



The seasonal influence on the spatial distribution of dissolved selected metals in Lake Naivasha, Kenya



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ABSTRACT

Lake Naivasha is the only freshwater Lake in Rift Valley, in Kenya. It lies in a fertile semi-arid basin. The Lake has no surface water outlet and is presumed to be under stress. Dissolved metals are directly taken up by bacteria, algae, plants, and planktonic and benthic organisms. Dissolved metals can also adsorb to particulate matter in water column and enter aquatic organisms through various routes. Cadmium, copper, lead and zinc may bioaccumulate within lower organisms, yet they do not biomagnify up the food chain as do mercury and selenium. This study reports on the levels and distribution of dissolved heavy metals and investigates the influence of physicochemical parameters on metal mobilization. The bioavailability of selected metals was investigated by relating the levels of dissolved metals to that in fish. Water abstraction for irrigation and domestic use, compounded with organic matter inflow will affect physicochemical parameters and hence influences the mobilization of heavy metals.

Dissolved Zn correlated highly with sediment pH ($r = 0.67$) indicating that dissolution increases with increase in pH. In addition, the fact that the pH also correlated positively with organic matter $r = 0.50$, Eh $r = 0.63$, temperature $r = 0.56$ and dissolved oxygen $r = 0.56$, would suggest that organic bound Zn contributed significantly to the concentration of dissolved Zn. In situ flux experiments indicated that the fringing papyrus reeds located along the shores of Lake Naivasha provided sites for metal immobilization due to their coprecipitation on redox sensitive.

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1. Introduction

Freshwater ecosystems accumulate the impacts of human activities and consequently the quality of fish habitat depends to a large extent upon the density of the human population and its activities within the basin (Zalewski and Welcomme, 2001). Water bodies and rivers bear the burden of industrialization and population explosion. The water bodies are choked with siltation, domestic and industrial pollution as well as over exploitation.

Lake Naivasha lays in a fertile semi-arid basin and is the only freshwater Rift Valley Lake in Kenya. The Lake has no surface outlet and is presumed to be under stress, reflected in the decline of fish stocks. Lake Naivasha was considered as the study site due to its importance as a natural resource supporting about 50% of the country's horticultural industry and providing a source of fish to the surrounding community. The Lakes commercial fishery is

based on three species: *Oreochromis leucostictus*, *Tilapia zillii*, *Micropogonias salmoides* (largemouth bass) and a crustacean *Procambarus clarkii* (crayfish). The average species composition of the catch between 1987 and 1998 was *O. leucostictus* 71.7%, *T. zillii* 8.8% and *M. salmoides* 19.5% (Hickley et al., 2002). Tarras-Wahlberg et al. (2002) reported that the concentrations of Fe, Zn, Cd and Ni in Lake Naivasha sediments were elevated compared to global averages.

Trace elements are found in natural water bodies at varying concentrations. The most potentially dangerous of these elements are heavy metals, viz., Pb, Cd, and Hg, and the metalloids, viz., As, Se, and Sb. Riverine suspended particulate matter is represented by a wide combination of inorganic material i.e. clay minerals and Fe and Mn oxyhydroxides and organic matter detritic or alive. These particles, due to their high surface area, and also to the carrier nature of oxides, are the main heavy metal carriers in fluvial systems (Jenne, 1968; Waren and Zimmerman, 1993). Copper and zinc are essential elements for all living organisms but elevated levels may cause adverse effects in all biological species. Cadmium and lead are presumed to be non-essential elements

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for life; more importantly, even at extremely low environmental concentrations these elements may create adverse impacts on biota. In fact molecular biology studies have demonstrated that Cd and Pb atoms may substitute for other divalent metals such as Cu and Zn within enzyme binding sites. Biochemical similarities between these atoms suggest that Cd and Pb may also compete with cell surface uptake sites or bind to sulfur and nitrogen donor atoms of various functional groups within the cell. This is more likely to occur in freshwater systems (where dissolved calcium can be low) than in saline water (Playle et al., 1993).

Dissolved metals are directly taken up by bacteria, algae, plants, and planktonic and benthic organisms. Dissolved metals can also adsorb to particulate matter in water column and enter aquatic organisms through various routes. Cadmium, copper, lead and zinc may bioaccumulate within lower organisms, yet they do not biomagnify up the food chain as do mercury and selenium (Moore and Ramamoorthy, 1984). Of all of these metals, copper is considered the most potent toxin at environmentally relevant aqueous concentrations. Copper is generally more toxic to lower aquatic organisms such as phytoplankton, copepods and ciliates than to birds or mammals because the higher animals seem capable of regulating copper concentrations in tissues (USF&W, 1998). Copper is more commonly found in herbivorous fish than carnivorous fish from the same location (USF&W, 1998). Copper is used as an aquatic herbicide to reduce algae growth in reservoirs and also applied (via antifouling paints) to boat hulls in marinas.

This study reports on the levels and distribution of dissolved heavy metals and investigates the influence of physicochemical parameters in metal mobilization. The bioavailability of selected metals was investigated by relating the levels of dissolved metals to that in fish.

1.1. Study site

Lake Naivasha is a fresh water lake, approximately 145 km² in area situated in the Eastern Rift Valley of Kenya (0°45' and 36°20'E). It lies in a closed basin at an altitude of about 1890 m above sea level. The basin is roughly circular in shape and is made up of three water bodies; the Main lake, the Crescent lake and the Ololdien lake.

About 90% of its freshwater inflow comes through River Malewa. The main catchment area is located in the Nyandarua and Kinangop Ranges (1730 km²). The remaining fresh water discharge is through rainfall, ground water seepage and ephemeral streams; main contributor being the Gilgil river which drains the Bahati highlands.

Thompson and Dodson (1963) described Lake Naivasha as a 'hydro graphic window' because water passes freely through the extremely porous volcanic rocks which form 80% of the lake basin. Water input by seepage has been shown to occur in the North-eastern and North-western sections while water loss by seepage occurs in the south and South-eastern section of the lake (Gaudet and Melack, 1981).

2. Sampling and methodology

2.1. Water column

Sampling was performed, during the dry and wet season, five sampling sites were identified, each to capture the effects of the various activities surrounding the lake as shown in Fig. 1. Crescent (SC) station has a different hydrodynamic setting it is deeper than the main lake and is isolated, has been referred to as a different lake (Gaudet and Melack, 1981). Sewage station (SS) is a shallow site averaging 2 m; it is exposed to domestic and industrial sewage

input and is located in the Northeastern section of the lake where seepage outflow is presumed to occur (Gaudet and Melack, 1981). River Malewa station (SR) is exposed to river inputs, it is a shallow site and is located in the Northeastern section of the lake where seepage outflow is presumed to occur (Gaudet and Melack, 1981). Station (SH) is located near the area with the most horticultural activities; and in the Southeastern section of the lake where water loss by seepage is presumed to occur (Gaudet and Melack, 1981). Station (SM) is located at the mid lake, it is deeper than stations SH, SS and SR and is removed from direct anthropogenic influence.

Water samples were collected 1 m above the lake bed, using a 2 l Ruttner water sampler bottle; six samples were collected per station and filtered through a cellulose nitrate membrane filter pore size 0.45 µm. The filtered samples were preserved in 2% HNO₃ acid, to await analysis for selected metals. The samples were then transported to the laboratory and stored in an air-conditioned room between 20 and 25 °C.

Water samples were analyzed by GF-AAS (Varian Spectr AA 400 plus Zeeman GTA. 96 Plus). Physicochemical parameters were taken in situ. A pH meter (Schoot Gerate model CG 817) was used to measure sediment and water pH while a WTW conductivity/temperature meter was used to measure temperature and conductivity of water samples. The sediment redox potential was obtained by using a platinum electrode and a saturated calomel reference electrode, connected to a digital multimeter model DT – 5802. Easily oxidizable organic matter was obtained by converting BOD 5 to mg of carbon equivalent per litre. It is noted that the BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C. The units are in mg/l of carbon equivalent.

2.2. Sediment

Four sediment samples were collected per station from the lake bed, at the indicated sampling sites (see Fig. 1). Only the interior portion of each sample was removed from the eckman grab into polyethylene bags. 10 g of dry sediment sample was weighed in 100 ml conical flasks, the sample was mixed with 10% HCl in a ratio of 1:3 (solid to HCl). The reaction leached out carbonates in the form of carbon dioxide gas, and was complete after about 24 h; the reaction period depended on the carbonate content in the sediment and was complete when there was no more effervescence. The remaining solution was decanted out carefully. The residue was then thoroughly washed in distilled water to remove the salts and excess acid. The rinsed residue was then dried in the oven at 105 °C for 12 h; the dried sample was then re-weighed. Loss in weight was used to determine the percent carbonate content in each sample.

2.3. Fish

Monofilament gillnets were set-up at sewage (SS) and crescent (SC) stations; where fish samples of the genus tilapia (*O. leucostictus*) were sampled. The two sites were selected due to their difference in hydrological settings and exposure to anthropogenic stress.

Once in the laboratory the fish samples were measured for their total length and sorted within the bracket 18 ± 2.5 cm. The organs were then removed and frozen to await analysis. Fish organs were thawed and dried at 80 °C for 12 h. 0.200 g of the sample was weighed in fluorocarbon microwave digestion vessels (analytical balance Precisa 310 M). The samples were digested with a mixture of 8 ml nitric acid (65%) and 2 ml hydrochloric acid (37%), in a microwave oven (Sanyo 800W Model EM-X412). The Microwave oven was programmed (15 min at 50%, 5 min at 0%, and 20 min at 85%) according to Nieuwenhuize and Poley-Vos (1989).

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