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An Environmental System Analysis of Lake Elementaita, Kenya With Reference To Water Quality

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ABSTRACT

Lake Elementaita, located in the Rift Valley of Kenya is a shallow hyper saline lake, with a mean depth of 0.7 meters and has a fluctuating lake area of between of 15 to 22 km^2.The major phytoplankton species is the cyanobacterium 'Spirulina' *Arthrosporia fusiformis*, which is the only food source of the lesser flamingo, *Phoeniconiconaias minor.* Lake Elementaita is hypertrophic with total phosphorus values of 0.9mg l^{-1} and total nitrogen values of 22mg l^{-1}.The main sources of inflow are rivers Mereroni, Mbaruk and Kariandusi; as well as fresh water and saline hot springs, located in the southern part of the lake. The objective of this study was to find out the effect of the hot springs on the lake water chemistry as well as to establish the source of the nutrients.

The Generalized Watershed Loading Function (GWLF) model was applied to simulate nutrient transport processes in the watershed. GWLF model estimates nutrient loads in stream flow as well as point sources. The hot springs were introduced in the model as point sources. Results indicate that the hot springs are an important source of dissolved phosphorus in the lake. The hot springs are fed by fracture flow along faults running on the rift valley floor.

Spatial variation of water quality was studied as well. The spatial variation of electrical conductivity gave a good indication of the water quality variation. This variation is influenced by winds, springs and surface water inflow (dilution effects).

The hydrological link between lakes Elementaita and Naivasha may explain the source of dissolved phosphorus. The water type of Lake Naivasha groundwater and rivers Mereroni and Kariandusi was found to be similar. This is due to the similar rock types in the area. This consists of Basalts, Trachytes and Rhyolites.

Keywords: Nutrient Modelling, Watershed, Hot Springs

INTRODUCTION

Lake Elementaita is a shallow, small saline lake located in the eastern arm of the Great Rift Valley, in the Nakuru district of Kenya. Fig.1 It is fed by inflows from the rivers Mbaruk, Chamuka and Mereroni. The main water source is the Mereroni River that initially flows parallel to the other rivers, abruptly changes direction to flow in a south-eastern direction along an extremely straight line. This is due to Rift Valley faulting (Githae, 1998). There is also some inflow from hot springs located on the south-eastern part of the lake. The lake Elementaita basin has subsurface flows from lake Naivasha (Muno, 2002). The lake levels fluctuate and in some cases the lake and its feeder rivers have been known to dry up (Murimi et al., 1993). This brings an effect on the water quality of Lake Elementaita. The lake and its riparian area are used as a breeding area for the pink backed pelican and as a feeding area for the lesser flamingo that feeds on the blue green algae 'Spirulina' *Arthrospira fusiformis*. Salt harvesting and game viewing are some of the major anthropogenic activities taking place in the area. There is small-scale peasant farming in the catchments. Live stock rearing is also a major anthropogenic activity in the area. The same activities could be having an impact on the water quality reaching the lake. The lake is also fed by geothermal hot springs in the southeast. The objective of the study was to establish the impact and effect of the hot springs on the lake water quality.

METHODS

To achieve this objective, a watershed model was applied to estimate the nutrient runoff into the lake from its catchment as well as establish the impact of the springs on the hydrochemistry of the lake. Fig. 2 Field measurements were carried out these included lake sampling as well as discharge measurements. Lake sampling as well as water sampling in the catchment was carried out from 1st to 12th October 2004.

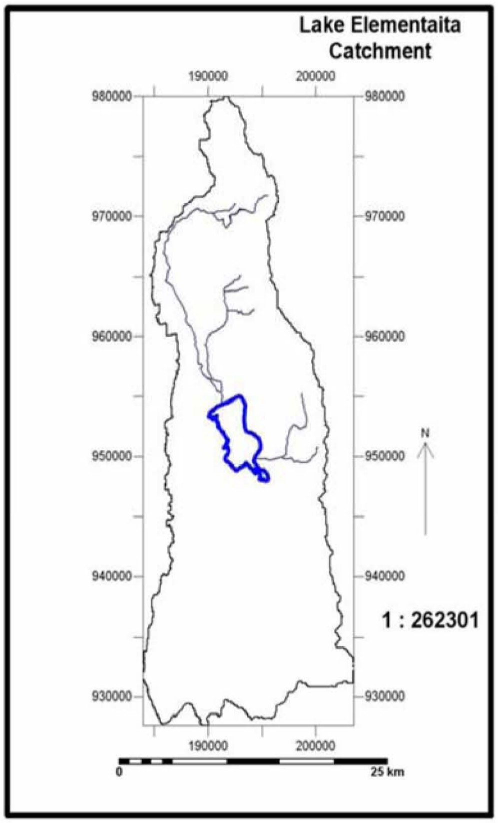

Figure 1. Catchment of Lake Elementaita

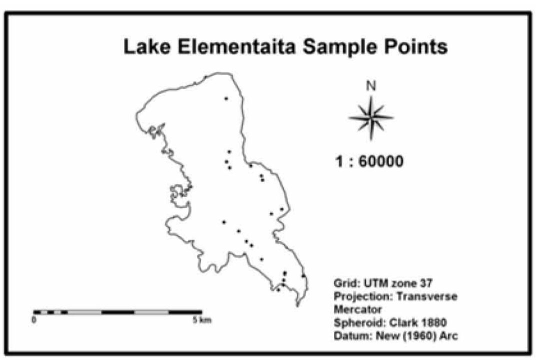

Figure 2. Water sampling points

In situ measurements were carried out on the water for pH, electrical conductivity and temperature. These were measured using a Hach Sension model number 156. Random sampling was carried out. Water samples were collected from the top 20 cm of the lake surface. The samples were filtered using a Wartman 0.45μm filter paper and preserved by adding a few drops of concentrated nitric acid HNO_3 for cation analysis on the ICP - AES. 200ml were preserved using concentrated hydrochloric acid (HCl) for anion analysis in the lab where the Hach spectrophotometer DR 2010 was used for anion analysis. The samples were stored at 4^{o}C before transportation and analysis in the laboratory. Analysis was carried out following the protocol outlined for the various anions and cations as indicated in the water quality analysis manual of Hach (Hach, 2004). The water samples were then analysed using Inductively Coupled Plasma-Atomic Emission Spectrophotometer (ICP-AES) out to determine concentration of following cations Potassium, Sodium, Calcium, Magnesium, Aluminium and Iron. The anions; Chlorides, Sulphates, Total nitrogen, Nitrates , Total Phosphorus and Phosphates were evaluated using the Hach DR 2010 Spectrophotometer following the procedures outlined on their online manual (Hach, 2004). Reliability check and basic statistical analysis was carried out to evaluate the accuracy of the analysis. This was done using the method from Hounslow (1995). The water types were established using Aquachem software fig.3. The different water samples when analysed gave one major water type (alkali carbonate) sodium hydrogen carbonate chloride ($NaHCO_3Cl$) with several different sub water types depending on the concentrations. These were dependent on the origin.

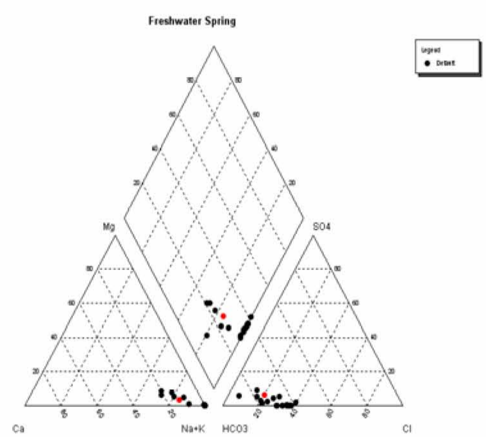

Figure 3. Water type from Fresh water Springs

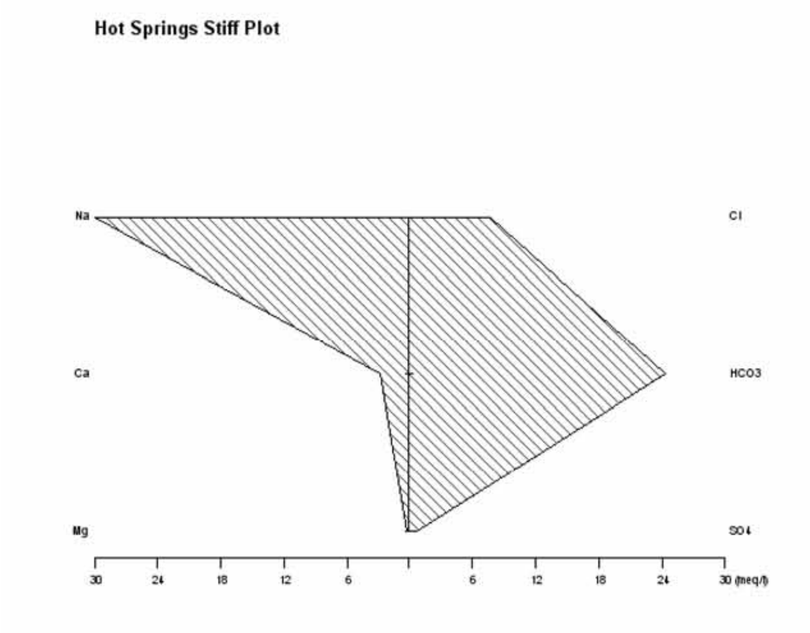

Figure 4. Stiff Plots of Hot water springs

Stiff plots were also generated of hot springs water fig. 4 type and the results indicate that the Elementaita area that is at the rift valley floor underwent eruption of fluid lava that has low viscosity this is mainly Rhyolites. Basalt rocks have high viscosity hence do not flow over long distances. Trachyte rocks have intermediate character. Basalt rocks are basic and relatively low amounts of silica (less than 45%) while Rhyolites are acidic rocks and hence rich in silica (greater than 45%). The parent rock has a lot of Sodium. This results in the rift valley lakes being soda lakes.

The piper plots indicate that the major source rocks are Rhyolite and Basalt(Hounslow, 1995). Further field observations indicate that Maji Moto is a tributary of the Kariandusi River. The fresh water springs and Maji Moto springs appear to have a similar composition.

The plots above indicate that the major ions of influence are Sodium, Bicarbonate and Chloride. The chemical composition of Lake Elementaita is dominated mainly by Sodium. This agrees with what was written by (Tegaye, 1998). Tegaye indicates that high bicarbonate and carbonate concentrations are coupled with low to only trace amounts of calcium and magnesium .Further, the magnesium and calcium ions appear to be eliminated in the middle or lake centre. These findings agree with what was observed by Talling (1965). This is common in many African rift lakes.

The basaltic rocks are basic and give rise to the sodium and bicarbonate ions. The high levels of chlorides are indicative of a closed lake system with high evaporation rates as well as the hot springs fed by geothermal aquifer. The major source of chlorides is the hot springs (Hounslow, 1995). The hot springs can also account for the high levels of Sodium in the lake. Other sources of sodium are the silicates that could be as a result of chemical weathering of the Basalts and Trachytes. Common Sodic silicates are Albites ($NaAlSi_3O_8$). The geothermal hot-springs give rise to plenty of sulphates as shown in the water sample analysis. These results agree with work done by (Morgan, 1998) who looked at the groundwater chemistry of the lake Naivasha area. The main lake water type was mainly sodium bicarbonate. The river inflows (Mereroni and Mbaruk) have sodium calcium bicarbonate water types.

The Generalized Watershed Loading Functions model (GWLF) was used to model the nutrient transport processes in the watershed. This chapter describes the steps taken to prepare the input files for running the model, the results of running the model and the outputs of the model. Three data files and four program modules are required to run the GWLF model. Data files required are Transprt.dat, Nutrient.dat and Weather.dat. These are created from the data collected during fieldwork as well as from previous studies of the area. They comprise mainly of source area parameters, Universal Soil; Loss Equation (USLE) factors and day hours for each month. The land cover map was prepared by collecting land cover points in the field then carrying out supervised classification of the Landsat ETM image of the area of March 2003, using maximum likelihood classification method. A majority filter was applied to smooth out the undefined pixels in the classified map. The major source areas were identified from the prepared land cover map. The area for each source area was calculated from land cover map. The watershed area was calculated from the Digital Elevation Model (DEM) using the watershed delineation tool of AVSWAT as described by (Muthuwatta, 2004). The DEM used was from the Shuttle Radar Topography Mission (SRTM) of 2000. The DEM has a pixel size of 90meters. The other USLE parameters were obtained from a soil map of Kenya, as well as tables of the GWLF manual.

The model was run for the 45 years. The first forty years were used for priming the model. According to the GWLF manual (Haith et al., 1992), the model is able to estimate monthly nutrient fluxes without calibration. There was a lack of data on stream-flow, fertilizer application and nutrient loadings. Therefore calibration was not carried out. The results were considered for the last six years. Year 40 to year 45, from 1997 to 2002.

The total nitrogen results indicate that the major source of Total nitrogen in the lake system appears to be agriculture. The agriculture contributed a high percentage of Total nitrogen to the lake in 1997 (56%) and 1998 (72%). However in the subsequent years the total nitrogen contribution from agriculture decreased. The other major source of total nitrogen was the point source or Hot springs. The graph in figure 5 clearly indicates that the major source of dissolved nitrogen in the system was the hot springs. However the percentage concentration varied depending on the other sources of inputs to the system. In 1998 Agriculture gave the highest inputs 10.29mg (71.59%). The hot springs gave a constant value of 3.78 mg per year. The major input of dissolved phosphorus appears to be the hot springs. They give about 0.76mg. Other sources of dissolved phosphorus are agriculture and bare soil. The dissolved phosphorus is used in living organisms as a source of cell building matter.

The nutrient file shows the different nitrogen and phosphorus inputs from the source areas into the Lake Elementaita system. Several land cover types were identified and used as source areas. The different nutrient values were obtained from the GWLF manual as well as previous studies of the area.

Table 1: Transport File Input Data

Source Area	Area (m2)	Area (ha)	CN	k	ls	c	p	klscp
Acacia	50453500	5045.35	43	0.150	2.356	0.004	1	0.001409
Salt Deposits	850500	85.05	77	0.140	0.038	1	1	0.005333
Grassland	126015400	12601.54	43	0.141	0.208	0.003	1	0.000088
Waterbody	12150000	1215	91	0.140	0.007	0	1	0.000000
Settlement	1315000	131.5	82	0.146	0.760	1	1	0.111011
Rock Outcrop	12384900	1238.49	91	0.141	0.650	1	1	0.091788
Shrubs	33963300	3396.33	48	0.154	0.245	0.1	1	0.003765
Agriculture	339076400	33907.64	74	0.159	1.209	0.2	1	0.038369
Bare soil	53962200	5396.22	77	0.145	0.630	1	1	0.091400
	630071200	63017.12						
	Area (km^2)	630.1712						

Table 2: Nutrient file input data

Nutrient Data				
Dissolved Nutrient	N(mg/l)	P (mg/l)	N (kg/ha-day)	P (kg/ha-day)
Acacia	3	0.25		
Grassland	1.8	0.3		
Water body	0	0.3		
Salt deposits	0.23	0.007		
Settlement			0.02	0.004
Rock Outcrop	0	0		
Shrubs	0.25	0.18		
Agricultural	2.9	0.26		
Bare soil	0.23	0.07		

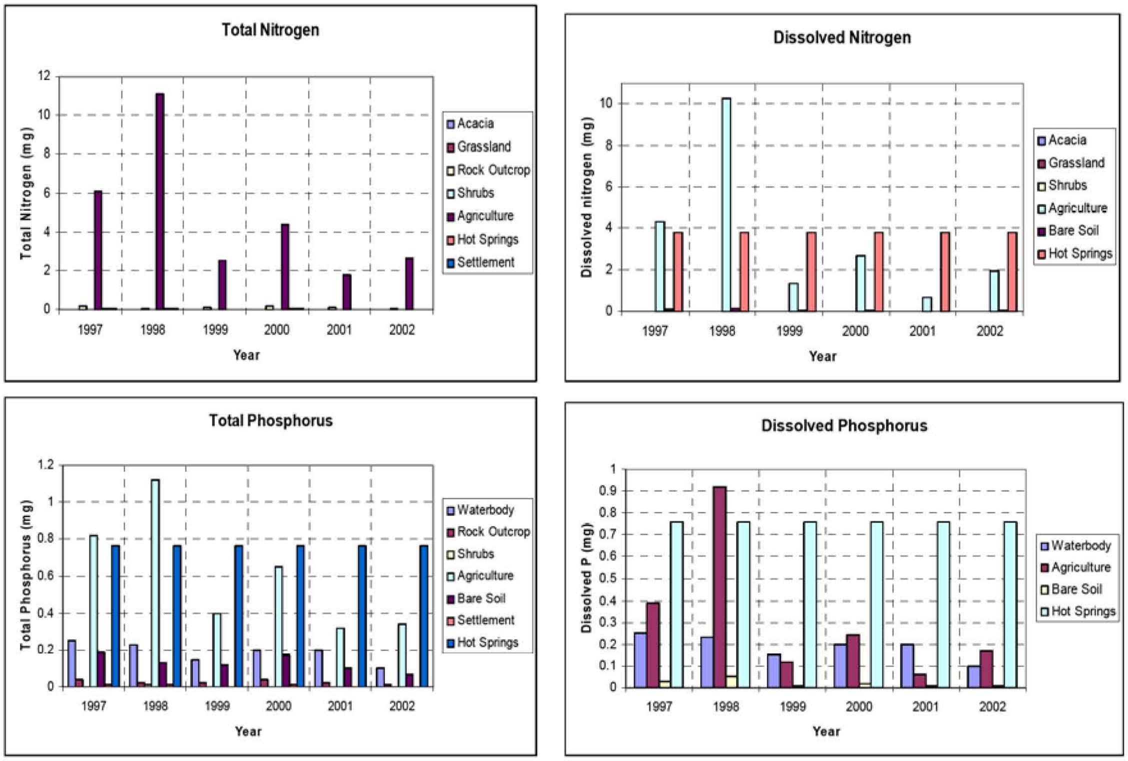

Figure 5 : Results of Watershed modelling.

RESULTS

Lake Elementaita watershed is a rural and agricultural watershed. The results indicate that the hot springs are a major source of dissolved nitrogen, dissolved phosphorus and Total phosphorus. It was possible to model the catchment despite lack of data on many of the nutrient transport processes. One of the major challenges was to model the input of animals especially the flamingo that feed and deposit their waste in the lake water.

The total nitrogen source areas are the agricultural land use. This may be due to the application of fertilizers in local farms to increase crop yields. Most fertilizers contain nitrogen. The output from the agricultural source area was highest in the year 1998 and followed by 1997. These were periods of high rainfall and consequently abnormally wet years. (El Nino). This means that during this time the sources of nutrients was from runoff from the watershed.

The major limitation of the hot springs discharge amount is that the "snap-shot" measurements taken in the field were assumed to be standard for every month. In reality this is not the cause. Discharges of hot springs did not consider diffuse flow from the lake bed.

The Hot springs are a major source of Phosphorus into the lake. The periods of wet years were also the times when the amount of phosphates from the agriculture land cover increased. This agrees with work done on Lake Naivasha where Kitaka (2000) found phosphorus flushing after heavy rainfall. The sources of phosphorus in the catchment includc wastc watcr, scwcragc and dctcrgcnts.

Hydrological connection between lakes Naivasha and Elementaita has been suggested by many researchers(Becht and Harper, 2002; McCall, 1967; Muno, 2002; Nabide, 2002; Ojiambo et al., 2003). Fracture flow has been shown by Ojiambo as well as Nabide by isotopic data and hydro-geological descriptions of the area. This can be seen on appendix 5. The main sources of phosphorus in the hot springs may be from the lake Naivasha sediments. Other sources of phosphorus into the Elementaita system may be from Atmospheric transport.

CONCLUSIONS

The objective of this study was to find out the effect of the hot springs on the lake Elementaita water chemistry. The major finding was that the Hot springs are a major source of phosphorus and nitrogen into the lake Elementaita system. These hot springs are fed by fracture flow along the faults running along the rift valley floor. The discharge of the hot springs is regular and it is an important source of water for Lake Elementaita.

The nutrient sources into Lake Elementaita are varied. The total nitrogen source is the agricultural land use. This could be due to fertilizer application. The output from the agricultural land use was highest in 1998 followed by 1997. These were periods of high rainfall and consequently wet years due to the "el nino rains". The main nutrient source during this period was runoff from the watershed.

The hydrological link between lakes Elementaita and Naivasha is an important source of phosphorus. Lake Naivasha is a fresh water lake located in an area that has high evaporation rates (1600-1800mm) and low rainfall (640mm). It has been established that it remains fresh due to underground outflow and seepage into shallow aquifers.

Both lakes Naivasha and Elementaita have similar water types. The main water type is Sodium hydrogen carbonate. This is due to the alkaline rocks, mainly basalt and trachytes found in the area. Volcanic activity had a major impact on the rocks of the area(Morgan, 1998). The main rivers flowing into Lake Elementaita are Mereroni, Mbaruk and Kariandusi. Kariandusi River was found to be a major source of sulphates and had a much higher electrical conductivity than Mbaruk and Mereroni.

Spatial variation based on Electrical conductivity (EC) values is affected by winds, springs and surface water inflow into the lake. The southern portion of the lake is fed by hot springs. The northern portion of the lake has inflows from river Mereroni, hence has a lower electrical conductivity value. The eastern part of the lake has the highest EC values. This can also be explained by the sheltering effect of the cliff running in the north-west direction along the eastern side of the lake.

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