollution. There is generally a positive relationship between algal and bacterial biomass and increased nutrient loading (R. Erikson, M. Pum, K. Vammen, A. Cruz, M. Ruiz & H. Zamora Limnologica 27 (2) (1997) 157-164). This relationship suggests either that bacteria and phytoplankton grow in response to common factors such as nutrient loading and temperature or that phytoplanktons or substances released by phytoplanktons are important substrates to bacteria (Mugidde R. 1993). Water such as Municipal wastewaters (mainly sewerage), run-off waters from farms, ranches and rangeland inhabited by wildlife, and certain industrial wastewaters contain a wide variety of pathogenic (disease-causing) organisms including bacteria, viruses, fungi and protozoa. Discharge of these wastes into the water resources results in the contamination of the water with the organisms. These organisms are water borne and contribute diseases to man such as bacillary and amoebic dysentery, cholera, typhoid and paratyphoid fevers, gastroenteritis, diarrhoea, enteritis, and infections hepatitis.

(APHA, AWWA, Standard methods for the examination of water and waste water 19^{th} ed). The end result that there is a cost element in treating the diseases

Definitions of disease causing organisms:

Bacteria

Any body of water will contain bacteria washed in from the soil and air, human and animal intestinal waste matter, in addition to indigenous aquatic bacteria. The total number of bacteria in a body of water can give a useful indication to the general water quality but Intestinal bacteria are more significantly related to the health of the persons using the water. Pathogenic bacteria such as salmonellae, shigellae and vibrios that cause typhoid and paratyphoid fevers, bacillary dysentery and cholera respectively cause disease if ingested by other individuals. Non – pathogenic bacteria re excreted in even higher numbers in faeces and some of those have been shown to be present exclusively in faecal material. Presence of these bacteria in water can therefore be taken to indicate the certain presence of faecal material in water, and the possible presence of pathogenic bacteria.

Viruses

A wide range of viruses are discharged in faecal material into receiving waters, and their presence in water constitutes a health hazard for subsequent users. The types of viruses that are of public health significance in water give rise to a wide range of diseases from poliomyelitis and infectious hepatitis to inflammations of the eyes and respiratory tract infections.

Algae

These are micro- organisms that contain the photosynthetic pigment chlorophyll-a. they occur as unicellular forms, colonial forms and branched filamentous forms. Algae are aquatic organisms, so they are not themselves indicative of faecal pollution. However, the addition of materials such as sewage and fertilizers to natural water increases the concentrations of phosphates and nitrates, which may ultimately stimulate the growth of algae. Excessive growths or blooms of algae in a body of water can have a public health significance as some algae produce toxins which can cause outbreaks of gastroenteritis in man, skin irritations, liver and kidney damage and even carcinogenesis. Algae also commonly cause water treatment problems.

Fungi

These are filamentous organisms often associated with soil, decaying animal and vegetable material, and sewerage polluted waters. The organisms are not excreted in faeces but play an active part in the degradation of sewage in receiving waters fungi give rise to strong irritating tastes and odours in waters.

Protozoa

Protozoa are a group of non-cellular animals, which are usually microscopic in size. They are all basically aquatic but some are parasitic and inhabit specialized habitats like intestines or blood vessels of the host. The only important protozoa pathogen that is commonly water-borne is Entamoeba histolytica that causes amoebic dysentery. In polluted waters the composition of the protozoa fauna may be used as a guide to the degree of purification.

Food Web Contamination

The physico-chemical conditions of the lake have been accompanied by a cascade of other changes in the fauna and flora.

Phytoplankton composition has changed and is now dominated by blue-green algae. Algal biomass has increased and are now higher than values of the 1960’s and phytoplankton production has increased. This has resulted in the decrease of water transparency (Ochumba, & Kibaara 1989). The change in water quality could have affected the species food and feeding habits, trophic relationships, reproduction and breeding habits, growth, mortality and migrations. (Ochumba, P B. O. & D. I Kibaara 1989)

The algal-bacterial compartment is both the producer and the sink for organic carbon and the system may be characterised by a tight coupling between algae and bacteria with little transfer of carbon and energy to higher trophic levels and therefore, affecting primary production in these other levels.(Rolf Erikson 1998)

The pattern of carbon flow and efficiency of transfer between trophic levels of food webs is much dependent on food web structure (Stockner and Antia, 1986; Stockner, 1988). The transfer may be very high in a tropical lake like Lake Victoria where herbivorous fish are common and the food chain is very short.

Industrial wastewater discharges into receiving streams and finally into lake Victoria bring with it toxic chemical pollutants into the lake water. The toxic chemicals include mercury, zinc, copper, arsenic and cadmium. These substances rapidly accumulate in the aquatic biota and biomagnifies upward through the aquatic food chain, attaining highest concentration in fish. Humans get affected through the consumption of fish and other aquatic animals. These substances are highly toxic and are harmful to body organs. (Linda M. Campbell; R.E. Hecky; J. Nyaundi; Rose Muggide; D. George Dickson. Great Lakes Research 29 (Supplement 2): 267-282). Some of the diseases caused by mercury ingestion are………………..

Loss of Fish Habitat

Water quality monitoring has shown that there is reduced transparency in the lake Victoriar. Present research has shown that algal blooms of blue green algae type now predominate, and chlorophyll concentrations have increased over the years resulting in high levels of primary production while reducing transparency significantly. Although a two fold increase in primary productivity by the phytoplankton has likely been positive for potential fish production, algal biomass has increased 5-10 times indicating that the productivity is not being used with high efficiency. Reduced transparency has at the same time reduced benthic algal production upon which many of the endemic species of fish depended and also the reduced transparency has led to a loss of biodiversity (Seehausen et al. 1997)..
The change in water quality could have affected the species food and feeding habits, trophic relationship, reproduction and breeding habits, growth mortality and migrations.(Ochumba, P B O. 1990).

Now much of the primary production and the increased algal biomass and even secondary productivity (e.g. insects) is not consumed. Instead when they die, they sink and, as they decay, deplete the water column of oxygen. The result is the development of extreme hypoxia in parts of the lake (deeper parts), which makes a large volume of the lake no longer available to fishes and other aerobic life.

Increase in growth and productivity of water hyacinth which is usually the result of availability of nutrients, especially phosphorus and nitrogen in the water, obstructs and disturbs the breeding processes of the fish. This occurs especially when it is blown into shallow waters of the lake which are known to be grounds of fish spawning. Extensive areas under these mats are usually anoxic further reducing availability of fish habitat even in shallow waters due to low oxygen.

*Two endemic tilapiines, Oreochronis esculentus and O.*variabilis, which formed substantial fishery, have virtually disappeared from the lake. Many other non-cichlid members previously of great commercial value have also declined substantially. (Ochumba, P B O. 1990). Although predation and hybridization may have played a role in the demise of these species, in the case of *O. esculentus* a change in the composition of the algal community may have. Early feeding studies on this fish showed that it had a strong preference for diatoms over other algal species.

All these changes together in visibility and oxygen conditions restrict the habitat volume available for many fish species and for all fish to some extent. in reduced catches for many native species, reduced diversity in the fisheries resources. The current fishery for Nile perch has been productive and has benefited from some of the water quality changes, but this fishery is now primarily for export. This has resulted in more costly fish in local markets, less profit to fishermen because of increased infrastructure costs necessary for the export market and reduced availability of fish and fish products to local consumers.

Massive fish kills

Massive fish kills in Lake Victoria have been reported in 1927, 1953, 1968 and 1985 (Wandera, 1988). An investigation into the causes of fish kills in the Kenyan side of Lake Victoria, carried out between 1985 and 1987, reached the conclusion that the main cause of these deaths was asphyxia, that is suffocation due to lack of oxygen (Wandera, 1988). It was, moreover observed that strong winds and storms tended to precede the fish kills, suggesting that turbulence resulted into upwelling of the water thereby exposing fish to the bottom water that is deficient in oxygen. All factors that lead to the depletion of oxygen could, therefore, be held responsible for fish kills. Besides toxins, pollutants, and deoxygenated water, fish pathogens have also led to occasional fish kills. Fish pathogens include bacteria, viruses and parasites (Achieng 1988; Wandera, 1988).

Biodiversity loss in the Kenyan fisheries

According to World Bank (1996), most of the fish species now in the lake also lived in the preceding, west-flowing rivers, but the *cichlids,* in particular, had a remarkable burst of speciation in response to the transition from rivers to lake conditions. Similar things happened in other great lakes, but in Lake Victoria it happened much more recently, more rapidly, and with, at first sight, fewer opportunities for ecological isolation in different types of habitats. The cichlids are capable of rapid genetic change and more prone to speciation than other groups of African fish. There are were more than 200 identified and classified endemic species and 4 endemic genera of cichlids in Lake Victoria, more than 150 species of which are of the genus *Haplochromis*. Another major lineage is the tilapiines. From the primitive insect-eating types, mouths and pharynxes have evolved to allow feeding on plants, molluscs, fish, and even eggs and young larvae carried in the mouths of brooding females of most cichlid species. This diversification was effective in transferring energy from algal and invertebrate animals sources into fish biomass.

Lake Victoria had very high species diversity before the 1960's. A large segment of the fauna is feared to have become extinct. The fish species diversity in Lake Victoria is still high compared to other lakes, it was formerly extraordinary. By 1960's stocks of the native species had been reduced. There has been a drastic loss in biodiversity and important fish species have virtually disappeared including the originally important commercial species. (Ochumba P.B.O. 1990). Many of these changes may have been due to changing water quality affecting the productivity of native stocks while predation pressure from Nile perch and fishing pressure was increasing.

Currently, fish species like *Oreochromis esculentus, Labeo victorianus, Barbus altianalis* and haplochromines are endangered or found only in marginal (satellite) lakes of Victoria. Other species which could be threatened include lung fish, mud fish and river eels. In addition, the introduction of alien species of fish and plants threaten the variety and productivity of the lake's fisheries.

The non-cichlids have also changed, and there are at least 50 species, of which 29 are endemic, and one endemic genus. The non-cichlids show much less divergence from riverine stock than in the case with non-cichlid fish in Lake Tanganyika, which has had a much longer time for them to diversify. While most of the species remain year round in the lake, there are a number (at least 13 species) of anadromous (ascending) fish, especially cyprinids, characids and siluroids, which swim up the river when they are in flood, breed in a suitable place, and return with their young fish to the lake as the level drops.

One of the main events of importance to the lake system in the past 30 years was the introduction of new species of fish in the lake. The first were four species of tilapia (Cichlidae), which were introduced in the early 1950s. In 1954 the Nile perch *Lates niloticus* (Centropomidae) was introduced into Lake Kioga, and when a few years later it was found in Lake Victoria, steps were taken to ensure its establishment there. Until 1978, Nile Perch remained a very small proportion of the commercial catch, less than 5%. Then in 1978 a very rapid expansion of the proportion accounted for by Nile Perch took place, with the result that by 1990 the commercial catch has a totally different composition, dominated by Nile Perch (60%) and Omena (40%). The haplochromines, and the mixture of other fish had virtually vanished from the commercial catch.

It is important to note that the size of the fishery also exploded from 1978 on, perhaps by a factor of five or more. From Kenyan waters alone the recorded catch climbed from around 25,000 tonnes in 1978 to more than 175,000 tonnes in 1990. In the years preceding introduction of the Nile Perch, the total fisheries yield from the lake may have been in the vicinity of 100,000 tonnes, while in more recent years yields have been estimated in the range of 300,000 to 500,000 tonnes
Nearly a million people in LVB depend directly or indirectly on fishing for their livelihood. Fish is a major source of protein intake in Kenya, and an important export. At present, Lake Victoria produces over 95% of Kenya's fish catch. Pollution and ecological disruption of the lake is therefore a major concern. The use of unauthorized fishing gear is another threat to conservation of aquatic resources. Over-fishing of resources through uncontrolled licensing of fishermen and fishing vessels exert pressure on sustainability of the resources.

Inefficient Food Webs

Water quality monitoring has revealed significant trends in the Lake Victoria aquatic environment. The relationship in the manner and extent to which nutrient supplies are converted into biological matter, including potentially toxic algae and other troublesome and life threatening organisms do exist.

With increasing eutrophication there is an increase in algal biomass (Linda M. Campbell, R.E. Hecky; S.B. Wandera Great lakes Research 29 (Supplement 2) 243 – 257)) when there is continuous supply of nutrients the same phytoplankton assemblages persist for many days in the lake and the species must be adopted or tolerant to the full range of environmental variation Species of blue-greens (Cyanobacteria) seem to be favoured under such conditions (R. Erikson, M. Pum, K. Vammen, A. Cruz, A. Ruiz& H. Zamora – Limnologia 27 (2) (1997) 157 – 164).

Food chains based on species of this group of algae are less efficient and often constitute dead ends, whereas food chains based on diatoms as primary producers are more efficient because of higher digestibility and nutritional value of diatoms. (classic food chain" Stockner & Antia 1986, Stockner 1988).
If algal-bacterial compartment exist in a trophic level, it may act as both the producer and the sink for organic carbon and the system may be characterised

by tight coupling between algae and bacteria with little transfer of carbon and energy to higher trophic levels and therefore affecting primary production in these other levels (Linda M. Campbell, (R.E. Hecky; S.B. Wandera Great lakes Research 29 (Supplement 2) 243-257)

The pattern of carbon flow and efficiency may be high in Lake Victoria when herbivorous fish are common and the food chain is very short (Hecky R.E. F.W.B Bugenyi 1992) with vigorous predatory fish community. The efficiency may be very low where such species are less important and where the primary production is dominated by algae that are not grazed or less digestible e.g. many Cyanobacteria. The spectacular growth in the Victoria fishery was in part due to the increased primary productivity of the system through the same time period. However, the productivity also caused an increase in algal biomass especially in Cyanobacteria indicating little direct use by grazers and inefficient energy transfer to the predaceous Nile Perch. Excess production represented by this poorly used algal biomass then can decompose causing anoxia in the hypollmnion. Algal primary productivity of the lake is now light-limited and cannot increase further. However reduction in nutrient loading could shift the the algal community to species such as diatoms and green algae (Chlorophyta) that could be used more efficiently by the food web. This diversification of the algal community along with some improvement in transparency will also be necessary to make conditions appropriate for restoration of biodiversity in the fishes.

Nuisance Macrophyte Growth

Lake Victoria has recently faced invasion by the water hyacinth (*Eichhornia crassipes*), with potential adverse effect on fish production through destruction of fish breeding areas, blockading piers or landing beaches, lake transport services for people and goods, power generation, water supply and harbouring disease vectors. Although its origin and how it found its way into the lake is still uncertain, it is believed to have come from the South America. According to local folklore, the weed was brought into Africa during World War II by foreign soldiers who considered its beautiful flowers to be of natural sentimental value while in combat abroad. The invasion can also be partly attributed to eutrophication resulting from sediment and nutrient deposition into the lake arising from soil erosion and other agents of pollution. Thus there has been the increased growth of aquatic weeds especially in areas receiving high nutrient loads from tributaries.

Probably the most serious environmental impact of the massive floating vegetative mat is oxygen depletion from the water and reduction of nutrients in sheltered bays which are breeding and nursery grounds for fish, particularly tilapia. Both processes have detrimental effects on the ecological functioning of fish, thereby impacting negatively on fishery productivity.

The weed is also affecting productivity by disrupting important food chains. Through its vegetative cover, the weed shades phytoplankton from sunlight, and in dense stands the hyacinth reduces aeration of the water.
Furthermore, the weed provides a preferred breeding habitat or the alternative host for Schistosomiasis (bilharzia), namely the *Biomphalaria* snail, a home for vector mosquito for malaria, and a haven for snakes.

However, its invasion has been brought under control through cooperation of the neighbouring countries, and with vigilance the control should be sustainable but aggressive action on nutrient reduction is necessary to eliminate “hot spots” of hyacinth growth in the vicinity of point sources of nutrients.

Other weeds found to exist in Lake Victoria favored by the availability of nutrients especially nitrogen and phosphorus include water lettuce and water fern which also threaten waterways, wetlands, darus, irrigation schemes and the lake itself. The three aquatic weeds are a cause for concern since they have enormous potential for their spread in the lake region. The identification and reduction of sources of nutrient enrichment becomes a critical issue, which requires urgent intervention measures to be implemented.

Ecosystem changes and management

Apart from the diversity loss in the fisheries, there have also been changes in phytoplankton composition with the blue greens becoming dominant giving rise to algal blooms. (Mugidde R. 1993) dominated by Cyanobacterial species that produce algal toxins that can be lethal to aquatic life and to humans as well as livestock.
Having the world’s second largest lake, in a condition of chronic Cyanobacterial dominance creates an unacceptable risk to the millions of people directly dependent on the lake for domestic use as well as threatening the efficient functioning of the ecosystem. Restoration will require nutrient reduction especially of phosphorus compounds from point sources which create conditions harbouring pathogens as well as causing eutrophication of local water. In the longer term non-point nutrients will require management to encourage retention of these critical nutrients on the land surface where they are essential for agricultural productivity.

The lake has been invaded by the water hyacinth which if left unchecked spreads at an alarming rate and has had far reaching effects in water quality (far reaching negative consequences in water quality). The introduced Nile perch and tilapiine species along with water quality changes have also reduced fish biodiversity in the lake. Kenya and the riparian states have suffered from some of the changes these species introductions that have caused socio-economic damage and social disruption. The East African community should take a leading role in adopting a strategy and policy for preventing future species invasions and introductions.

It appears that the reduction in biodiversity has left much of the excess organic matter unconsumed. Prior to the big shift in the lakes biological communities, more than half of the fish biomass was contributed by the aquatic organisms specialized in eating algae and detrius, thus capturing this abundance of energy in the production of fish flesh. Now nearly all these species have disappeared and this along with other factors has greatly reduced the ecological efficiency of the lake. Water quality degradation pose a threat to the functioning of aquatic ecosystems. Dissolved oxygen (DO), which is a requirement in ensuring the aquatic biological functions should be maintained at a minim level of acceptance. Restoration of fish habitats and transparency will be essential to restoring biodiversity and will require nutrient reduction strategies to be agreed upon by all

Low concentrations of DO, when combined with the presence of toxic substances may lead to stress responses in aquatic ecosystem because the toxicity of certain elements, such as zinc, lead and copper is increased by low concentrations of DO. These persistent toxicants are difficult to remove once they have been added to aquatic ecosystem. Fortunately concentrations remain low in Victoria waters and biota . Pollution prevention is the most cost-effective way to deal with these toxic compounds. Protection measures should be taken to safeguard the lake water to protect the integrity of aquatic ecosystems and to incorporate specific requirements for sensitive and specially protected waters and their associated environment such as wetland areas and the surrounding areas of surface waters which serve as sources of food and as habitats for various species of flora and fauna.

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