METAL STATUS OF NAIROBI RIVER WATERS AND THEIR BIOACCUMULATION IN *LABEO CYLINDRICUS*

N. L. M. BUDAMBULA* and E. C. MWACHIRO
Department of Botany, Jomo Kenyatta University of Agriculture and Technology, P.O Box 62000, 00200, Nairobi, Kenya
*(*author for correspondence, e-mail: nbudambula@yahoo.com or nbudambula@jkuat.ac.ke; Tel: 254-67-52511 or 254-722-524051*

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Abstract. This study focused on the analysis of metals in water and fish from Nairobi River. Water from Kikuyu, Kawangware, Chiromo, Eastleigh, Njiru and Fourteen Falls along the Nairobi River was analyzed for the presence of metals. Most of the metal levels in water were below the critical limit of World Health Organization and Kenya Bureau of Standards except for lead, chromium, iron and manganese. Isolated cases of mercury and aluminium pollution were recorded. Except for iron, sodium and potassium, there was no significant difference in the concentration of metals at different sites. This study also analyzed metal levels in fish organs and tissues of fish caught from downstream (Fourteen Falls). The highest zinc concentration (360 μg/g) was in the scales, copper recorded the highest concentration in the kidney (45 μg/g), while cadmium recorded high values (167 μg/g) in the heart. Lead recorded high values (178 μg/g) in the heart and mercury recorded high values also in the heart (1000 ng/g). Most of these organs, are however, not eaten by man as food. Although metal levels were within normal levels in the water at Fourteen Falls, mercury, copper, lead and iron recorded higher than accepted levels in some fish organs. This calls for caution in the consumption of fish from Fourteen Falls.

Keywords: bioaccumulation, fish, Fourteen Falls, metal, Nairobi River, pollution

1. Introduction

Water pollution is the result of human activities that makes the water dangerous to human beings, unfit for industrial use and adversely affects the aquatic fauna and flora among others. Water pollution is associated with human population explosion and industrialization. The main sources of water pollution are industrial discharge, sewage, agricultural waste, fertilizers, seepage from waste sites, decaying plant life, road, railway and sea accidents involving large oil carriers (Kinchella and Hyland, 1993).

The city of Nairobi has experienced rapid industrialization and growth in population during the last 100 years (Okoth and Otieno, 2001). This rapid growth has not been matched by development of infrastructure to deal with waste disposal. As a result problems have arisen with regard to garbage, human and industrial waste disposal leading to pollution of the water resources. Sources of pollution of the

Nairobi River include industrial effluent, effluent from petrol stations and motor vehicle garages, surface run off, from factories and other business premises, raw sewage from broken or overloaded sewers as well as raw sewage from informal settlements (Ndwaru, 1994; Otieno, 1995; Okoth and Otieno, 2001).

Metals enter the aquatic ecosystem primarily through the indiscreet disposal of chemical and metal wastes from agricultural, industrial and mining activities. Being non-biodegradable these metals accumulate in the tissues and organs of living aquatic organisms thereby affecting the normal processes of the body. Some of these metals, such as mercury, are very toxic to human beings. Essential metals are required in micro amounts in living systems although at higher concentrations the metal ions are toxic. These metals are iron, nickel, zinc, vanadium, manganese, molybdenum, cobalt, chromium, tin, and copper. Non essential metals are not required by living systems and include cadmium, mercury, lead, titanium, arsenic, antimony, and bismuth (Tyagi and Mehra, 1992). Iron, molybdate, manganese, zinc, nickel, copper, vanadium, cobalt, tungsten, chromium, arsenic, silver, cadmium, tin, lead, mercury and uranium are of biological significance (Nies, 1999). Manganese, iron, copper, zinc, chromium, cadmium, lead and mercury are reviewed in this study.

Manganese is used in the manufacture of steel, dry batteries, paints, glass and organic compounds (Baudo, 1989). Concentrations higher than 50 μg/l in water may lead to neurological disorders in human beings (Tyagi and Mehra, 1992). Iron is necessary for the healthy growth of bacteria, fungi, algae, insects, birds and mammals (Powell, 1993). Iron overload in man results in oxidative degradation of lipids, destruction of proteins, DNA damage, mutagenicity and carcinogenicity (Richardson *et. al.*, 1989). Copper is widely distributed in nature in the free ionic state as sulphides, arsenics, chlorides and carbonates. Copper is not acutely toxic to human beings (Moore and Ramamoorthy, 1984). Zinc is an essential element that occurs in over 80 proteins and enzymes. It is used in the manufacture of steel, rubber and viscose rayon (Tyagi and Mehra, 1992). Chromium is a relatively common element that is used as a pigment, catalyst, in data storage, tanning and galvanising industry. Chromate is toxic, carcinogenic and allergenic to man (Costa, 1997).

Cadmium is the best known toxic metal and it is used in electroplating, battery, paints and plastic industry (Tyagi and Mehra, 1992). Lead is used in piping, building materials, paint, ammunition, castings, storage batteries, metal products, chemicals and pigments. Effects of lead include anaemia, severe abdominal pain, diarrhoea, sleep disorders, neurobehavioral effects, cardiotoxicity, impairment of the thyroid and adrenal functions (Ewers and Schlipöter, 1991). Mercury is a liquid metal of group IIb and is the most toxic known metal. It is used in dentistry, electrical instruments and measuring apparatus such as thermometers, barometers and manometers. Effects of mercury include depression, neurological disorders, nervous system disorder and immunotoxicity (Von Burg and Greenwood, 1991).

Metals reach the food chain through water, plants, animals and human activity. Industrial waste, agrochemicals, raw sewage from broken or overloaded sewers, effluent from petrol stations and raw sewage are all discharged into the Nairobi

River upstream of Fourteen Falls (Ndwaru, 1994; Okoth and Otieno, 2001). Such waste probably contains metals such as mercury and cadmium which are highly toxic (Von Burg and Greenwood, 1991; Nies, 1999). The local communities around Fourteen Falls use the river water for domestic and fishing purposes. This study aimed to investigate the concentration levels of metals in the Nairobi River waters and whether their concentration levels in water and fish indicate cause for concern with respect to potential health hazards.

2. Materials and Methods

The source of the Nairobi River is the Kikuyu springs at an altitude of 2000 m above sea level. From Kikuyu the river flows eastwards through Dagoretti, Kawangware, Chiromo, the central business district, Eastleigh and Kariobangi sewage treatment works. After Kariobangi the Nairobi River runs through barren Njiru quarry sites where the Gitathuru and Ruaraka Rivers join it. The Nairobi River then flows past the Nairobi Falls and Fourteen Falls. The river joins the Athi River and eventually the Sabaki River which discharges its water into the Indian Ocean at Malindi on the East African coast.

Six sampling sites along the pollution gradient of Nairobi River were selected for this study based on the physical appearance of the water, land use patterns and economic activities. The sites were Kikuyu (site 1), Kawangware (site 2), Chiromo (site 3), Eastleigh (site 4), Njiru (site 5) and Fourteen Falls (site 6) as shown in Figure 1.

Water samples for metal analysis were collected in triplicate from Kikuyu, Kawangware, Chiromo, Eastleigh, Njiru and Fourteen Falls in clean 250 ml plastic bottles. Concentrated nitric acid was added to reduce the pH to 2 and to preserve the water samples. Samples were collected once every three months over a period of one year during the year 2001.

Fish are ideal indicators of metal contamination in aquatic systems because they occupy different trophic levels, are different in size and age. Fish was therefore chosen as an indicator of pollution of the Nairobi River. Fresh fish identified as *Labeo cylindricus* from the family *Cyprinidae* were caught from the river at Fourteen Falls in February 2002. No fish were caught from the other five sampling sites. The fish were placed in crushed ice and transported to the laboratory. The fish were then dissected for their different organs. The organs were later digested in Kjeldhal flasks using 8 ml concentrated sulphuric acid and 2 ml concentrated perchloric acid. The digest was made up to 50 ml with distilled water. The fish organs investigated were; kidney, heart, gills, muscles, intestines, skin, vertebrae, ovary, brain, eyes and liver. Water samples from Fourteen Falls were also collected for analysis alongside the fish organs. The results obtained were expressed in μg/g wet weight and μg/l for fish organs and water respectively. Mercury results were expressed as ng/g wet weight and ng/l.

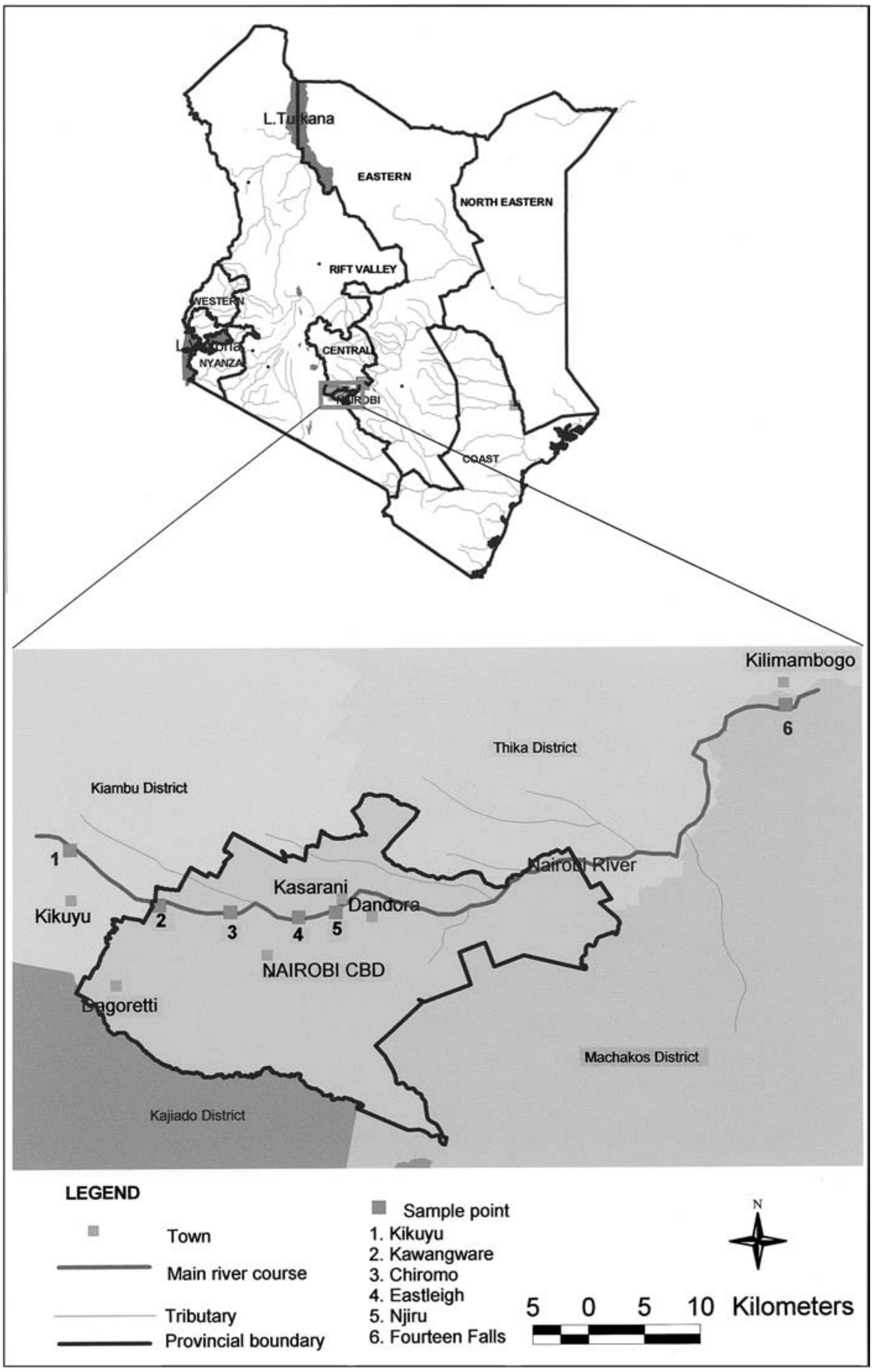

Figure 1. A map of Kenya and Nairobi City showing the study area and sampling sites.

The concentration levels of manganese, zinc, copper, cadmium, lead, iron, chromium, aluminium, calcium magnesium and mercury in river water and the digest of fish tissues and organs were determined using the Atomic Absorption Spectrophotometer Buck scientific model 210 VGP. Commercial standards (Buck scientific) containing 10^6 μg/l of zinc, copper, cadmium, lead, iron, chromium, aluminium, calcium magnesium or mercury were diluted to provide working standards of 10^5 μg /l which were further diluted to provide standard solutions of 0 to 10^4 μg/l. Using the Atomic Absorption Spectrophotometer, the absorption of the standard solutions was recorded. The absorption of standard solutions was plotted against concentration to give a standard curve. Distilled deionised water was used as a blank. The absorption of the blank, water sample solutions and the digest of fish tissues and organs were recorded. The concentration of metals in water samples and the digest of fish tissues and organs were extrapolated from the graph of standard solutions.

Sodium and potassium concentrations in river water and the digest of fish tissues and organs were determined photometrically using the Flame photometer Jenway model. Commercial standards (Buck scientific) containing 10^6 μg/l of sodium or potassium were diluted to provide working standards of 10^5 μg/l which were further diluted to provide standard solutions of 0 to10^5 μg/l. Distilled deionised water was used as a blank. The Flame photometer was used to determine the emission of the standard solutions which then was plotted against concentration to give a standard curve. The emission of sample solutions and the digest of fish tissues and organs were recorded. The concentration of metals in water sample solutions and the digest of fish tissues and organs were extrapolated from the graph of standard solutions.

Water temperature, pH and dissolved oxygen were determined in the field using a Portable Electrochemistry Analyser (Model 3405). Total dissolved solids were measured in the field using a total dissolved solids (TDS) meter (Model 4076 Jenway). The nitrate concentration in water samples of Nairobi River were determined using a calorimetric method modified from Allen (1989). The Molybdenum Blue Method (Allen 1989) was used to determine the phosphate concentration. Alkalinity was determined using the alkalinity method modified from Allen (1989). The biochemical oxygen demand was estimated using methods modified from American public health association (APHA, 1989).

3. Results

3.1. Metal concentrations in river water

The six sampling sites recorded varying concentration levels of the metals investigated (Table I). Copper remained below detectable limit during the year 2001. However, in July small amounts (50 μg/l) were recorded at Chiromo, Eastleigh and Njiru. Although cadmium also remained below detectable limit, small amounts

TABLE I

Concentration levels of metals in water at six sampling sites along the Nairobi River

Sampling site	January	April	July	October
		Manganese (μg/l)		
Kikuyu	830.0	4300.0	1250.0	1800.0
Kawangware	750.0	800.0	680.0	500.0
Chiromo	730.0	630.0	450.0	700.0
Eastleigh	1180.0	1500.0	1430.0	1200.0
Njiru	1830.0	1750.0	1450.0	1800.0
F. Falls	1400.0	950.0	630.0	1200.0
		Copper (μg/l)		
Kikuyu	BDL	BDL	BDL	BDL
Kawangware	BDL	BDL	BDL	BDL
Chiromo	BDL	BDL	50.0	BDL
Eastleigh	BDL	BDL	50.0	BDL
Njiru	BDL	BDL	50.0	BDL
F. Falls	BDL	BDL	BDL	BDL
		Lead (μg/l)		
Kikuyu	BDL	BDL	7500.0	BDL
Kawangware	BDL	BDL	BDL	BDL
Chiromo	BDL	BDL	BDL	BDL
Eastleigh	BDL	BDL	BDL	BDL
Njiru	BDL	BDL	200.0	BDL
F. Falls	BDL	BDL	200.0	BDL
		Chromium (μg/l)		
Kikuyu	BDL	BDL	850.0	BDL
Kawangware	BDL	BDL	1110.0	BDL
Chiromo	BDL	BDL	950.0	BDL
Eastleigh	BDL	BDL	850.0	BDL
Njiru	BDL	BDL	700.0	BDL
F. Falls	BDL	BDL	750.0	BDL
		Calcium (μg/l)		
Kikuyu	3000.0	8000.0	7500.0	31000.0
Kawangware	18000.0	8000.0	16000.0	20000.0
Chiromo	41000.0	7000.0	19000.0	15000.0
Eastleigh	42500.0	11000.0	9800.0	22000.0
Njiru	18500.0	8000.0	10000.0	16000.0
F. Falls	14500.0	5000.0	4500.0	15000.0

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TABLE I
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Sampling site	January	April	July	October
		Sodium (μg/l)		
Kikuyu	31000.0	41000.0	29900.0	51000.0
Kawangware	76000.0	60000.0	91700.0	80000.0
Chiromo	73000.0	68000.0	66700.0	78000.0
Eastleigh	92000.0	84000.0	91600.0	80000.0
Njiru	84000.0	84000.0	54900.0	80000.0
F. Falls	50000.0	60000.0	31700.0	73000.0
		Zinc (μg/l)		
Kikuyu	50.0	80.0	80.0	480.0
Kawangware	50.0	80.0	100.0	250.0
Chiromo	25.0	80.0	80.0	130.0
Eastleigh	175.0	280.0	230.0	130.0
Njiru	75.0	80.0	400.0	230.0
F. Falls	75.0	50.0	100.0	480.0
		Cadmium (μg/l)		
Kikuyu	BDL	BDL	25.0	BDL
Kawangware	BDL	BDL	25.0	BDL
Chiromo	BDL	BDL	25.0	BDL
Eastleigh	BDL	BDL	25.0	BDL
Njiru	BDL	BDL	25.0	BDL
F. Falls	BDL	BDL	25.0	BDL
		Iron (μg/l)		
Kikuyu	9000.0	8000.0	10000.0	1100.0
Kawangware	7500.0	2000.0	1500.0	3600.0
Chiromo	1750.0	1660.0	900.0	2900.0
Eastleigh	1250.0	1860.0	2500.0	1100.0
Njiru	1500.0	1860.0	2700.0	1100.0
F. Falls	9500.0	3000.0	1300.0	25600.0
		Alminium (μg/l)		
Kikuyu	BDL	BDL	BDL	3500.0
Kawangware	BDL	BDL	BDL	BDL
Chiromo	BDL	BDL	BDL	BDL
Eastleigh	BDL	700.0	BDL	1800.0
Njiru	BDL	BDL	BDL	BDL
F. Falls	BDL	2100.0	BDL	BDL

(*Continued on next page*)

TABLE I
(*Continued*)

Sampling site	January	April	July	October
		Magnesium (μg/l)		
Kikuyu	6000.0	7000.0	6750.0	3800.0
Kawangware	7000.0	3000.0	8250.0	6000.0
Chiromo	7000.0	6000.0	7750.0	7000.0
Eastleigh	7000.0	5800.0	7000.0	6000.0
Njiru	6000.0	2600.0	6750.0	5500.0
F. Falls	5000.0	3100.0	3750.0	4500.0
		Potassium (μg/l)		
Kikuyu	12000.0	14000.0	11000.0	15000.0
Kawangware	15000.0	15000.0	13000.0	17000.0
Chiromo	17000.0	17000.0	14000.0	19000.0
Eastleigh	24000.0	24000.0	15000.0	30000.0
Njiru	22000.0	19000.0	13000.0	27000.0
F. Falls	12000.0	11000.0	6000.0	20000.0

Mercury remained below the detectable limit except in July when 12500 ng/l was detected at Kawangware.

ranging 25 to 30 μg/l were recorded at all the sampling sites in July. This amount is above the critical limit of 5 μg/l stipulated by the World Health Organization (WHO, 1985) and Kenya Bureau of standards (KBS, 1996) as shown in Table IV.

Lead was below detectable limit during the period under consideration except for July 2001 at Kikuyu, Njiru and Fourteen Falls. Chromium and aluminium also remained below the detectable limit during most of the sampling period. Chromium however, recorded high values of 700 to 1110 μg/l in July. These values are above the WHO and KBS limit of 50 μg/l.

Mercury remained below detectable limit during the study period. One incident of mercury (13 μg/l) was recorded at Kawangware in July 2001. Manganese on the other hand remained above the critical limit of 100 μg/l (WHO, 1985; KBS, 1996). Exceptionally high values of 4300 and 8000 μg/l were recorded at Kikuyu and Kawangware, respectively. Zinc was generally below the critical limit of 5000 μg/l (WHO, 1985a; KBS, 1996). Slightly elevated amounts of zinc were recorded in October at all the sampling sites (Table I).

During the year 2001 iron remained above the critical limit of 300 μg/l (WHO, 1985) and 50 μg/l (KBS, 1996). Chiromo was the least polluted site while Kikuyu and Fourteen Falls were the most polluted sites in relation to iron as shown in Table I. Although magnesium levels were slightly elevated in the middle section of the Nairobi River at Kawangware, Chiromo and Eastleigh, these amounts were below the critical limit (100000 μg/l) of the KBS (1996) as shown in Table IV.

Calcium and Sodium remained below the critical limit of WHO (1985) and KBS (1996). Generally higher values were recorded in the middle section of the river. Higher values of potassium were recorded at Eastleigh compared to the other stations (Table I).

Analysis of variance showed that there were no significant differences in the concentrations of manganese, aluminium, zinc, copper, cadmium, lead, chromium, calcium and magnesium at the six sampling sites. A significant difference (5%) exists in the concentration of iron, sodium and potassium at the sampling sites. The concentration level of iron declines as the river flows from Kikuyu towards the central business district and then increases as the river exits the central business district towards Fourteen Falls. The sodium and potassium levels increase as the river flows towards the central business district. They peak at Eastleigh and then begin to decline as the river flows towards Fourteen Falls.

3.2. Metal concentrations in river water and fish tissues and organs at fourteen Falls

Metal concentration levels in fish organs of *Labeo cylindricus* and water from Fourteen Falls recorded different concentration ranges as shown in Table II. The manganese level in water was 1 μg/l. In the fish organs the highest concentration of manganese was recorded in the liver (142 μg/g) followed by the vertebrae (137 μg/g) and the scales (117 μg/g). The lowest concentrations were recorded in the skin (12 μg/g) followed by the eyes (18 μg/g).

Copper levels in the water samples from Fourteen Falls were below the detectable limit of the equipment used. However substantial levels were detected in the fish organs. The concentration levels ranged between 4 μg/g in the muscles and 45 μg/g in the kidney. The scales, vertebrae, ovary, brain, eyes and liver recorded similar levels (7 μg/g) of copper.

Although the lead levels were below detectable limit in the river water, in fish organs the levels of 26 μg/g were recorded in the brain and 178 μg/g in the heart. Relatively high amounts (121 μg/g) were also detected in the kidney. The ovary, eyes, liver, intestines and muscles each recorded 53 μg/g of lead. The gills, skin, scales and vertebrae contained 60 μg/g of lead each.

Zinc concentration in water was recorded at 1 μg/l. The zinc levels in fish organs ranged from 55 μg/g in the ovary to 360 μg/g in the scales. Concentrations of 333 μg/g, 118 μg/g and 114 μg/g were recorded in the eyes, heart and kidney respectively.

The cadmium levels in water were below the detectable limit. In the fish organs, concentration levels of 167 μg/g and 114 μg/g were detected in the heart and kidney respectively. The other organs; gills, muscles, intestines, skin, scales, vertebrae, ovary, eyes and liver contained cadmium levels in the range of 50 μg/g and 70 μg/g.

The concentration level recorded for iron in water was 3 μg/l. Iron levels in the fish organs ranged between 186 μg/g in the scales to 1467 μg/g in the heart. The

TABLE II

Concentration levels of metals in fish organs of *Labeo cylindricus* harvested from Fourteen Falls along the Nairobi River

		Fish organs (concentration in μg/g)												
Metal	Water μg/l	Kidney	Heart	Gills	Muscles	Intestines	Skin	Scales	Veterbrae	Ovary	Brain	Eyes	Liver	Guidelines**
Manganese	1.0	100.0	93.0	28.0	40.0	92.0	12.0	117.0	137.0	45.0	56.0	18.0	142.0	–
Zinc	BDL	114.0	117.0	100.0	70.0	63.0	78.0	360.0	100.0	55.0	95.0	333.0	80.0	–
Copper	BDL	46.0	26.0	8.0	4.0	16.0	4.0	7.0	7.0	7.0	7.0	7.0	7.0	–
Cadmium	BDL	114.0	167.0	53.0	52.0	50.0	53.0	53.0	55.0	53.0	70.0	55.0	57.0	100
Lead	BDL	121.0	178.0	60.0	53.0	53.0	60.0	60.0	60.0	53.0	26.0	53.0	53.0	500
Iron	3.0	757.0	1467.0	333.0	246.0	653.0	246.0	186.0	220.0	333.0	272.0	333.0	533.0	–
Chromium	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	–
Alminium	2.0	159.0	233.0	76.0	70.0	870.0	BDL	70.0	BDL	70.0	BDL	70.0	150.0	–
Calcium	5.0	2500.0	1333.0	23600.0	6000.0	1200.0	1600.0	1600.0	18800.0	1700.0	28400.0	6800.0	2000.0	–
Magnesium	BDL	266.0	557.0	490.0	1600.0	233.0	367.0	783.0	1166.0	367.0	844.0	466.0	1016.0	–
Sodium	60.0	4320.0	3660.0	3000.0	4000.0	3100.0	1300.0	1400.0	1800.0	1600.0	3450.0	2300.0	2800.0	–
Potassium	11.0	2040.0	1660.0	1300.0	2400.0	1800.0	900.0	700.0	600.0	1000.0	870.0	1700.0	1600.0	–
*Mercury	BDL	BDL	1000.0	700.0	500.0	300.0	BDL	BDL	BDL	BDL	500.0	BDL	500.0	1000

BDL: Below detectable limit.
*Mercury was measured in ng/g or ng/l.
**Guidelines by West-German Federal Health Agency (1986). *Bundesgesundheitsblatt* 29: 22–23.

kidney, intestines and liver contained 757 μg/g, 653 μg/g and 533 μg/g of iron respectively.

The levels of aluminium in the fish organs ranged from nil in the skin, vertebrae and brain to 870 μg/g in the intestines. Levels of 70 μg/g were detected in eyes, muscles, scales and ovary. The heart, kidney and liver contained 233, 159 and 150 μg/g respectively. In water aluminium was recorded at 2 μg/l.

High concentration levels of magnesium detected were in the muscles (1600 μg/g) followed by vertebrae (1166 μg/g) and the liver (1016 μg/g). Modest amounts of 367 μg/g were recorded in the skin and ovary. The amount of magnesium detected in the kidney was relatively low (266 μg/g). Magnesium in water was recorded at 3 μg/l. Chromium was characteristically absent in both the water and the fish organs.

The concentration level of potassium in the organs ranged between 600 μg/g in the vertebrae and 2400 μg/g in the muscles. The kidney, heart and liver contained 2040, 1660 and 1600 μg/g respectively. The potassium concentration in water was 11 μg/l.

The concentration level of calcium recorded in the water sample was 5 μg/l. The amount of calcium in the fish organs ranged from 1200 μg/g in the intestines to 28400 μg/g in the brain. High amounts of calcium (23600 and 18800 μg/g) were also recorded in the gills and the vertebrae respectively. The kidney, heart, muscles and liver contained 2500, 1333, 6000 and 2000 μg/g of calcium respectively.

The river water recorded 60 μg/l sodium. In the fish organs the lowest amount detected was 1300 μg/g in the skin and the highest amount was 4300 μg/g in the kidney. Other organs that contained relatively high amounts of sodium were the brain (3450 μg/g), intestines (3100 μg/g), muscles (400 μg/g), gills (3000 μg/g) and the heart (3660 μg/g).

Mercury was below the detectable limit in the river water. It was recorded nil in the kidney, skin, scales, vertebrae, ovary and eyes. In the intestines 300 ng/g was recorded while the heart contained 1000 ng/g of mercury. The muscle, brain and liver each contained 500 ng/g of mercury.

3.3. Other water quality variables

The water temperatures ranged from 14.80 to 32.10 °C recorded at Kikuyu and Eastleigh, respectively. The lowest water temperatures were recorded at Kikuyu and Kawangware while the highest temperatures were recorded at Eastleigh. The pH ranged from 4.81 recorded at Kawangware to 7.40 at Chiromo in the present study. A wide range (300 to 9100 μg/l) was observed in the amount of dissolved oxygen. In general the concentration of dissolved oxygen fluctuated from season to season and varied among the different stations. The lowest concentration of dissolved solids was recorded in April at all the stations except Kawangware (Table III).

Phosphates along the Nairobi River ranged from 2000 to 3340 μg/l. Low phosphate concentrations (2000 to 9600 μg/l) were recorded in July and October at all the sampling sites. Nitrates in the present study were between 1200 and

TABLE III
Selected parameters of Nairobi River water

Parameter/Site	January	April	July	October
Water temp. °C/Sampling site				
Kikuyu	22.4	18.6	14.8	16.5
Kawangware	23.8	19.5	16.5	17.7
Chiromo	27.4	20.1	16.5	18.2
Eastleigh	32.1	22.9	18.9	21.5
Njiru	23.3	22.6	18.4	20.7
Fourteen Falls	22.8	24.3	19.2	22.4
pH/Sampling site				
Kikuyu	5.6	6.2	6.4	6.0
Kawangware	4.8	7.0	7.4	7.3
Chiromo	7.4	6.9	7.3	7.3
Eastleigh	7.2	6.8	7.1	7.1
Njiru	6.1	7.3	7.4	7.4
Fourteen Falls	5.3	7.0	7.3	7.3
Dissolved Oxygen μg/l Sampling site				
Kikuyu	5700.0	3800.0	500.0	1300.0
Kawangware	4810.0	8000.0	9100.0	6100.0
Chiromo	7400.0	7900.0	7200.0	5900.0
Eastleigh	5000.0	900.0	300.0	900.0
Njiru	3700.0	4000.0	3200.0	2800.0
Fourteen Falls	1200.0	4300.0	4400.0	3200.0
Alkalinity μg/l/Sampling site				
Kikuyu	69200.0	120000.0	60000.0	80000.0
Kawangware	72000.0	110000.0	85000.0	80000.0
Chiromo	80000.0	100000.0	70000.0	75000.0
Eastleigh	150000.0	180000.0	80000.0	90000.0
Njiru	220000.0	173000.0	75000.0	75000.0
Fourteen Falls	86000.0	68000.0	35000.0	65000.0
Phosphates μg/l/Sampling site				
Kikuyu	22000.0	11000.0	2500.0	3500.0
Kawangware	23000.0	12000.0	1500.0	3300.0
Chiromo	24000.0	14000.0	1400.0	4000.0
Eastleigh	27000.0	12000.0	9000.0	9600.0
Njiru	24600.0	10000.0	3700.0	5300.0
Fourteen Falls	31250.0	9000.0	2000.0	5600.0

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TABLE III
(*Continued*)

Parameter/Site	January	April	July	October
Nitrates μg/l/Sampling site				
Kikuyu	6200.0	6000.0	27200.0	1700.0
Kawangware	40200.0	22800.0	29500.0	520600.0
Chiromo	40600.0	39500.0	61000.0	63500.0
Eastleigh	30600.0	13300.0	31500.0	8300.0
Njiru	8100.0	12300.0	28000.0	6700.0
Fourteen Falls	30700.0	21800.0	32000.0	156700.0
BOD μg/l/Sampling site				
Kikuyu			33000.0	20720.0
Kawangware			37200.0	29030.0
Chiromo			114010.0	178360.0
Eastleigh			183000.0	204020.0
Njiru			171000.0	226420.0
Fourteen Falls			30000.0	46400.0
Hardness μg/l/Sampling site				
Kikuyu	195000.0	85000.0	98000.0	65000.0
Kawangware	270000.0	135000.0	122000.0	80000.0
Chiromo	305000.0	100000.0	195000.0	78000.0
Eastleigh	320000.0	90000.0	202000.0	80000.0
Njiru	410000.0	95000.0	170000.0	80000.0
Fourteen Falls	210000.0	55000.0	85000.0	73000.0

520600 μg/l. During most of the year the nitrates concentration remained below 100000 μg/l. However, in October nitrate concentrations of 156700 and 520600 μg/l were recorded at Fourteen Falls and Kawangware respectively. Alkalinity, in the present study, ranged between 35000 and 220000 μg//l. Although no clear maximal peak was recorded, all the stations recorded a clear minimum in July. Kawangware, Chiromo, Eastleigh and Njiru recorded higher levels of hardness than Kikuyu and Fourteen (Table III).

Biochemical oxygen demand (BOD) was recorded once during the dry season (July) and once in the rainy season (October). During the dry season the lowest BOD (30000 μg/l) was recorded at Fourteen Falls and the highest BOD (183000 μg/l) was recorded at Eastleigh. In the rainy season, the lowest BOD (20720 μg/l) was recorded at Kawangware and the highest BOD (226420 μg/l) was recorded at Njiru. Overall, high BOD values (114010 to 226420 μg/l) were recorded at Chiromo, Eastleigh and Njiru, low BOD values ranging from 20720 to 46400 μg/l, were recorded at Kikuyu, Kawangware and Fourteen Falls.

TABLE IV

Standard guidelines for metals in drinking water and mean concentrations of metals at six sites along Nairobi River

	Standard guidelines		Sampling sites						
Metal	WHO	KBS	Kikuyu	Kawangware	Chiromo	Eastleigh	Njiru	F. Falls	Detectable limit
Manganese (μg/l)	100.0	100.0	2310.0	650.0	665.0	1327.5	1707.5	1045.0	10.0
Zinc (μg/l)	5000.0	5000.0	172.5	120.0	78.8	203.8	196.3	176.3	5.0
Copper (μg/l)	1000.0	100.0	BDL	BDL	12.5	12.5	12.5	0.0	20.0
Cadmium (μg/l)	5.0	5.0	6.3	6.3	6.3	6.3	6.3	6.3	5.0
Lead (μg/l)	50.0	50.0	1875.0	BDL	BDL	BDL	50.0	50.0	100.0
Iron (μg/l)	300.0	50.0	7025.0	3650.0	1802.5	1677.5	1790.0	9850.0	30.0
Chromium (μg/l)	50.0	50.0	212.5	277.5	237.5	212.5	175.0	187.5	50.0
Alminium (μg/l)	200.0	100.0	875.0	BDL	BDL	625.0	BDL	525.0	100.0
Calcium (μg/l)	–	250000.0	12375.0	15500.0	20500.0	21325.0	13125.0	9750.0	10.0
Magnesium (μg/l)	–	100000.0	5887.5	6062.5	6937.5	6450.0	5212.5	4087.5	1.0
Sodium (μg/l)	200000.0	200000.0	38225.0	76925.0	71425.0	86900.0	75725.0	53675.0	2.0
Potassium (μg/l)	–	–	13000.0	15000.0	16750.0	23250.0	20250.0	12250.0	10.0
Mercury (ng/l)	1000	1000	BDL	3125	BDL	BDL	BDL	BDL	

WHO: World Health organization (1985) Guideline for drinking water quality Vol 1. Recommendations.
KBS: Kenya Bureau of Standards (1996) Kenya Standard. Specification for drinking water.
BDL: Below detectable limt.

4. Discussion

Most of the metal concentration levels in the Nairobi River waters were below the critical limit of World Health Organization (WHO, 1985) and the Kenya Bureau of Standards (KBS, 1996) during the year 2001. The dry month of July recorded elevated amounts of copper, cadmium, chromium, lead and mercury. The elevated amounts are probably due to evaporation.

The concentration levels of copper, zinc, magnesium, calcium and sodium were below the critical limit of WHO (1985) and KBS (1996). Therefore there is no metal pollution in Nairobi River that can be attributed to these elements. Isolated cases of pollution by mercury and chromium were recorded in July during the dry season. The concentration levels of lead, manganese and iron were above the critical limit of WHO and KBS. The metal pollution of Nairobi River is due to these metals. Occurrence of lead and mercury pollution is of grave concern due to their toxic effects.

Fish were harvested only from Fourteen Falls. There were no fish at the other sampling sites. This is probably due to pollution that was characterised by high biochemical oxygen demand. The metal concentration levels in the river water at the Fourteen Falls were generally below the critical level set by the World Health Organization (WHO, 1985) and the Kenya Bureau of Standards (KBS, 1996). Higher concentrations of metals were however observed in fish organs. While some of these metals are essential, others are toxic and their presence can lead to health problems (Edward and Dooley, 1981). Although cadmium is known to be very toxic (Tyagi and Mehra, 1992), the levels recorded at Fourteen Falls are within the acceptable levels (WHO, 1985; KBS, 1996).

Okoth and Otieno (2001) reported high concentration levels (150 μg/l) of lead in Nairobi River at Chiromo. In this study lead was below detectable limit at Chiromo. Uptake of contaminated feed leads to accumulation of lead in animal tissues. Lead has been shown to accumulate in the kidneys and liver. Lead does not play a major role in aquatic food chains. The concentration levels in fish depend on the amount of lead pollution in the environment (Hapke, 1991).

The levels of mercury recorded in the present study are above the critical limit in fish organs. According to Hapke (1991) older predatory fish can accumulate large quantities of mercury (1 μg/g). Fresh water fish show accumulation of higher quantities of mercury (3 μg/g) than fish caught in the open sea (0.1 μg/g). Mercury can be passed to domestic animals via fishmeal. Mercury accumulates in beef (0.02 μg/g), milk (0.01 μg/g), poultry (0.04 μg/g) and eggs (0.03 μg/g). Poultry and eggs show higher values due to the wide spread use of fishmeal (Hapke, 1991).

Although higher zinc concentrations were observed in fish organs as compared to the river water, these levels were within the normal accepted range. Normal levels in meat, fish and poultry range between 10 and 200 μg/g. The levels in liver range between 100 and 150 μg/g and in kidney between 50 and 100 μg/g. Zinc does not accumulate and has no health significance as a pollutant in foodstuffs (Hapke, 1991).

Although most countries do not have critical limits for calcium, the calcium in river water was below the guideline limit of the WHO (1985), while the amount of calcium in fish organs exceeded the critical limit. The accumulation was highest in the gills and the vertebrae. A study by Mwachiro and Durve (1997) also showed the highest accumulation of calcium in fish occurred in the vertebrae and the gills. However, these organs are not utilised by man as food.

The amount of iron in river water was ten times higher than the critical limit for drinking water (WHO, 1985). The amounts accumulated in fish organs were much higher. The highest amount was recorded in the heart. Other organs also had relatively high amounts. The fish are thus a potential source of an iron rich diet. Iron overload in man is not common but may occur due to a genetic defect. Such overload results in oxidative degradation of lipids, destruction of intercellular and extra cellular proteins and DNA damage. Indirect effects like mutagenicity and carcinogenicity may arise (Richardson *et al.*, 1989).

The potassium concentration in water was within the acceptable concentration range. The concentration ranges in the fish organs though slightly biomagnified are within the acceptable range. Potassium is an important enzyme activator that is normally present in large quantities inside living cells. The sodium concentration levels in the river water were also within the acceptable international standards (WHO 1985). However, the concentration level in most of the organs was about twice as much as the acceptable concentration. Sodium is not normally toxic because of excretion by the kidney.

Alkalinity and hardness increased with increasing levels of pollution. More polluted sites such as Eastleigh and Njiru recorded the highest concentration levels of metals as well as alkalinity and hardness. Overall the levels of pollutants were fairly low at the source (Kikuyu) but increased as the river passed through Kawangware and Chiromo to the Central business district. After the Central business district there was dramatic increase in the levels of pollutants at Eastleigh. The pollution level began to decrease at Njiru reaching fairly low levels at Fourteen Falls.

The metal load of the river water at Fourteen Falls is within the accepted international standards (WHO, 1985) and the water is therefore not a potential health hazard. However, the concentrations of some metals (mercury, lead, iron and copper) in some fish organs are higher than the permissible international levels. Current results indicate that the higher concentration levels of metals are as a result of bioaccumulation. Although bioaccumulation of metals is not a new phenomenon (William and Hook, 1977; Thompson and Neckay, 1981; Hapke, 1991), there is need for caution in consumption of fish from Fourteen Falls.

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