Water quality trends and input loads to Lake Nakuru

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Abstract

Water quality trends of Lake Nakuru, Kenya and its feeder streams were monitored in 2001-2004. Water samples were obtained from eleven stations in the lake and five points on inflowing streams. The items monitored were physico-chemical and biological components. The drainage basin was characterized by recurrence of dry spells throughout the period with water losses in the lake exceeding the amount received to cause a fall in water volume. The lake water salts content rose – conductivity and alkalinity reached 58 ms/cm and 5,200 mg/l respectively. PH was more or less constant (10.00 – 10.36). Daytime oxygen concentration in the mid-lake system rose (to greater than 20 mg/l) while remaining low in the inflow portions of the lake. On one occasion, the lake suddenly deoxygenated resulting to fish kills. Silt and organic loading were intensive in the north and south, contributing significantly to a decline in water transparency (secchi depth, 13 cm or less). Total phosphates varied significantly (4.39-9.128 mg/l). Of the nitrogen forms, only ammonia and total nitrogen were detected in appreciable amounts. The phytoplankton biomass was high and was mainly dominated by populations of Arthrospira fusiformis (mean, 158-2924 coils/ml). Various strains of Anabaenopsis spp. with Coccoids also occurred at low biomass. The only exception was in 2003 and 2004, when they developed into a dense bloom that was followed by flamingo mortalities. The northern portion had very low phytoplankton content while in the south, the phytoplankton community was one with relatively higher numbers of zooplankters and Anabaena spp. The yearly input load of the lake was 40,000 tons with Rivers Makalia and Njoro contributing significantly to the load. These results suggest eminent change of the lake ecosystem, which could arise due to human impacts from catchment degradation and urbanization.

Key words: Biomass, Load, Mortalities

Introduction

Past studies have highlighted the importance of Lake Nakuru as home of wildlife and an important tourist attraction. The lake is a hypereutrophic soda lake located at 0º 22' S 36º 05' E and altitude 1759 m.a.s.l. It is characterized by high evaporative processes which with its catchment geochemistry makes it an extreme ecosystem, unfavorable to most aquatic life. Only a few tolerant and adapted species attain high population density: (Jenkins 1929; 1932 & Veraschi 1981). The lake therefore supports a unique and highly productive community of algae, and few invertebrates that form the food basis of the lake food chain.

Principal input to its water budget are, rainfall, stream flow and springs which are major determinants of its salinity state. Effluent run off from the adjacent Nakuru town also end up in the lake. Various human activities are within the surrounding L. Nakuru basin which makes it highly vulnerable to pollution. For its long time conservation, a continuous monitoring system is vital. This is the objective of the current monitoring program.

Materials and methods

The locations of sampling points are shown in Figure 1. Water samples were obtained monthly. A total of 16 stations were monitored.

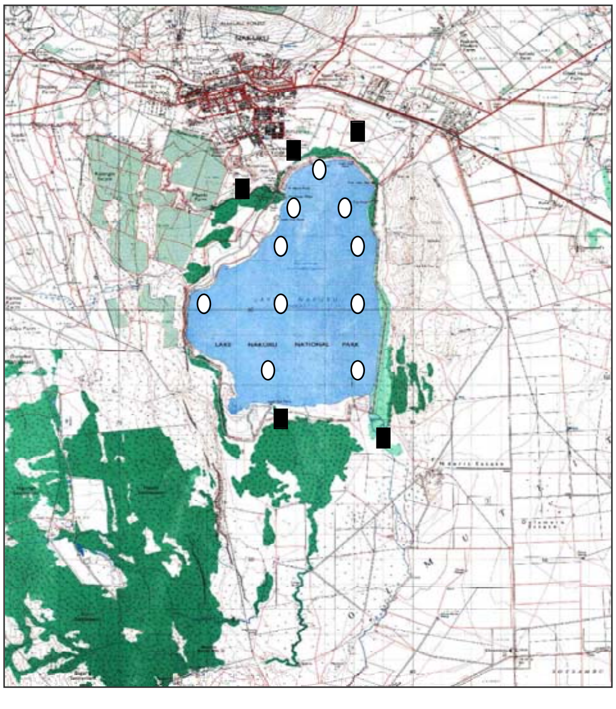

Figure 1. Sampling Locations.

Note: Dark squares = feeder streams sites; white circles = Lake sites

Water temperature, pH, conductivity, Salinity and Dissolved Oxygen were determined on site using a

WTW multiline meter. A secchi disc (40 cm diameter) with black and white quadrants was used for transparency measurements. Chlorophyll samples were filtered on site and transported to the laboratory in aluminium foils under cold storage. Stream flow discharges were measured using a Hiroi Current meter while lake levels were taken using standing gauges in the north of the lake. All laboratory parameters were analyzed at the Nakuru Water Quality Testing Laboratory using the Standard Methods 18th Edition procedures for Examination of Water and Waste Water. Stream flow discharges were measured using a Hiroi Current meter while lake levels were taken using standing gauges in the north of the lake.

Results

Lake levels

Variation in mean lake level during 2001-2004 is shown in Figure 2.

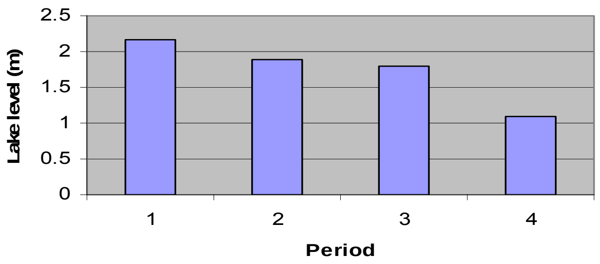

Figure 2. Lake levels during 2001 – 2004 (Note: x axis, 1-4 = 2001-2004)

The last major lake level rise was caused by the heavy 'Elnino' rains in 1998. After this episode, it declined steadily in a period that was characterized by low precipitation and low stream flow discharges. Major feeder streams (with the exception of the sewage drain), dried out lasting for several months. The lake level stabilized in 2004 after dropping by over 1 meter to start showing very small oscillations.

Light Conditions

The lake was characterized by remarkably high, long lasting phytoplankton content which inhibited underwater light for several months. Over the monitoring period, transparency was very low. In the very clear water phase, it hardly surpassed 40 cm. In the inflow sections, it was relatively lower (as low as 5 cm) with obvious turbid water. As figure 2 below implies, seasonal variations were quite distinct. Annual mean transparency increased steadily, showing much higher values during rainfall seasons. Occasionally, light shading and coloring of water by algal scum intensified underwater light inhibition resulting in very low transparencies. In the near shore areas, masses of scum transported by wind accumulated which together with the upwelling water (with its sediment content), had a remarkable effect on water transparency.

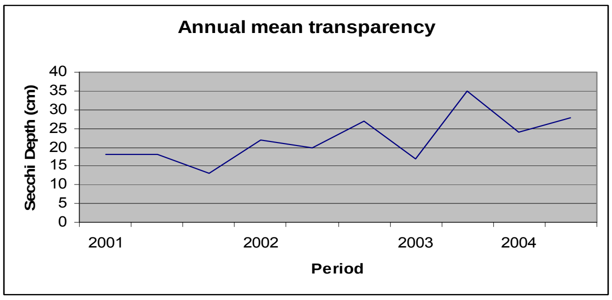

Figure 3. Mean Transparency in L.Nakuru during 2001-2004

Dissolved oxygen

High variance in the vertical profiles and daytime concentration were indicated throughout the period. Measured oxygen concentration showed steep vertical gradients during the daylight hours, euphotic zone oxygen rising to super saturation (10-22 mg/l), before depletion in the later hours. Spatial variation was also indicated in each sampling occasion. The Sewage and Makalia inlet areas showed extreme oxygen depletion with concentrations as low as 2 mg/l being recorded. These areas had remarkable numbers of low oxygen favoring organisms such as protozoa, and relatively low phytoplankton content. In August 2004, extreme oxygen depletion occurred suddenly, causing massive fish kills.

pH

The lake water pH was fairly constant, showing very small fluctuations. The annual mean value lied between 10.00 and 10.36.

Conductivity and Salinity

During 2001-2004, changes in conductivity and salinity tracked precipitation trends.

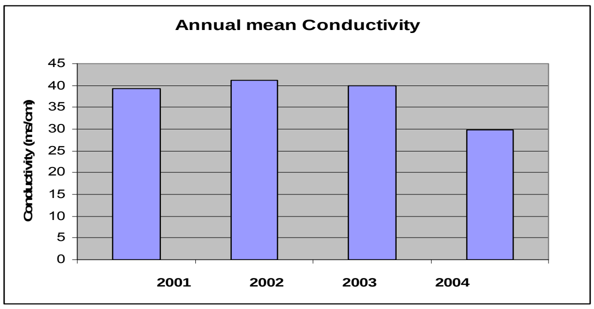

Figure 4. Mean conductivity in L. Nakuru during 2001-2004.

Droughts occurred during December-March every year, causing falls in water level with subsequent rise in conductivity and salinity. Yearly mean conductivity was 40 ms/cm in 2001-2003 but dropped to 30 ms/cm in 2004. In rainfall seasons, conductivity salinity values fell remarkably showing relatively lower values in inflow sections of the lake. During March 2002, the mid-lake system attained a level up to three times greater the yearly average value. Changes in spatial and temporal conductivity levels are known to exert major influences on the biota of the lake, since each aquatic species has individual tolerance level. Values obtained during this monitoring period were in the lower range of reported normal levels for L. Nakuru (range 9.5 – 165.5 ms/cm) though the maximum value for 2002 (58 ms/cm) might have exceeded the upper tolerance limit of 50 ms/cm for *Arthrospira fusiformis* (Vareschi 1982) for L. Nakuru.

Nutrients

Phosphate levels were high and quite variable. Total phosphate ranged 4.39-9.128 mg/l while soluble phosphate ranged 1.742-4.670 mg/l. However, no obvious spatial difference in phosphate levels was observed. Of the nitrogen forms, nitrite levels were very low, showing near constant levels (~6µ g/l) throughout the period. The annual mean concentration ranged 11-210 µg/l. Ammonia was the dominating form of inorganic nitrogen and showed sporadic elevations with algal decay. The annual mean concentration ranged 2.79-1.48 mg/l with maximal values (2.29 and 2.63 mg/l) in August and October 2002 respectively. Levels recorded in the north and south were also high indicating pollution. The mean concentration of nitrate ranged 0.04-0.45 mg/l, highest value (0.89mg/l) recorded in June 2001. However, no clear seasonal variation in nitrate concentrations was observed and the true trend could probably be revealed by continued monitoring. The total nitrogen content of the water was high and ranged 5.0-15.7 mg/l. Mid-lake areas showed relatively lower levels. The sewage area had very high total nitrogen levels suggesting high levels of organic load possibly from Nakuru town.

Table 1. Annual mean concentration of the nitrogen forms in L. Nakuru (Numbers in brackets indicate the range of mean concentration per year).

Year	NH3-N mg/l	NO2-N µg/l	NO3-N mg/l	TN mg/l
2001	0.69(0.4-1.17)	210(90-329)	0.45(0.37-0.87)	9.29(1.93-16.64)
2002	1.48(0.3-2.63)	11(5-8)	0.04(0.01-0.12)	15.65(74.70-25.64)
2003	0.28(0.04-0.81)	54(6-237)	0.05(0.02-0.11)	5(0.36-1.22)

Phytoplankton biomass, species composition and density.

Phytoplankton biomass was estimated by measurement of chlorophyll ‘a’. The yearly mean chlorophyll ‘a’ ranged from 159- 619 mg/m³. Surface concentrations occasionally rose to levels as high as 980mg/ml**.** Chlorophyll concentration in the sewage area was however, much lower.

Table 2. Biological parameters in L. Nakuru during 2001-2004.

	2001	**2002**	**2003**	**2004**
Chlorophyll ‘a’, mean (mg/l)	159	241	575	619
Arthrospira Fusiformis, mean (coils/ml)	-	158	2924	1504
Anabaena arnoldii, mean (coils/l)	-	86	1187	518
Anabaena arbijartae, mean (coils/l)	-	108	383	540
Rotifers, mean (no./ml)	-	13	889	88
Ciliates	-	216	-	206

The phytoplankton community was dominated by cyanobacteria species *(Arthrospira fusiformis, Anabaena abijartae*, *Anabaena arnodii, Anabeana spp. and coccoid cyanobacteria)* which showed considerable temporal and spatial variation in density, composition and distribution throughout the period. *Arthrospira fusiformis* was the dominant cyanobactria species (1500 – 8700 coils/ml), accounting for more than 75% of the cyanobacteria biomass. But twice in the period (2003 and 2004), the phytoplankton composition shifted to a dense bloom dominated by *Anabaena Anrnoldii and Anabaenopsis spp.* In each occurrence, the bloom crushed to be followed by flamingo mortalities, underscoring the fact that a food source can also act as the course of toxicosis. The northern portion of the lake had very low phytoplankton content while in the sourth, the composition seemed to change to one dominated by *Anabaena Arnodii* with low biomass of *Anabaena abijartae* and coccoids.

Export load through influent streams

The export loads of the major feeder streams (Njoro, Makalia, Nderit, Baharini Springs and the Sewage drain) were monitored. The yearly, input load of the lake was 40,401.2t/yr. 78% of this was total dissolved solids while the remaining 12% comprised, total suspended solids, organic matter and nutrients. Over 69.5% of the load entered the lake through River Njoro, highest proportion being total dissolved solids. The annual suspended solids input load was 2,597t/yr, over 70% being delivered through River Makalia. Of the total nutrient load, 80-90% was delivered through rivers Njoro and Makalia, with the former carrying highest proportion. The total external organic matter input load was mainly through direct urban run-off, though sewage load had also important component.

Table 3: Mean discharge rates (m^3/day) for the feeder stream of L.Nakuru.

Stream	Mean flow	Minimum flow	Maximum flow
River Njoro	52116	0	268980
River Makalia	26065	0	174539
River Nderit	13703	0	53571
Baharin springs	1831	301	3924
Sewage drain	2184	173	5140

Table 4. Selected stream input loads (tons/yr) to L. Nakuru (2001-2002).

Stream	Suspended solids	Total Phosphate	COD	Total Nitrogen	Other inputs	Total load
Sewage drain	50	2.98	122	40.8	1164.22	**1380**
Baharin Springs	3	0.34	248	3.7	640.96	**896**
River Nderit	541	1.75	548	25.0	1107.25	**2223**
River Makalia	1852	10.54	168	56.6	7086.86	**9174**
River Njoro	200	20.88	712	176	26984.12	**28093**
Total load	**2646**	**36.49**	**3096**	**302**	**36982.42**	**40401**

Discussion

Human induced modifications in the L. Nakuru drainage basin are more or else responsible for the present unpredictable climate experienced in the region today that may affect the lake water quality. Evaporation losses were high, reducing the water volume with a remarkable shift in conductivity and salinity levels that might have influenced changes in phytoplankton composition observed over the period. Conductivity and salinity in 2002 probably exceeded the physiological tolerance limit for *Arthrospira fusiformis*.

The direct effect of siltation was especially marked in the inflow sections of the lake causing a decline in water transparency, especially during rain seasons. This influenced the dominance of the main algal species, *Arthrospira fusiformis* in favour of *Coccoids* and strains of *Anabaenopsis spp.* The Sewage area had a remarkable organic load content which inhibited phytoplankton production in favour of protozoa which were present in high numbers. High nutrient loading was indicated both in the north and south of the lake probably due to the direct effect of agriculture and urban run-off. Stream export load, data indicate River Makalia to be highest transporter of silt load reflecting extensive erosion occurring in its drainage area. Both River Njoro and Makalia that drain off agricultural areas were found to be highest nutrient transporters, reflecting the prevalent use of nitrogen and phosphorus-based fertilizers in their drainage areas. High organic load reach the lake through urban run-off, sewage drain and River Njoro.

Conclusion

Results of this monitoring exercise shows that conductivity states of the lake are linked to the climatic cycle, responding accordingly from low to high conductivity states. That the lake water is well buffered against changes, with PH only changing little. Water transparency results indicate that light conditions in the mid-lake and sheltered areas is regulated by the phytoplankton content while in the inflow zones, silt load has some significant role. The phosphate levels are high and quite variable implicating high reserves in sediment probably regulated by absorption de-sorption processes. Total nitrogen is also high reflecting a low nitrogen-phosphate ratio which indicates nitrogen to be in limited supply. Frequent elevations in ammonia levels also occur especially during bloom decay and near the river mouth. Marked influence of stream inputs occur in the north and south affecting the dominance of the main algal species. Shift in dominance to undesirable algal species occur in the entire lake, ending up with crashes that at times, spark off flamingo mortalities. The decaying algae create anoxic conditions which cause adverse effect on the introduced fish.

Acknowledgement

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