



The Physico-Chemical Characteristics, Total Trace and Major Elements in Water and Surficial Sediments during Drought Conditions in the Highly Turbid Perennial Rivers, Hotspring and Lake Baringo, Kenya

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Abstract

Environmental degradation, climate change impacts and increasing water pollution exacerbates the challenges and threats facing lotic and lentic ecosystems, resulting in the continued loss of aquatic habitats and biodiversity, contamination of drinking water sources and reduced fisheries production. We collected surface water and sediment grab samples during the dry conditions (March 2008 and February – March 2009) and characterized the trace element contents, sources and distribution in major perennial rivers, hot-spring and Lake Baringo, for better resource use planning and management. Dried sieved sediments and water sampled were acid digested with Aqua-Regia and concentrated Nitric acid respectively, before metal analysis using

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Atomic Absorption Spectrophotometer equipment. Cold vapour technique was used for mercury analysis. Standard method were used for chloride and fluoride determination. Sediments accumulated higher trace elements than those in aqueous phase. Mean F levels in lake (92% of samples) and warm spring (83%) water were above the maximum allowable concentration for drinking water. Lake Baringo surficial sediments exhibited depletion to minimal enrichment for Cr, Mn, Zn, Co, Pb, Ni, Hg and the geo-accumulation index indicated moderate sediment pollution with respect to Ni, Hg, Co, Cu and Zn. River sediments were enriched with Mn, Zn and Cd, Ni. The findings indicate that anthropogenic sources contribute to sediment Cd, Zn and Mn contents in river and lake sediments, besides lithogenic sources. The Ramsar wetland area is sensitive to climatic changes and the previous dry conditions greatly contributed to the changes in the hydrochemistry due to increased processes of evaporative concentration.

Keywords: Lake Baringo; trace elements; aquatic pollution; surficial sediment quality.

1. Introduction

Lake Baringo is an endorheic basin which receives water inputs from precipitation, underground recharge, inflowing rivers and surface runoffs. Historical and current changes in lake water levels are well documented (Okech et al. 2019; Aloo 2002; Walumona et al. 2021; Schagerl & Oduor 2003; Kiage and Liu 2009; Kiage et al. 2007; Odada et al. 2006), with significant social and economic consequences. However, prior to the year 2010, the prolonged drought caused a significant drawdown in the lake, which was thought to impact the fisheries and water chemistry. However, no clear effects were documented with respect to trace elemental characteristics. Elsewhere, new studies point to possible relationship between bacterial resistance and multi-metal contamination (Di Cesare et al., 2016; Chen et al. 2019; Wright et al., 2006), but from limited studies. Although several studies have investigated trace elements in rift valley lakes (Campbell et al., 2003b; Gikunju et al. 2002; Nair et al., 1984; Ochieng et al., 2007; Yang et al., 2017; Plessl et al. 2017; Oduor & Schagerl 2007; Wilke et al 2020; Verwoerd, 2017; Barasa et al., 2017), L. Victoria (Campbell et al., 2003abc, Bootsma et al. 2003), and workplace in neighboring towns (Odongo et al. 2019); little is documented on inflowing rivers. Previous water quality assessment studies highlighted occurrences and presence of high F (Gaciri and Davies 1993) in rivers, lake and ground waters in the central Kenya rift valley region, largely overlain by volcanic rocks (Olaka et al., 2016; Edmunds and Smedley 2013). Increasing water abstraction and demand for better water quality are of major concerns within the basin. River Molo has several fish species, but the riverine habitats are continuously under the impact of anthropogenic activities (Kobingi et al., 2018). Previous and current studies conducted in the shallow rift group of lakes, including L. Nakuru, Naivasha, Bogoria, Elementeita and Baringo (Jirsa et al., 2013; Sunguti et al., 2024; Ochieng et al., 2007; Tarits et al., 2006) report on dissolved and suspended sediments trace elements contents. However, there are only a few studies providing information on toxic elements in inflowing permanent rivers, numerous hot springs and ephemeral streams. Again, previous mass mortalities of the bird species in the rift valley lakes were also linked to a possible poisoning by cyanobacterial toxins and heavy metals (Krienitz et al., 2003; Tenai et al., 2016). Therefore, climate change effects on algal blooms, and economic costs of public health risks and water treatment costs, are issues of concerns for the management of surface waters. Different international organizations (e.g WHO, 2017,1999; EFSA 2004; USEPA 2019), regional frameworks (e.g EU Water 1998) and national government authorities (e.g NEMA 2006) regulate various toxic chemicals (WHO 2016,1990; ATSDR 2019) and organic contaminants in effluent discharges, and sources of drinking water, to safeguard against toxicity and associated public health based targets, and protection of biodiversity. Lake Baringo lies at a low elevation (975 m.a.s.l) within the highly faulted and tectonically active floor of the central Kenya rift valley, a source of several hot-springs (Cioni et al. 1992; Renaut et al. 2017). The Baringo Ramsar wetland's protection depends heavily on these rivers and hence the need for frequent monitoring of its interconnected ecosystems for protection of the ecosystem services and its sustainability. Climate warming is expected to lead to shift in phytoplankton community composition that favor bloom-forming cyanobacteria that are often capable of toxin production (Paerl and Huisman 2009). The lake experiences water level changes over time (Walumona et al. 2026; 2022; 2021; Okech et al. 2019; Obando et al. 2016; Onywere et al. 2013; Kimtai et al. 2024) and is eutrophic (Okech et al. 2018; Walumona et al. 2021; Ochuka et al. 2019). Therefore, detailed studies on the complex interactions between lotic and lentic ecosystems are valuable, amid the frequent water level changes and the influence of climate change effects. Understanding catchment conditions and riverine conditions on nutrient and element loadings can be valuable tools in aid in understanding cyanobacterial blooming and associated pollution consequences. This study was undertaken

before the current rising water levels; and provides an indication of the prevailing physico-chemical conditions and status of the trace elements levels during the low water levels (drought conditions) experienced before 2010, in L. Baringo. Prior to 2010 lake water rise, the lakes turbidity, TDS, salinity and pH were high due to the reduced water volume (Aloo 2002; Olaka et al., 2022; Towett et al., 2013).

2. Materials and Methods

2.1 Study Area

Lake Baringo (Fig. 1a) is a closed basin alkaline lake, among the freshwater lakes designated as a Ramsar site (Ramsar Secretariat, 2011). It lies within the eastern arm of the great rift valley in Kenya, at 975 m.a.s.l. The shallow lake lies in a semi-arid area, between longitude 036° 00' and 036° 10'E and latitude 00° 30' and 00° 34'N, with a recorded surface area and mean depth varying from about 112.7 km² to 129 km² and 5m to 3m respectively (Omondi et al 2014; Walumona et al. 2021; Hickley et al. 2004; Aloo 2002). Watershed degradation is evident (Kiage et al. 2007) and is reflected in the water quality status (Schagerl & Oduor 2003).

2.2 Sampling Stations

Sampling points (Fig. 1) were marked (using a Garmin GPS equipment) and selected to cover the river influenced southern zone (S1, S2, S3); central islands (C1, C2, C3) and northern (N1, N2, N3) zone with several small bays and exposed rocks at the shore. Islands with hot springs are within the central zone of the lake. The major rivers (Molo and Perkera) and a small hot spring at Lorwai (Loboi swamp) were also sampled at the lower and upper reaches. Water quality parameters were determined according to APHA (1998).

2.2.1 Sampling and Pretreatment of Bottom Sediments

Sampling for lake sediments were not done in March 2008. Bottom sediments were collected using a precleaned Ekman grab sampler (Chapman et al. 1996) and kept frozen in sterilized zip-lock bags. The sediments were dried in oven at 105 °C, crushed to powdered form and sieved (to less than 63 µm) using a stainless steel sieve (BS 410). The sediments were characterized by determination of the percentage water, carbonate and organic matter contents. The water content was determined by oven – drying about 5.0g of the wet sediment at 105 °C for 6 hours and to constant weight. The carbonate (950 °C), organic matter contents and the Loss on Ignition (% L.O.I) was also determined by heating about 1.0g of the dry sediment at 550 °C (Hakanson and Johansson 1983) in a furnace and determining the weight loss.

All reagents used were of analytical grade. to check for possible contamination, and the blanks were carried through the same procedures. Acid digestion reagent blanks (Aqua regia reagents) together with the digested sample solutions were diluted to mark in 50ml volumetric flasks.

2.2.2 Metals Analysis in Sediments

About 1.0 g of the dry (dried at below 50°C) sample (<63 µm) was digested with 10 ml aqua-regia (3HCl:1HNO₃), after adding 2-3ml of distilled deionised water to make a slurry. The reaction vessel is covered with a watch glass or a condensation tube, and gently boiled under reflux for 2 hours, cooled, watch glass rinsed (with 2M HNO₃), filtered and diluted to mark.

2.2.3 Sampling for Water and Metal Analysis

Lake and river water samples were collected at each site, below the water surface in precleaned 500ml polyethylene bottles, acidified with conc HNO₃ and filtered using 0.45µm membrane filters. Blanks of distilled water were also filtered in a similar manner. Prior to collection, water bottles were first rinsed with the lake and river water. Metal analysis was done using an Atomic Absorption Spectrophotometer (Varian Spectra AA, Varian Inc.).

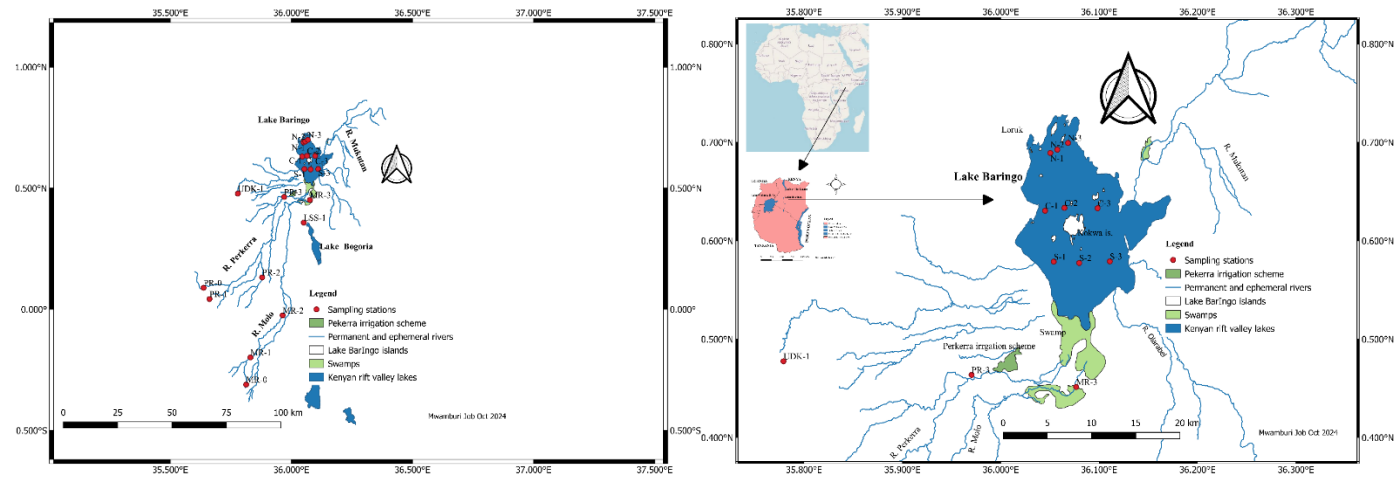


Fig. 1a. Map of the catchment area (a) of Lake Baringo (b) showing the inflowing the perennial rivers and sampling stations

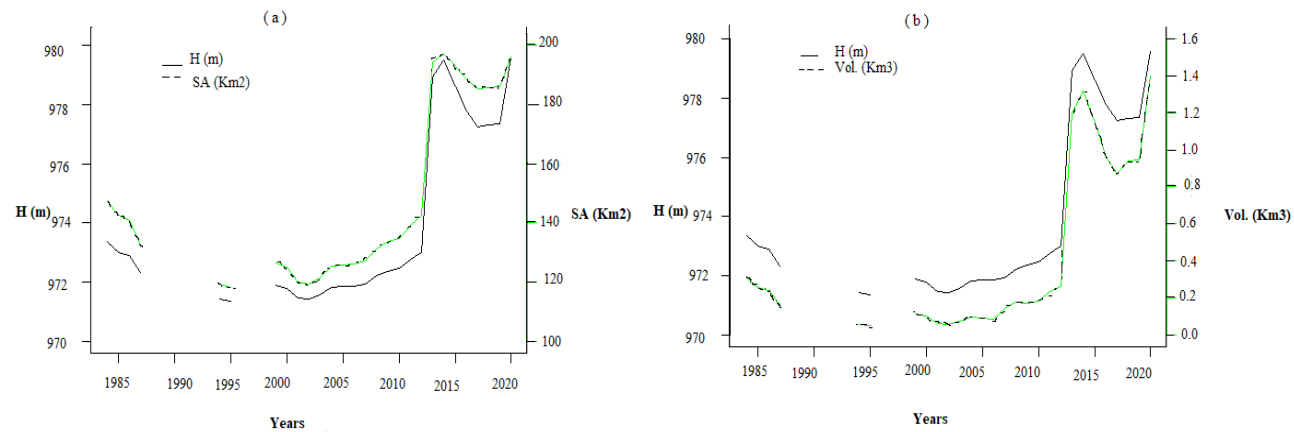


Fig. 1b. Water levels, surface area (a) and volume (b) changes in Lake Baringo from 1984 to 2020 (No data values for 1988,1990,1993,1996-1998)
(Source: Herrnegger et al. 2021)

2.3 Evaluation of Elemental Contamination and Sediment Quality

A geo-accumulation index (I_{geo}) value was calculated according to Muller (1969)

$$I_{geo} = \log_2 [(C_n) / (B_n \times 1.5)] \quad (1)$$

where C_n = measured concentration of element in the sediments; 1.5 = a correction factor to cater for the influence of the natural geochemical variation; and B_n = the shale rock background concentration value (Turekian and Wedepohl, 1961). The evaluation of metal pollution was done using the seven categories ranging from class 0 ($I_{geo} < 0$, none) to class 6 ($I_{geo} > 5$, very strong) (Muller, 1969).

The sediment enrichment factor (SEF) index of measured levels of metal elements in sediments was used to understand their sources (anthropogenic and natural or geogenic) in the surficial sediments (Reimann & De Caritat, 2005). The SEF was calculated as follows:-

$$SEF_{element} = [(C_{es} / C_{rs}) \text{ sample}] / [(C_{ebk} / C_{rbk}) \text{ background}] \quad (2)$$

where C_{es} and C_{ebk} = the measured element concentration in sediments and its background levels; C_{rs} and C_{rbk} = the reference conservative element concentration in the sample and its background levels (Salomons & Forstner 1984; Taylor 1964; Turekian and Wedepohl 1961; Sutherland 2000; Chatterjee et al. 2007). When the metal SEF is greater than 1, then the metal in the sediment originates from man-made activities, whereas an SEF of less than 1 indicates lithogenic sources. The categories for evaluation of elemental enrichment in the sediments ranged from no enrichment (SEF <1) to extremely severe (SEF >50) (Birth, 2003).

The contamination factor (CF) for each of the determined potentially toxic elements (PTE) was calculated as follows:

$$CF_{element} = (C_i / C_{rf}) \quad (3)$$

Where: C_i = PTE concentration in the sample and C_{rf} = the reference background value of the PTE. The categories of CF range from a value of < 1 (low contamination) to $6 \geq$ (very high contamination). The ecological risk factor was applied to evaluate the potential ecological risk of a specific PTE (Hakanson 1980), where Tr^i values used were as proposed by Hakanson (1980).

$$Er^i = Tr^i (CF) \quad (4)$$

The Tr^i and CF are the toxic response factors and contamination factor values respectively. A Tr^i value ranges from < 40 (low potential ecological risk) and > 320 (very high ecological risk). The PTE potential ecological risk index (PERI) was applied to evaluate the sum of the potential risk factors where:-

risk of a specific PTE (Hakanson 1980), where Tr^i values used were as proposed by Hakanson (1980).

$$PERI = \Sigma(Er^i) \quad (5)$$

The PERI categories range from low ecological risk (, 150) to very high ecological risk (PERI > 600).

2.4 Statistical Data Analysis

The distribution of the data collected was checked for normality, described and analysed using Microsoft Excel and Statistical Package for Social Sciences (IBM SPSS version 20) software. Multivariate analysis was done using R software (R Core Team 2021).

3. Results

3.1 River and Lake Water Characteristics

There was a pronounced downstream increase in most of the physico-chemical parameters (Table 1a - 1c) in both rivers (surface water temperature, conductivity, alkalinity, hardness, pH, turbidity and TSS), with significant correlation between the determined parameters (Table 2). The river water recorded a lower temperature during March 2008 compared to February – March 2009. Upstream river sampling sites (high altitude areas), recorded a relatively lower water temperature and turbidity, but with less variation in other parameters. The lake stations recorded much higher water temperatures (24.6°C – 29.3 °C), than the values for river water (12.6 °C – 28.4 °C). The warm clear waters at the Lobi swamp stream recorded a

Table 1a. The physical and chemical characteristics of river surface water at each sampling station

Site Code	Lat. / Long.	Alt. (m)	Temp. (°C)	D.O (mgL ⁻¹)	D.O (% sat.)	T. Alk. (mgL ⁻¹)	Hard. (mgL ⁻¹)	Cond. (µScm ⁻¹)	TDS (mgL ⁻¹)	pH (mgL ⁻¹)	Turb. (NTU)	BOD (mgL ⁻¹)	TSS (mgL ⁻¹)	Month/ Year
UDK-1	00°28'39.20" N 35°46'45.20" E	1850	18.4 22.1(0.7)	3.80 6.72(0.62)	— 78.0(3)	86 34	52 46	208 146(0)	118 52.3	8.43 8.20(0.01)	18.3 10.4(0.4)	— 1.6	196 14	a b
PR-0	00°02'34.1" N 35°39'44.0" E	2301	— 18.2(0.6)	— 7.19(0.52)	— 80.0(3)	— 36	— 16	— 70(0)	— 224	— 8.34(0.0)	— 19.6(8.3)	— 4.4	— 16	a b
PR-1	00°05'27.20" N 35°58'16.5" E	2259	— 12.6(0.1)	— 4.65(0.39)	— 61.0(1)	— 44	— 34	— 118(4)	— 150	— 8.15(0.03)	— 32.8(4.4)	— 3.2	— 16	a b
PR-2	00°07'54.60" N 35°52'46.60" E	1595	25.1 22.5(0.1)	2.80 7.16(1.36)	— 87.8(8)	60 50	46 32	152 120(1)	142 114	8.27 8.30(0.04)	214.0 48.5(7.9)	— 5.6	94 14	a b
PR-3	00°27'26.60" N 35°58'13.60" E	1053	27.1 28.4(0.4)	2.80 8.22(0.18)	— 99(0)	60 56	46 56	193 187(1)	138 33.6	8.41 8.73(0.03)	772.0 23.6(1.6)	— 3.2	132 16	a b
MR-0	00°00'27.70" S 35°57'52.80" E	2463	— 20.3(0.4)	— 5.23(0.44)	— 46.0(32)	— 38	— 34	— 220(2)	— 81.0	— 8.30(0)	— 53.8(0.6)	— 3.6	— 16	— b
MR-1	00°11'55.75" S 35°49'52.20" E	1915	18.5 19.6(0.6)	7.80 8.52(0.2)	— 94(3)	54 62	24 34	241 190(1)	226 184	8.12 8.52(0.07)	874 29.7(3.3)	— 2.8	196 16	a b
MR-2	00°21'28.50" N 36°03'04.90" E	1565	22.9 22.7(0.5)	2.80 5.89(0.2)	— 73.0(5)	74 52	28 38	251 216(0)	194 258	8.35 8.22(0.01)	95.9 40.6(1.7)	— 2.4	44 22	a b
MR-3	00°27'05.10" N 36°03'36.20" E	1000	26.1	4.00	—	124	42	303	428	8.09	989	—	382	a b
LSS-1	00°21'28.50" N 36°03'04.90" E	1036	36.4 30.9(0.1)	4.80 4.59	— 64.4±9.8	296 242	18 28	556 604	416 84.2	7.48 7.56	7.9 14.6	— 1.6	6 20	a b

(NB: TDS = Total dissolved solids; TSS = Total suspended sediments; - = not determined; Turb = Turbidity; Lat = Latitude; Long. = Longitude; Alt = altitude; Temp = temperature; D.O = Dissolved oxygen; % sat. = % saturation; T. alk. = Total alkalinity; Hard = Hardness; Cond = Conductivity; BOD = Biological Oxygen Demand; Mean (±) = standard deviation; a = March 2008 b = February - March 2009)

Table 1b. The physical and chemical characteristics of lake surface and bottom water at each sampling station

Site Code	Lat. / Long.	Depth (m)	Temp. (°C)	D.O (mgL ⁻¹)	D.O (% sat.)	T. Alk. (mgL ⁻¹)	Hard. (mgL ⁻¹)	Cond. (µScm ⁻¹)	TDS (mgL ⁻¹)	pH (mgL ⁻¹)	Turb. (NTU)	TSS (mgL ⁻¹)	Month/ Year
S_1	00°33'58.5" N	4.6	27.5(26.2)	6.40(1.8)	—	230	52	537(532)	350	8.83(8.83)	98.6(126)	22(48)	a
	36°04'49.3" E	4.2	24.6(23.4)	6.89(6.63)	84.0(79.5)	228	66	613(607)	—	8.85(8.86)	79(99)	—	b
C_1	00°36'25.5" N	5.0	26.5(25.1)	4.6(3.6)	—	222	48	541(549)	506	9.20(9.18)	88.7(114)	32(30)	a
	36°02'16.9" E	4.8	29.3(24.9)	8.10((5.6)	93.0((69.9)	236	66	598(593)	97(125)	8.91(8.93)	80.0(91)	—	b
C_2	00°37'58.1" N	5.0	27.2(24.9)	4.6(3.8)	—	228	48	542(553)	390	9.11(9.2)	97.3(90.9)	44(22)	a
	36°04'06.0" E	5.2	28.3(25.5)	8.76(5.34)	97.5(76.9)	230	68	596((597)	95(119)	8.86(8.87)	76.0(85)	—	b
C_3	00°37'24.3" N	4.0	27.2(25.7)	4.4(3.8)	—	216	50	534(546)	406	9.16(8.99)	90.8(145)	20(24)	a
	36°05'47.1" E	3.9	25.1(25.4)	6.98(6.44)	87.0(81.4)	228	78	615(604)	118(125)	8.84(8.69)	77.0(90)	—	b
N_2	00°41'48.8" N	6.0	27.4(25.4)	4.6(4.0)	—	220	48	538	392	9.16(9.23)	86.3	42(126)	a
	36°03'39.0" E	4.0	27.2(25.2)	7.24(4.8)	92.7(68.8)	216	56	582(595)	106(113)	8.92(8.95)	75.0(90)	-	b

(NB: Surface and (bottom water) values; a = March 2008; b = February – March 2009; TDS = Total dissolved solids; TSS = Total suspended sediments; - = not determined; Turb = Turbidity; Lat = Latitude; Long. = Longitude; Alt = altitude; Temp = temperature; D.O = Dissolved oxygen; % sat. = % saturation; T. alk. = Total alkalinity; Hard = Hardness; Cond = Conductivity)

Table 1c. The mean (±s.d) physical and chemical characteristics of river, hot spring and lake water

Water body	Months	Temp. (°C)	D.O (mgL ⁻¹)	D.O (% sat.)	T. Alk. (mgL ⁻¹)	Hard. (mgL ⁻¹)	Cond. (µScm ⁻¹)	TDS (mgL ⁻¹)	pH (mgL ⁻¹)	Turb. (NTU)	TSS (mgL ⁻¹)	Secchi (cm)	Depth (m)
R. Perkerra	ab	21.2(5.90)	6.3(1.9)	81.9(15.6)	48(9)	35(14.2)	130.7(44.5)	142.7(26.7)	8.40(0.20)	97.1(200.6)	47(52.6)		
R. Molo	ab	21.3(2.20)	6.1(1.90)	71.0(26.3)	67.3(30.2)	34.8(7.70)	222.9(31.5)	252.3(89.9)	8.30(0.20)	194.3(345.7)	112.7(149.1)		
Both rivers *	b	20.8(4.30)	6.72(1.36)	77.4(19.3)	48(9)	36(11)	158(51)	167(57)	8.35(0.19)	32.4(14.6)	16(3)		
Both rivers *	a	23.02(3.80)	4.3(1.88)		73(29)	36(12)	225(52)	208(115)	8.28(0.15)	494(431)	174(117)		
Hot spring	ab	32.2(2.7)	4.6(0.3)	64.5(9.9)	269(38.2)	23(7.1)	591.8(23.9)	418(2.8)	7.50(0.10)	13.0(4.5)	13.0(9.8)		
Lake	b	25.88(1.43)	6.74(0.83)	84.9(7.3)	228(7)	67(8)	604(14)	98.7(38.7)	8.90(0.07)	81(6)		33(4)	4.1(0.8)
Lake	a	26.10(0.86)	4.2(1.0)		223(6)	49(2)	545(7)	41(31)	9.12(0.15)	99.3(14.2)	41(31)	24(4)	4.9(0.7)

(NB: TDS = Total dissolved solids; TSS = Total suspended sediments; - = not determined; Turb = Turbidity; Temp = temperature; D.O = Dissolved oxygen; % sat. = % saturation; T. alk. = Total alkalinity; Hard = Hardness; Cond = Conductivity; Mean (±) = standard deviation; a = March 2008; b = February – March 2009; * = excluding hot spring water)

much high surface water temperature (30.9 °C – 36.4 °C). The dissolved oxygen in river water varied spatially with very low values (2.8 mgL⁻¹ – 4.0 mgL⁻¹) at MR-2, PR-3, PR-2 and UDK – 1 during the two sampling periods.

3.2 Trace and Major Elements Concentration in River and Lake Surface Water

There were spatial and temporal variations in the concentration of Fe, Mn, Al, F⁻ and Cl⁻ in river and lake surface water during March 2008 and February – March 2009 (Fig. 2). Calcium, cobalt, nickel were not determined in March 2008. Aluminum concentration in river waters varied from 0.2 µgmL⁻¹ (LSS – 1) to 11.72 µgmL⁻¹ (2008), and nd to 19.4 µgmL⁻¹ (2009). The highest concentrations were at the downstream sampling stations ($\bar{X}$ = 12.8 µgmL⁻¹ MR – 3 in R. Molo and $\bar{X}$ = 7.4 – 13.5 µgmL⁻¹ to PR – 1 – 3 in R. Pekerra). Much higher mean Al concentrations were recorded rivers in 2009 compared to 2008 sampling at each station. Other high concentrations were at UDK – 1 and LSS – 1 (2009) ranging from 10.2 – 13.0 µgmL⁻¹. In lake water, Al concentrations were much higher and ranged from 46.4 to 75.8 µgmL⁻¹ (Feb – Mar 2009). Similarly, Fe and Ca contents were much higher in the lake than river water. The Fe and Ca concentration in river water ranged from 4.6 – 29.6 µgmL⁻¹ and 120 – 376 µgmL⁻¹ respectively. Much higher Cr and Pb concentrations were recorded in river water in March 2008 than February – March 2009. In lake water, Cd and Co were below detection levels, but Mn, Fe, Ni, Pb, Zn, Cu, and Cr, recorded detectable levels in both surface and bottom water. In March 2008 (Fig. 2), the concentration (µgmL⁻¹) in surface and bottom waters ranged from nd – 0.008 ($\bar{X}$ =0.005±0.002 Cu), nd – 0.4 ($\bar{X}$ = 0.04±0.03 Zn), nd – 0.2 (Ni), nd – 0.6 ($\bar{X}$ = 0.029±0.012 Pb), nd – 0.02 ($\bar{X}$ = 0.008±0.004 Cr), 6.6 – 66.6 ($\bar{X}$ = 13.58±5.33 Fe), 0.03 – 0.21 ($\bar{X}$ = 0.14±0.12 Mn) respectively. The variations in mean levels of Cu, Zn, Pb, Fe, Mn, Cr for surface and bottom waters (March 2008) were not significantly different (p>0.05), but Mn and Fe levels were more pronounced throughout the lake zones. The highest F⁻, Cl⁻, Ni, Ca, Al, Cu, Zn, Mn, Fe, Pb and Fe levels were found at N – 2 (F⁻), N – 2 (Cl⁻), C – 3 (Fe, Ni and Al), N – 2 (Ca), C – 1, N – 2, S-2 (Cu), N-2, C – 1 (Mn), C – 3 (Fe) and S – 2 (Pb and Zn). The overall mean contents (± s.d µgmL⁻¹) of Al, Fe, Mn, Pb, Zn, Cu, Ca, Ni, F⁻, Cl⁻ in lake water were 42.63±29.38 (Al), 17.74 ±4.69 (Fe), 0.13±0.12 (Mn), 0.06±0.14 (Pb), 0.06±0.09 (Zn), 0.005±0.002 (Cu), 527.5±141.8 (Ca), 3.04 ±1.31 (F⁻) and 15.5±17.80 (Cl⁻).

In general, the fluoride concentrations in perennial river water remained constant and showed a narrow range with no clear trends downstream. The mean fluoride and chloride concentrations in lake water were much higher than contents the found in river water. The fluoride anion contents in rivers ranged from 0.002 – 2.94 µgmL⁻¹ and 0.17 – 3.99 µgmL⁻¹ in March 2008 and Feb – Mar 2009 respectively. A wider range in F⁻ concentration occurred in water from UDK – 1 and LSS – 1. The highest F⁻ concentrations were found in the warm Lorwai spring waters, with a mean concentration of 2.0 µgmL⁻¹ (March 2008) and 3.71 µgmL⁻¹ (February – Mar 2009). The F⁻ concentrations in lake water varied from 0.02 µgmL⁻¹ – 1.72 µgmL⁻¹ (March 2008) and 3.35 – 4.08 µgmL⁻¹ (February – March 2009). Surface water chloride concentrations recorded in March 2008, in both water types and sampling stations were much higher than values of Feb – Mar 2009. The mean concentrations in river water ranged from 0.99 – 3.32 µgmL⁻¹ (Feb – Mar 2009) and (11.9 – 27.9 µgmL⁻¹) in March 2008, with peak concentrations at PR – 2, MR – 2 and LSS – 1. In March 2008, the Cl⁻ concentrations decreased downstream in both rivers (11.9 – 19.9 µgmL⁻¹ in R. Pekerra and 19.9 – 39.9 µgmL⁻¹ in R. Molo), but varied slightly from 0.99 – 6.99 µgmL⁻¹ (R. Molo) and 0.99 – 1.49 µgmL⁻¹ (R. Pekerra) in February – March 2009. Spatially, lake water Cl⁻ concentrations remained fairly constant, with the highest levels recorded in March 2008 (35.9 – 47.9 µgmL⁻¹) and the lowest values were in February – March 2009 (3.99 – 4.49 µgmL⁻¹). Inter – elemental associations in surface water of the lake and rivers (Table 3) showed strong and significant positive correlations between Al-Fe, Al-F⁻, Fe-Mn, Fe-Cu and Zn-Pb. The rest of the significant positive coefficients between Fe, Al, Mn, Cu, Cr, Zn, Pb and other elements ranged from weak to moderate.

3.3 Trace and Major Elements Concentration in River and Lake Sediments (Dry Weight Basis)

Accumulated elements in river and lake sediments (Fig. 3a-3b) shows much higher contents of Hg in river sediments than those found in the lake deposits. The overall mean Hg contents in lake sediments was 0.0059±0.0014 mgKg⁻¹. In deposited sediments of both systems, Cd was mostly below detection levels. Strong to very strong associations were evident between Cd, As, Cl⁻, F⁻ (River sediments), Fe, Mn, Ca, Zn, Co, Cu, Ni (Lake sediments) and other elements (Table 4). Mercury was highly

variable in river sediments and showed a high variation among the elements in Lake Baringo and perennial rivers sediments (Table 5). Table 6 and 7 provide a comparative analysis of determined elements in both surface water and rivers sediments of L. Baringo. The lake and river sediments calculated mean geo-accumulation indices (I_{geo}) were all below zero (except for Mn) for Cr Cu, Hg, As, Ni, Zn (except for station C – 2, $I_{geo} = 0.10 \pm 0.09$), Pb, Co and Ca indicating that the sediments are unpolluted with respect to these trace elements (Fig. 4). The I_{geo} index for manganese ranged from 0.052 (N – 2) to 0.38 (C – 2) and indication of unpolluted to moderately polluted lake sediments. Similarly, river sediments indicated moderate Mn pollution (I_{geo} of 0.18 to 1.17). The river sediment Pb, As, Ni, Cr and Cu contents show a probable lithogenic source within the catchment, with probable anthropogenic sources of Hg, Co, Cd, Zn and Mn. The lake sediments revealed a low contamination factor (CF) for Cu, Cr, Hg, As and Ni, whereas Zn, Pb and Co revealed a moderate CF. In the river sediments, Pb, Cu, Cr, Hg, As and Ni showed a low contamination factor and a moderate contamination factor for Zn, Co and Cd elements. The potential ecological risk index (PERI) was low in surficial sediments. Cadmium levels revealed a moderate potential ecological risk in river sediments. However, the rest of the elements (Zn, Pb, Co, Cu, Cr, Hg, As and Ni) potential ecological risk was low in both river and lake sediments. The lake sediments had over 50% of the samples exceeding the threshold effect concentration (TEC) value of Mn, Cr, Cu, Ni and Zn (MacDonald et al., 2000), but still below the midpoint effect concentration. Similarly, the percentage of river sediment samples exceeding the TEC for Cr, Cu, Cd, Zn, Hg, Mn and Fe were 24%, 29%, 43%, 57%, 88% and 100% (Mn and Fe) respectively, but still only Fe and Mn exceeded the probable effect level.

Table 2. Significant correlation coefficients (* and ** = significant at 0.05 and 0.01 level of significance respectively) between the determined physico - chemical parameters in the river (a) and lake water (b)

(a) River water (n = 34)

	Temp	pH	D.O	Cond	Turb	TSS	TDS	T. alk	Hard
Temp	1.000								
pH	-0.129	1.000							
D.O	-0.191	**0.499	1.000						
Cond	**0.534	-0.310	*-0.405	1.000					
Turb	-0.039	0.109	-0.245	0.155	1.000				
TSS	-0.025	0.030	-0.200	0.398	*0.824	1.000			
TDS	*0.622	*-0.539	0.236	**0.818	0.245	0.275	1.000		
T. alk	0.492	-0.166	-0.309	**0.747	-0.176	0.300	*0.503	1.000	
Hard	-0.063	*0.552	0.179	-0.069	0.090	0.271	-0.187	0.205	1.000

Sample size for Total suspended solids (TSS), Total dissolved solids (TDS), Total alkalinity, and Hardness = 16; D.O = dissolved oxygen

(b) Lake water (n = 54)

	Temp	pH	D.O	Cond	Turb	TSS	T. alk	Hard	Secchi
Temp	1.000								
pH	-0.181	1.000							
D.O	0.114	-0.268	1.000						
Cond	**0.443	-0.273	*0.386	1.000					
Turb	0.083	0.112	**0.611	**0.717	1.000				
TSS	-0.091	0.123	-0.450	-0.156	0.287	1.000			
T. alk	0.475	-0.629	0.477	0.359	0.128	0.300	1.000		
Hard	0.012	*-0.747	**0.827	**0.807	*-0.681	-0.783	0.470	1.000	
Secchi	0.121	0.164	0.381	0.140	-0.533	-0.300	-0.281	0.427	1.000

Sample size for dissolved oxygen (D.O) = 34, Total suspended solids (TSS), Total alkalinity, Hardness and Secchi depth = 10

Table 3. Significant correlation coefficients (* and ** = significant at 0.05 and 0.01 level of significance respectively) between the elements in the lake (a) and river water**(a) Lake water (n=29)**

	Fe	Al	Mn	Zn	Cr	Cu	Pb	F-	Cl-
Fe	1.000								
Al	**0.751	1.000							
Mn	0.010	*-0.407	1.000						
Zn	0.361	0.317	0.056	1.000					
Cr	-0.410	0.081	-0.272	-0.208	1.000				
Cu	*-0.410	0.081	-0.272	-0.208	-0.368	1.000			
Pb	0.368	*0.441	-0.099	**0.912	-0.174	0.275	1.000		
F-	*0.390	**0.609	*-0.400	0.331	0.131	**0.518	*0.438	1.000	
Cl-	-0.338	0.130	-0.369	-0.170	**0.958	*-0.477	-0.110	*0.310	1.000

(b) River water (n = 29)

	Fe	Al	Mn	Zn	Cr	Cu	Pb	F-	Cl-
Fe	1.000								
Al	**0.655	1.000							
Mn	**0.741	**0.543	1.000						
Zn	0.307	*0.389	**0.689	1.000					
Cr	-0.345	*-0.412	-0.363	-0.248	1.000				
Cu	**0.627	*0.339	**0.766	0.215	-0.274	1.000			
Pb	-0.318	*-0.369	-0.342	-0.245	*0.444	-0.271	1.000		
F-	-0.088	0.185	0.000	0.170	0.145	-0.108	0.083	1.000	
Cl-	*-0.422	*-0.426	**0.517	-0.351	0.257	*-0.447	0.362	*0.032	1.000

Table 4. Inter – element correlation coefficients in river (a) and lake (b) surficial sediments (* and ** = correlation significant at 0.05 and 0.01 level, 2 tail test respectively)**(a) River surficial sediments (n = 21)**

	Al	Mn	Fe	Zn	Cd	Ni	Cu	Cr	As	Hg	Cl ⁻	F ⁻
Al	1.000											
Mn	0.416	1.000										
Fe	*0.548	0.336	1.000									
Zn	-0.363	*-0.483	-0.419	1.000								
Cd	**0.673	0.404	*0.566	*-0.480	1.000							
Ni	**0.842	-0.193	-0.333	0.405	**0.615	1.000						
Cu	-0.259	-0.170	*0.453	-0.182	-0.197	0.264	1.000					
Cr	-0.397	0.034	0.379	-0.060	-0.182	**0.592	**0.649	1.000				
As	**0.611	0.192	-0.117	-0.303	*0.456	**0.819	**0.579	**0.770	1.000			
Hg	**0.717	0.265	0.147	-0.362	*0.528	**0.796	-0.291	*-0.540	**0.754	1.000		
Cl ⁻	**0.822	0.421	*0.468	**0.593	**0.732	**0.828	-0.191	-0.331	**0.694	**0.706	1.000	
F ⁻	**0.554	0.261	-0.070	-0.099	0.246	**0.561	**0.557	**0.654	**0.604	**0.616	0.382	1.000

(b). Lake surficial sediments (n = 15)

	Mn	Fe	Ca	Zn	Pb	Co	Ni	Cu	Cr	Hg
Mn	1.000									
Fe	0.537	1.000								
Ca	0.028	0.118	1.000							
Zn	0.368	**0.953	0.216	1.000						
Pb	0.313	**0.699	*0.576	**0.753	1.000					
Co	*0.557	0.468	-0.495	0.461	0.136	1.000				
Ni	0.274	0.442	*-0.621	0.427	0.037	**0.829	1.000			
Cu	**0.717	**0.850	-0.015	**0.771	0.477	*0.615	0.439	1.000		
Cr	0.316	**0.755	-0.189	**0.726	*0.598	0.504	*0.624	*0.561	1.000	
Hg	*0.604	0.133	**0.766	-0.070	-0.350	*0.625	*0.547	0.372	0.162	1.000

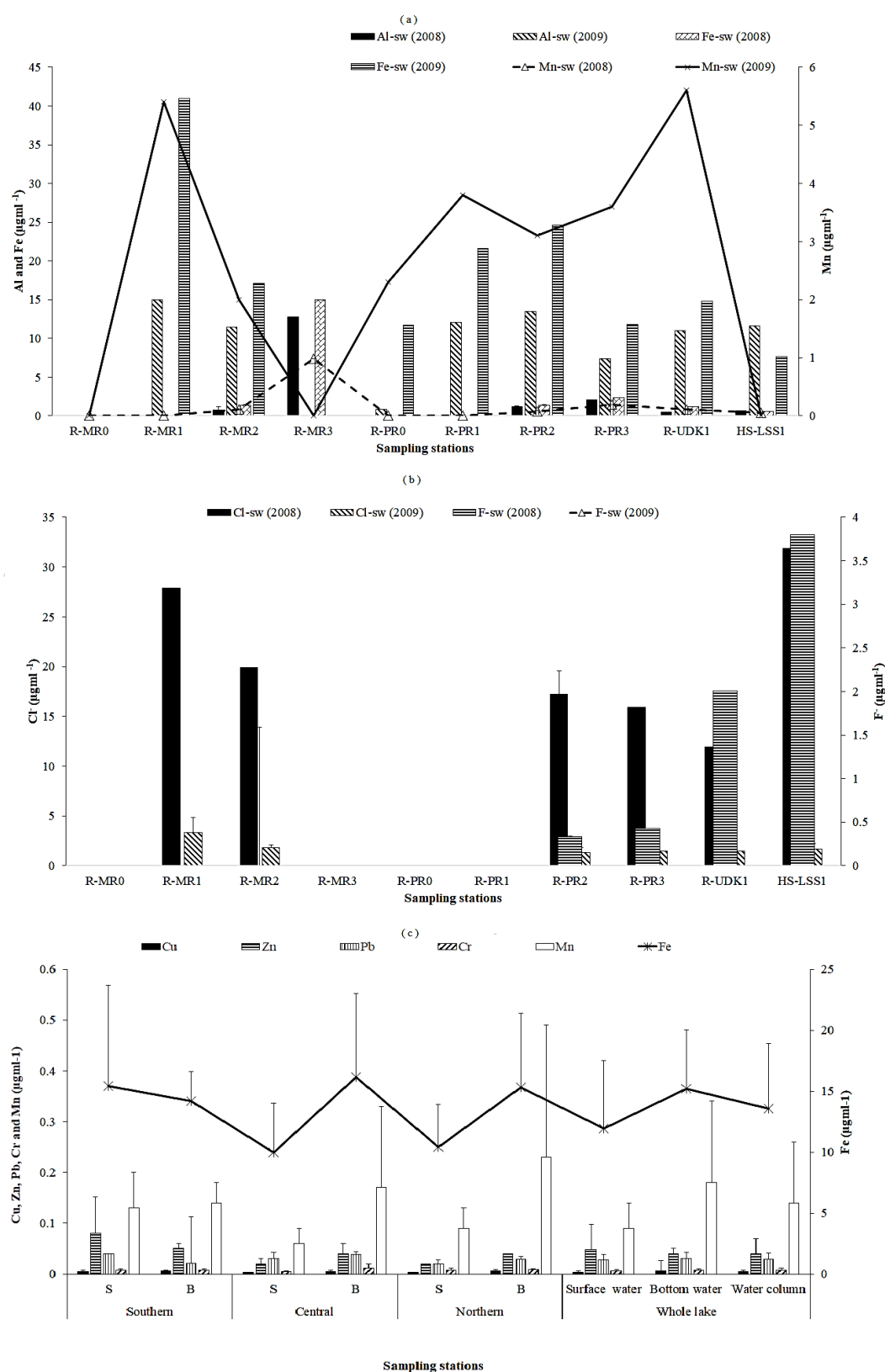


Fig. 2. The mean ($\pm$ s.d) concentrations (μgml^{-1}) of Al, Fe (a), Mn (b), Cl⁻ and F⁻ ions (c) in river surface water and the Cu, Zn, Pb, Mn, Cr and Fe concentrations in the lake surface (S) and bottom (B) water at the southern (S), central (C) and northern (N) stations in L. Baringo during 2008 and 2009

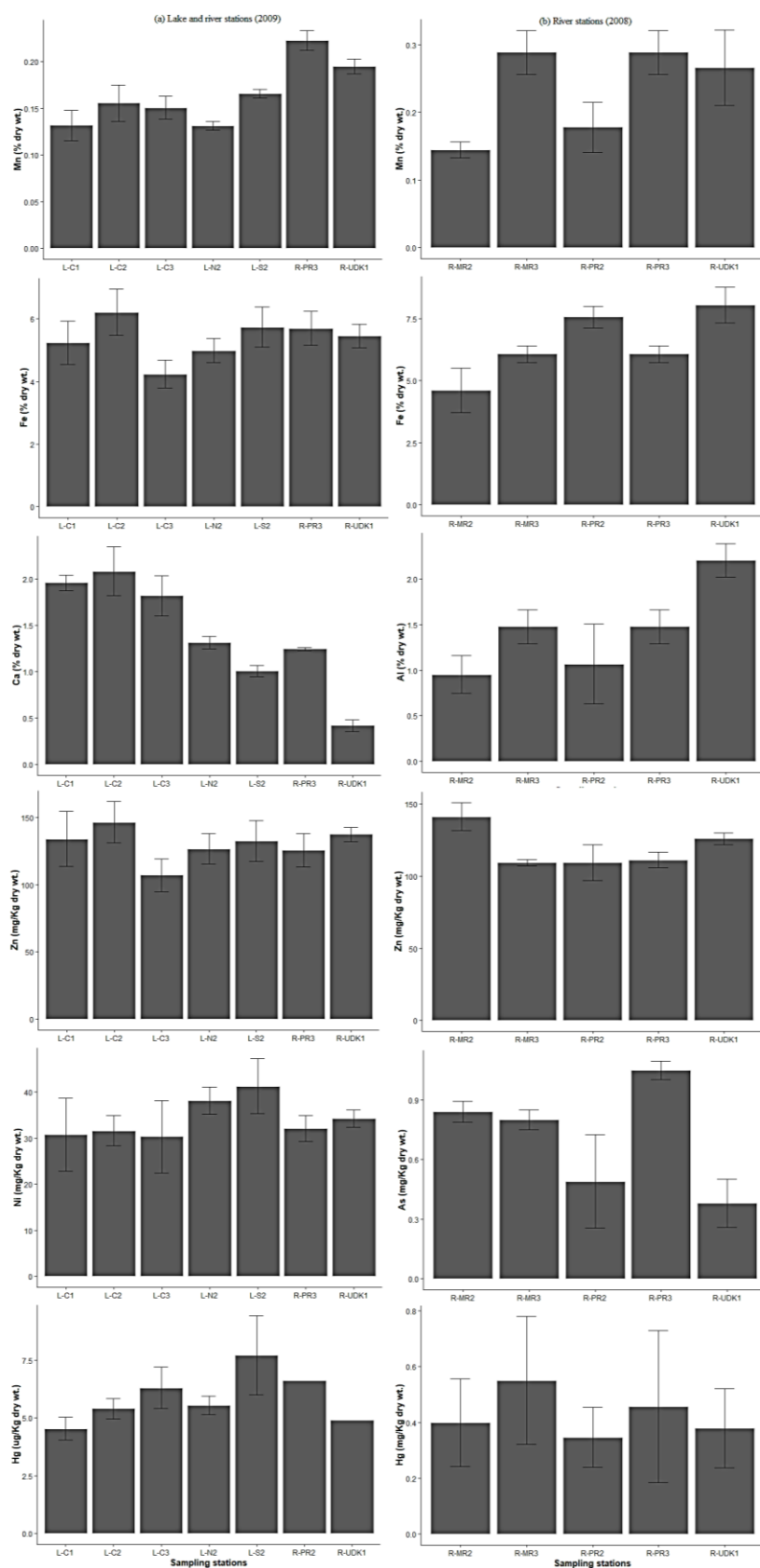


Fig. 3a. The mean ($\pm$ s. d) concentrations of Al, Ca, Fe Mn (% dry wt.) and Ni, Zn and Hg (μgKg^{-1} and mgKg^{-1} dry wt.) in lake and river surface sediments during 2009 (a) and 2008(b)

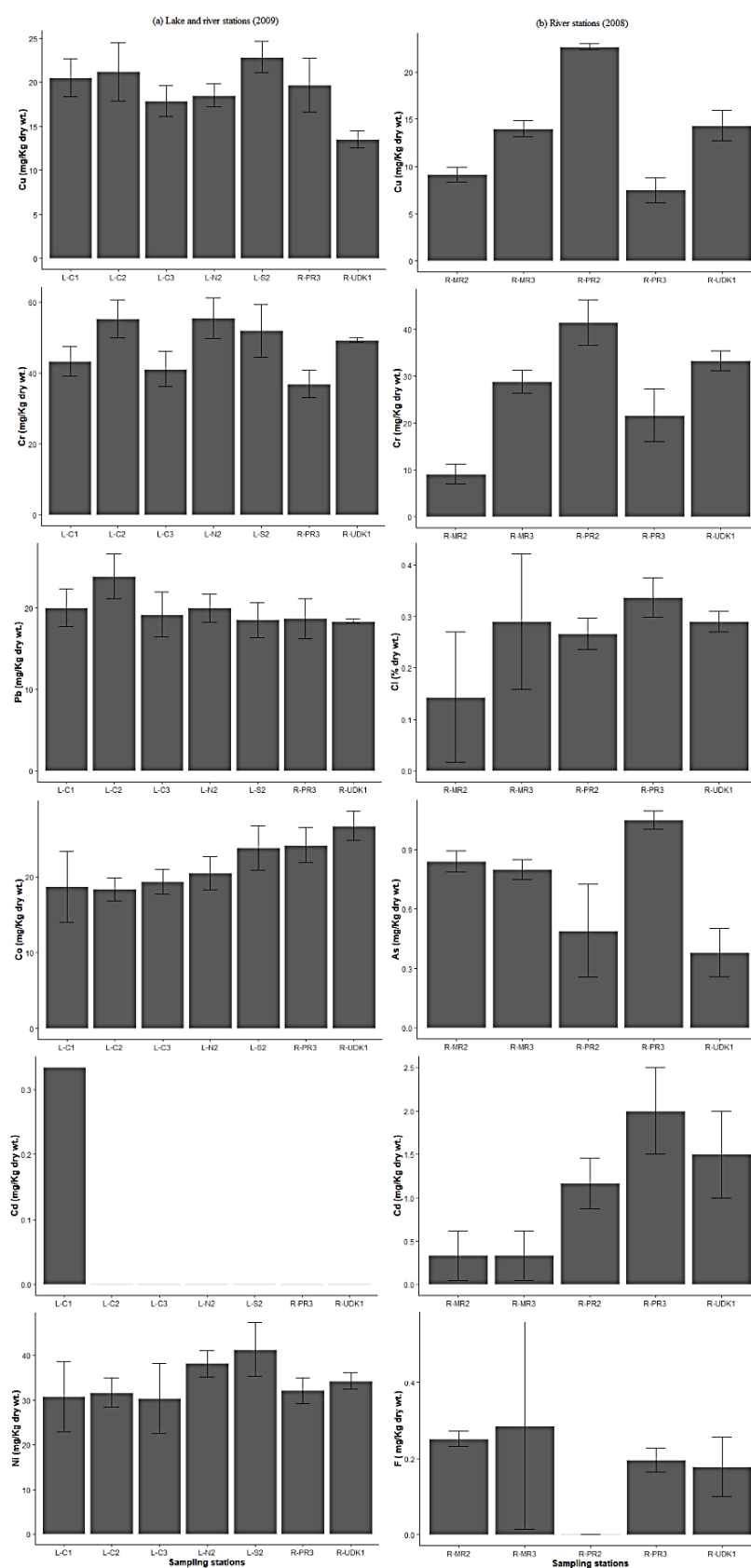


Fig. 3b. The mean ($\pm$ s. d) concentrations of Pb, Cu, Cr, Cd, Co, F (mgKg⁻¹ dry wt.) and Cl (% dry wt.) in lake and river surface sediments during 2009 (a) and 2008(b)

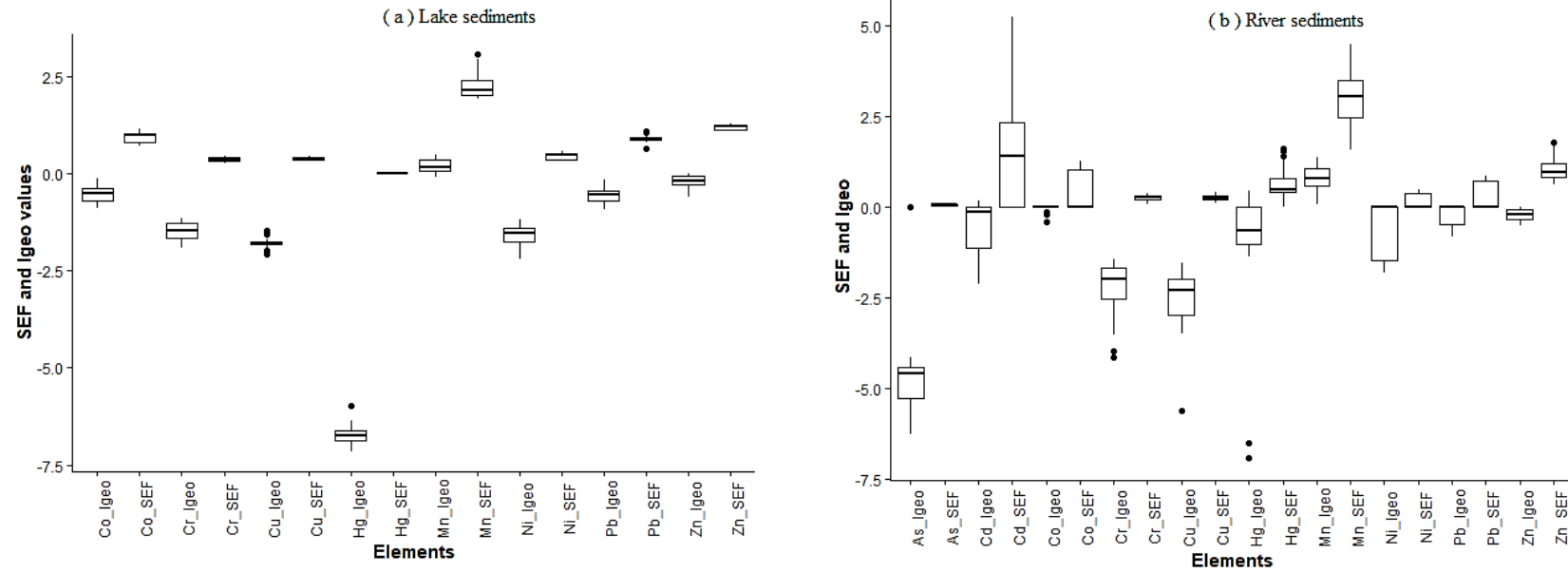


Fig. 4. A box plot of the mean ($\pm$ s. d) of the calculated geo-accumulation index (Igeo) and sediment enrichment factors (SEF) in lake (a) and river (b) sediments

Table 5. The concentration and dispersion values of all elements in Lake Baringo and perennial rivers sediments

	Al	Fe	Mn	Ca	Co	Cu	Cr	Cd	Pb	Ni	Zn	As	Hg	Cl	F
	(%)	(%)	(%)	(%)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(mgKg ⁻¹)	(%)	(mgKg ⁻¹)
Min.	0.738	3.735	0.121	0.350	15.50	6.00	7.50	nd	16.00	22.00	93.00	0.25	0.004	0.170	0.130
25 th P	0.963	4.995	0.143	1.028	18.50	13.50	31.13	0.50	17.75	30.25	112.89	0.50	0.006	0.240	0.170
50 th P	1.475	5.838	0.174	1.305	20.50	17.50	41.50	1.00	19.00	34.50	124.75	0.80	0.009	0.280	0.230
90 th P	2.290	7.725	0.293	2.058	27.20	23.00	58.15	2.20	22.50	43.90	145.70	1.05	0.540	0.405	0.496
$\bar{X}$	1.433	5.828	0.193	1.408	21.64	16.81	39.01	1.15	19.79	34.12	125.50	0.71	0.203	0.284	0.250
± S.d	0.504	1.174	0.061	0.573	3.78	5.17	14.15	0.66	2.59	5.87	16.28	0.27	0.244	0.068	0.113
U95%	1.712	6.225	0.214	1.669	23.36	18.55	43.80	1.52	20.97	36.79	131.01	0.86	0.291	0.324	0.330
L95%	1.154	5.431	0.173	1.148	19.92	15.06	34.23	0.79	18.61	31.45	119.99	0.56	0.115	0.245	0.170
Max.	2.350	8.750	0.329	1.305	28.00	25.00	61.50	2.50	27.00	45.00	163.00	1.10	0.810	0.430	0.540

(NB: P = percentile value; Min = minimum value; Max. = maximum value; U and L = upper and lower bound; C. L = Confidence limit; S. d = standard deviation; $\bar{X}$ = Mean value)**Table 6. The overall mean concentration (± s.d, µgml⁻¹) in surface waters during different sampling periods and other reported data**

	Al	Fe	Mn	Zn	Cu	Cd	Pb	Cr	F	Cl
Lake surface water										
A	34.7(18)	27.8(15.3)	0.24(0.12)	0.10(0.09)	0.02(0.01)		nd			
B		616.5(166.4)	5.2(1.3)	1.94(1.0)	0.1(0.1)	nd	0.79(0.43)	0.44(0.18)		
C		11.9(5.6)	0.09(0.05)	0.04(0.04)	0.003(0.003)	nd	0.02(0.01)	0.006(0.003)		
D	17.82	4.20	nd	0.01	nd	nd	nd	0.13	1.27	40.9
E	62.5(12.9)	43.6(13.6)	nd	nd	nd	nd	nd	nd	3.840	4.20
Diss ^s			0.05-0.282	0.029-0.235	0.0047-0.1	0.002-0.043	0.025-0.563	0.025-0.188		
Diss ^{&} (ngml ⁻¹)	485-1562	112.9-476.1		1.98-94.31	3.09-5.89	nd-0.07	0.16-0.48	0.47-2.28	1.9-9.8	29-92
River surface water										
B *		164.5	3.75	0.96	nd	nd	0.24	nd		
B **		775	22.60	2.31	nd	nd	0.84	0.06		
D *	1.54(0.52)	1.77(0.53)	0.12	nd	nd	nd	0.02	0.02	0.23	16.70
D **	5.57(6.64)	6.79(11.6)	0.46	0.04	nd	nd	nd	nd	0.40	24.70
E *	9.9(7.5)	18.2(6.5)	3.1(0.6)	nd	0.5(0.3)	nd	nd	nd	0.25	1.14
E **	24.8(28.1)	18.2(6.4)	2.9(2.2)	0.20	0.9(0.1)	nd	nd	nd	0.51	3.20
Diss ^{&} (ngml ⁻¹)	530.5-992.1	303.7-700.5		3.17-15.05	1.21-1.9	nd-0.01	0.14-0.36	0.09-0.36	0.2-0.3	6-10
NEMA				1.5	0.05	0.01	0.05		1.5	

(NEMA= National Environmental Management Authority 2006; Diss^s = dissolved Ochieng et al., 2007; Diss[&] = dissolved Tarits et al., 2006; A = May 2004; B =March 2007; C = May 2007; D =March 2008 E =February – March 2009)

Table 7. The overall mean concentration (mgKg⁻¹) in surface sediments during different sampling periods and other reported data (Values of Al, Fe, Cl and Mn are in % dry weight)

	Al (%)	Fe (%)	Mn (%)	Zn	Cu	Cd	Pb	Cr	Ni	Co	F	Cl (%)
	Lake	sediments										
A				127(20)		3.5(1.6)	49.9(22.9)					
C		5.28(0.86)	0.147(0.018)	129.3(18.4)	20.2(2.6)	nd	20.5(2.7)	49.5(7.9)	34.5(6.8)	20.1(3.2)		
D			0.06671-0.39468	96.2-229.6	1.46-20.95	0.05-1.18	10.92-38.98	1.94-4.91	11.69-39.72	0.17-1.38		
SS &	0.74-13.2	9.3-10.3	0.15-0.186					4.8-7.5				
	River	sediments									-	-
A *				148(5)		2.0(0.3)	26.9(1.0)					
B *	1.21(0.34)	5.34(1.0)	0.217(0.082)	125(18.5)	11.6(2.7)	0.3(0.3)		19.0(11.8)			0.32(0.13)	0.26(0.1)
B **	1.43(0.496)	8.54(1.34)	0.344(0.204)	115.4(10.6)	14.8(6.7)	1.6(0.5)		32.2(9.5)			0.19(0.05)	0.31(0.04)
C **		5.58(0.44)	0.20(0.02)	131.4(10.7)	16.6(3.9)	nd	18.5(1.6)	43.2(7.2)	33.3(2.5)	25.4(2.3)		
SS &												
LVN-Sediments ^a	-	5.3655(8.054)	0.15(0.03)	231.94(23.42)	33.74(5.12)	-	22.11(5.54)	27.44(3.42)	-	24.04(3.42)	-	-
IG-R ^s	8.2	6	0.1	70	55	0.2	12	100	75	25		
Shale	3	4.67	0.085	95	45	0.3	20	90	68			
Ag Soils - CK				247.39	88.59	0.42	26.89	59.69	12.56			
SubSSoils (X)	3.3927	2.7954	0.0466	29	17		37	64	19			
SubSSoils (median)	3.4187	2.0789	0.0276	20	13		18	45	12			
SubSSoils (Min-Max)	0.0094-8.9068	0.0020-18.1691	0.00016-6.575	0.3-138	0.3-114		0.3-639	0.7-598	0.3-364			
Soils - WR ^s X (R)	7.1(1-30)	3.8(0.7-55)	0.085(0.01-0.4)	50(10-300)	20(2-100)	0.06(0.01-0.7)	10(2-200)	100(5-3000)	40(10-1000)	8(1-40)		

(Diss^s = dissolved Ochieng et al., 2007; Diss^a = dissolved and SS^a = Suspended sediments = Tarits et al., 2006; IG-R^s Igneous rocks and WR^s = world range = Bowen 1979; X = Mean; R = range; Shale = Turekian and Wedepohl 1961; Ag soils CK = Mungai et al., 2016; SubSSoils = Sub-Saharan Africa = Towett et al., 2015; * = R. Molo; ** = R. Perkerra; A = March 2007; B = March 2008; C = February – March 2009; D = Ochieng et al., 2007; LVN sediments^a of (May 2016; n = 41) < 53µm grain size XRF analysis = Olando et al., 2020)

Multivariate principal component analysis (PCA) results of the first two dimensions (Fig. 5a-b) was done using the elemental concentrations and environmental variables in river and lake water. The results show high loadings on PC 1 for water temperature, D.O and conductivity. The total alkalinity, hardness, pH and the elements in water were more correlated with PC 2 (explained 16.4% of the variation). The hot spring site was more associated with temperature, Cr element and the anions (F⁻ and Cl⁻). Operative processes in the lake during the prolonged drawdown prior 2010 lake levels rise may be having more influence on the aqueous elements and physico-chemical conditions during the sampling period. The two components (PC1 and PC2) explained over 76% of the variation in elemental contents in both the river and lake surficial sediments. All the elements were well correlated with PC1 (Al, Ca, Pb, Co, Hg and Cl showed the highest correlations), except for Fe, Cu, and Cr (PC2) and Zn (PC3). Negative correlations with PC1 were evident for Hg, Cd, F⁻ and Cl⁻ elements.

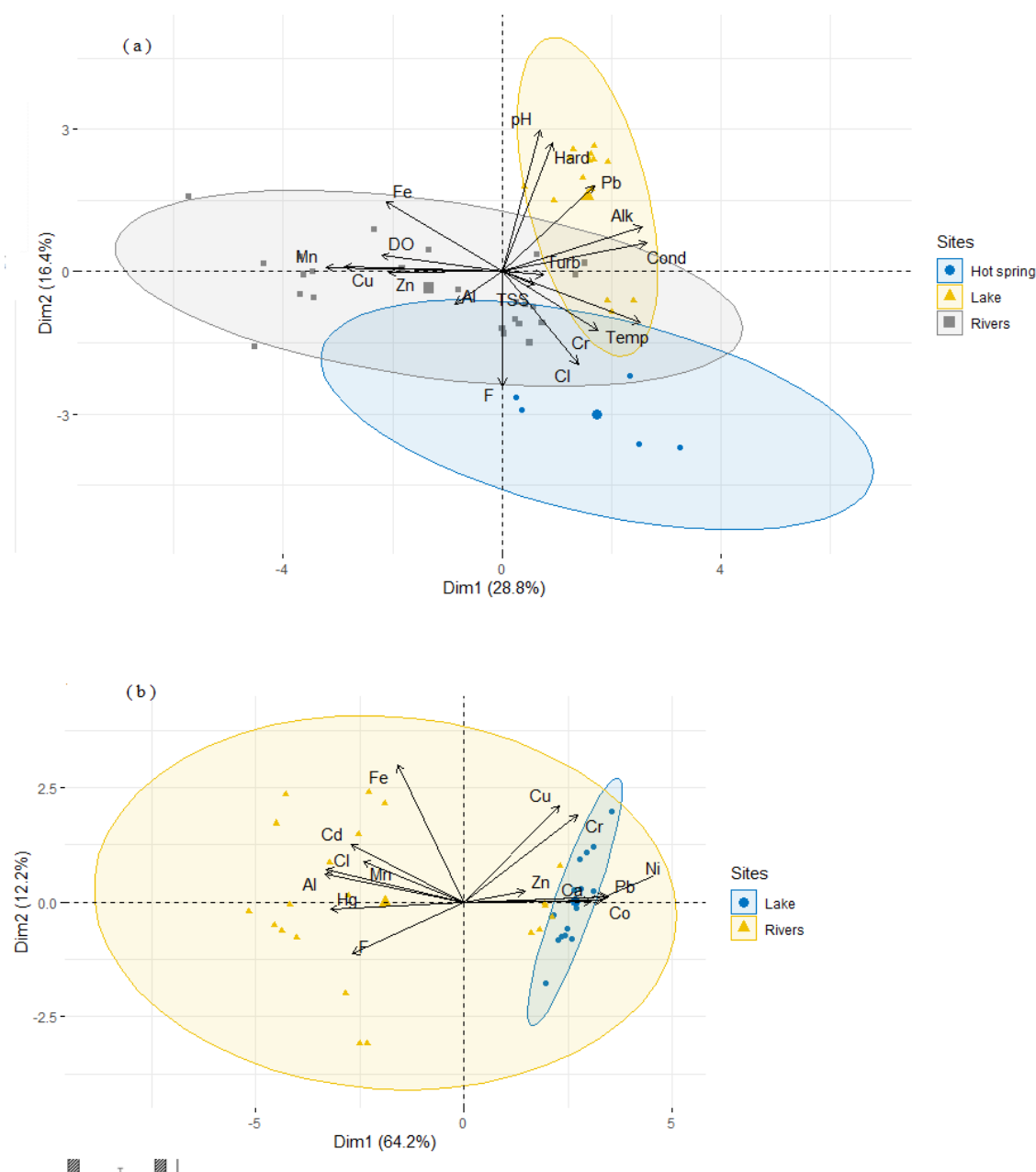


Fig. 5a A principal component analysis (PCA) and ordination biplot diagram using environmental and elemental variables measured in river, hot spring and lake water (a), and surface sediments (lake and rivers) elemental contents (b)

The PC 1 (53.7%) was positively correlated with temperature, alkalinity, hardness, conductivity and pH, whereas PC 2 (17.7%) showed a positive and negative correlation with turbidity and D.O levels respectively (Fig. 5b). High turbidity was evident in the rivers whereas high conductivity, alkalinity and temperature were evident in the lake waters.

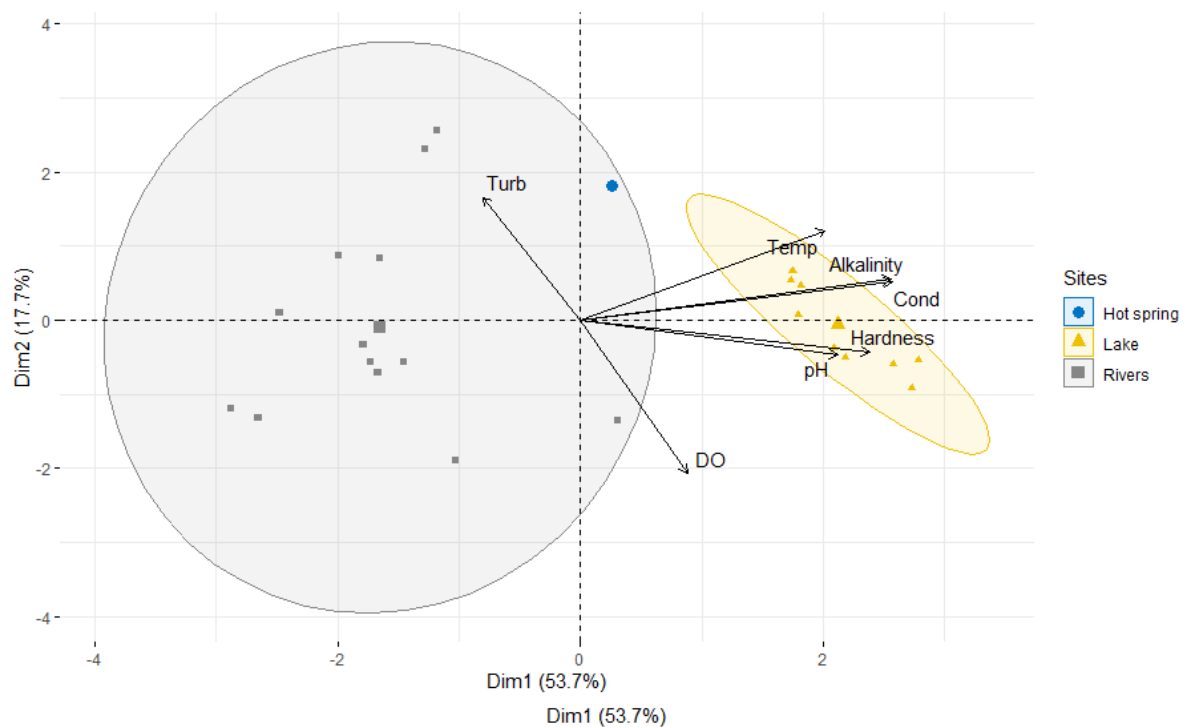


Fig. 5b. A principal component analysis (PCA) biplot of the lake (orange colour), river (grey colour) and hot-spring (blue colour) samples and correlation with some of the environmental variables

4. Discussion

4.1 The Physico - chemical Characteristics of the Lake and Rivers

River water in L. Baringo basin was alkaline, with a mean pH range within the allowable range (6.5 – 8.5) for drinking water sources (WHO, 2017; EPA, 2019). However, lake waters were found to be more alkaline, due to the high evaporative concentration and rich volcanic formations. Water of the perennial rivers at upstream sites, in relatively forested zones, was relatively less turbid when compared to exposed areas and downstream sites. Both rivers show presence of a high particulate loads downstream as a result of upland erosional processes. In rivers receiving minimal industrial discharges, downstream increases in surface water TDS, TSS, temperature, turbidity, pH, conductivity are common (Wafula et al., 2018; Nyairo et al., 2015). These conditions are characteristic of most of the small to large tropical rivers where expanding human settlements on forested areas, poor agricultural practices and loss of buffer vegetation, wildlife and livestock grazing; and high landscape gradients increase vulnerability of land degradation. Warm spring waters were characterized by less particulate matter as reflected by a very low turbidity. Earlier measurements recorded a lake depth range of 5.2 to 7m (Omondi et al., 2014; Kiage & Liu 2009). Seasonal fluctuations in water level were commonly observed, with a significant temporal increase in mean lake water depth from 2.95m (December 2009) to 9.55m (September 2012) (Omondi et al., 2014). The lake is surrounded by high gradient landscapes in the south west and south east basin with agricultural and settlement areas exposing the soils to high erosional forces. Significant water inputs into Lake Baringo originate from the highly variable rainfall, surface runoffs and rivers inflows and subterranean inflows. The area receives normal rains from around April to August and October to November. Before 2010, the lake experienced prolonged dry seasons with reduced precipitation as shown by the physico-chemical conditions expressed in this study (March 2008 and February – March 2009) results. The low river

discharge and flow is normally experienced during the dry season. The rivers exhibited high turbidity and TSS which resulted in a high reduction in light availability in lake water potentially affecting algal production. The coincidence of dry conditions during both sampling periods, and the high evaporation rates influenced the lake hydrochemistry, with intermittent precipitation upstream causing the influx of high levels of suspended materials, which exceeded the WHO maximum levels of 5 NTU limits (WHO, 2017) most of the times.

In general, conductivity and alkalinity increased towards the central zone, with slight vertical variations in temperature, TSS, TDS turbidity and conductivity in the water column. Spatially, the basin deepens northwards but frequent wind mixing of the shallow waters, riverine inputs (perennial and ephemeral rivers), surface runoffs and easy re-suspension of the surficial sediments, results in variations in surface water effects on suspended load and light penetration, due to the relatively small surface area. This is indicated by a significant negative correlation of water turbidity, light penetration and dissolved oxygen, due to significant amounts of particulate associated organic matter. Temperature, hardness, alkalinity TDS, and conductivity were also positively associated in and river lake water. The lake is also considered eutrophic (Ballot et al., 2003; Ochuka et al., 2019ab), due to the high nutrient loads and other sediment sourced nutrients. The warm spring waters analysed are located on the southern side of Lake Baingo, and lie between the saline alkaline Lake Bogoria and Lake Baringo basin, which have previously been described by Owen et al. (2004); as slightly acidic (pH of 6.4 and temperature of 36.7 °C), and also feed the Loboï swamp. The swamp waters are slightly alkaline and generally reflect the mixing of fluvial, spring and groundwater inflows (Owen et al., 2004). Within and amongst variations in D.O saturation is common in alkaline saline lakes, with supersaturation from phytoplankton production during relatively calm weather conditions, and near anoxic levels followed sediment disturbances by flamingoes (Kotut et al., 2006). Lake Baringo is becoming eutrophic from the varied sources of nutrients, with current presence of cyanobacterial blooms and water hyacinth. The relatively lower D.O levels observed in 2008 were related possibly to the reduced volumes and increasing loading of terrestrially washed organic materials and wastewater discharges from the catchment and around the southern areas where there exists irrigation farms near the inlets (potential leaching of fertilizers) of Perkerra river, and sisal farms upstream the Molo river drainage basin. These observations are supported by the recent observations by Ochuka et al. (2019a) which depict similar physicochemical conditions, increasing turbidity and human activities. The influence of the area geology on river water quality is also shown by the ionic composition of source waters of R. Molo (Chebet et al., 2020) which also contain similar high fluoride at some sites (nd to 3.28 mgL⁻¹). In 2018, the lake water remained fresh and eutrophic (TP ranged from a mean of 0.5±0.57 mgL⁻¹ in lake water and 1.0±0.0 to 2±1.16 mgL⁻¹ in river water), with the salinity reduced to a range of 0‰ to 0.2 ‰ (Ochuka et al., 2019a) from a range of 0.5‰ to 0.7 ‰ in June 2001 to May 2002. Several other ephemeral rivers (e.g Ol Arabel, Makutan, Tangelbei) drain the lake and were not included in this study, but still their contribution can be of significance during the prolonged rainfall events causing a rise in water levels.

4.2 Trace and Major Elements Concentration in River and Lake Water

In general, the arid and semi-arid lands suffer from significant climate variability which has huge implications on water resources (Koskei et al., 2018). The total chemical composition reflects the waters of the central rift valley, which are of the Na- HCO₃⁻ - Cl⁻ type, with the lakes being the most highly mineralized and alkaline, and rivers the least. In this study waters of L. Baringo had undetected levels (i. e below detection level) of Co, Ni, and Cd in water, but with measurable Cu, Zn, Pb and Cr. Tarits et al. (2006) found a higher range of dissolved Cu and Zn in L. Baringo water. In this study, the high pH of lake and river waters causes precipitation of cations with reduced free ions as shown by much lower dissolved concentrations reported in earlier studies. The highland areas and irrigated lowland areas traversed by the two perennial rivers are fertile agricultural lands where leached fertilizers and soil sourced metals contribute to increased accumulation of metals downstream. Also, around volcanic formations, mineral weathering and dissolution is responsible for the increased ionic contents in surface and groundwaters within the areas of study. The mineralogy and elemental geochemistry of volcanic rocks shows a high percentage content of the oxides MnO, CaO, Al₂O₃, Fe₂O₃ (Wilke et al., 2020). The sudden flushes of highly turbid running waters into the lake and enhanced solute transport adds to the loading of river and lake water with high contents of complex Al, Fe and Mn oxides and hydroxides from the weathering of the alumino-silicate minerals. The Lake Baringo surface water concentrations of Fe, Mn Al were all above the level recommended for aesthetic water quality (EPA, 2019; WHO, 2017), but the rest of the regulated trace metals were below the set drinking water standards. A study of Tarits et al. (2006) in August 1996 and Walumona et al. (2021) recorded a much higher range of dissolved fluoride, chloride and calcium contents in the lake, hot spring and river water, when compared to this study. The river sediment F contents were much

lower and within a small range (0.18 to 0.43 mgKg⁻¹) in comparison with the high levels from the rift volcanic rock minerals. The geological formations in the catchment area of the central Kenya rift influence the underground water chemistry, and water quality of some underground sources is unacceptable due to high F concentrations from weathering and chemical mineral dissolution. Groundwater sources and saline lakes water (Olaka et al., 2016; Mwiathi et al. 2022) contained variable but relatively higher F levels (0.02 to 75 mgL⁻¹) than river waters (0.2 to 9.2 mgL⁻¹). This is of concerns, as chronic ingestion of high doses of F has been linked to the development of dental fluorosis, and in extreme cases skeleton fluorosis (Raju 2017; IPCS 2002; WHO, 2006). The high concentration of suspended sediments in both systems implies increased and variable mineralogical compositions contributing to the high elemental concentrations in water. This common source is also reflected in the significant inter elemental associations especially between zinc, nickel, copper, chromium, manganese, aluminum and iron in water. Longer residence times and reduced volumes in lake water means enhanced levels of Cl⁻ and F⁻ from evaporative concentration of the surface waters. The higher and different Cl⁻ concentrations in both systems in March 2008 than February - March 2009 may be due to the reduced volume and the increasing evaporative concentration during the persistent dry conditions in 2008 than 2009. To address the challenges of exposure to high flouride in surface water sources within the area, simple affordable deflouridation systems and commercial reverse osmosis can be employed to alleviate problems related to exposure to the naturally high flouride levels in water.

4.3 Trace and Major Elements Concentration in River and Lake Sediments (Dry Weight Basis)

Surficial lake and river sediments are of relatively low organic matter (0.04 to 3.44 % and 0.18% to 1.06% as percentage LOI in lake and river sediments respectively). The lowland and mid altitude areas are mostly woodlands with sparse savanna type of vegetation. Therefore, there is an apparent dominance of allochthonous than autochthonous materials. With increasing erosion of surrounding soils and low in lake primary productivity results in a more sandy – clay lake sediments deposits and of a relatively low organic matter content. In a separate study, Koskey et al. (2020) observed a high content of Cd, Cu and TOC in lake sites with high percentage of silt and clay in sediments, but here were no significant differences in Cd and Hg contents. The prevailing alkaline conditions and presence of presence of hydrated oxides of iron and manganese oxides, carbonate and silicate colloids and other organic complexes are efficient sorbents for metal ions (often regarded as efficient metal scavengers) which contribute to sedimentary metal accumulation. In this study, anthropogenic sources contribute to sediment Cd, Zn and Mn contents in river and lake sediments, and the rest of the elements in both systems are lithogenic. The concentrations of Fe and Co in surface sediments of L. Baringo are of the same magnitude with those of Lake Naivasha (Olando et al., 2020), and are of lithogenic sources. Comparatively lower levels of Cu, Hg, Cd, Pb, were found in lake water by Mbuthia, (2015), and only Zn, Pb, Fe, Cd, Cu (Nyingi et al., 2016; Mbuthia, 2015) were accumulated in fish tissue. The lake river sediment recorded a wide range of Hg contents, but with lower enrichments (< 2, indicating moderate pollution) and were unpolluted according to the Igeo index. Although aqueous contents were not provided in this study, other studies within the lake (Mbuthia, 2015) report a mean ($\pm$ S.E) concentration of 0.003 $\pm$ 0.002 ppb (Ol Kokwe area) to 0.001 $\pm$ 0.001 ppb (R. Molo mouth area) of total Hg in L. Baringo water. These concentrations are still much lower than the levels recommended (6 ppb) for drinking water by WHO (2017), and are reflected in the extremely lower levels found in lake sediments compared to river sediments. Car washing and alluvial gold panning and amalgamation with mercury during extraction along the rivers are other potential sources of metals and Hg mercury in river sediments. Storm water, runoffs and direct human activities in rivers (car washing activities, sand mining, and their use as receptors of wastes) contribute to the chemical loads in water and sediments. Therefore, concentrations of trace elements should often be monitored in natural surface and ground water sources; public drinking water supplies, and water for various uses (e.g irrigation water, aquaculture production e.t.c), to ensure there is no human exposure to the toxic elements and their compounds.

5. Conclusions

Prior the 2010 lake water level rise, the lake drawdown revealed significant influence on the water quality. The mean levels of Fe, Al, and Mn in lake and river water exceeded the aesthetic guideline values for drinking water, while fluoride in lake and warm spring water were elevated. In general, and on the basis of EF's, the lake surficial sediments exhibited depletion to minimal enrichment with the geo-accumulation index indicating moderate sediment pollution with respect to Ni, Hg, Co, Cu and Zn; and only Mn levels indicated moderate to strong pollution. Similarly, the geo – accumulation index results indicated up to moderate pollution of Mn, Cu, Cd, Ni, Hg and Co in surficial river sediments. Therefore, the findings indicate that anthropogenic sources

contribute to sediment Cd, Zn and Mn contents in river and lake sediments, and the rest of the elements in both systems are of lithological origins.

Finally, the rising lake water levels and flooding of shoreline areas needs continuous studies to clearly understand the ecosystem response and develop better strategies for mitigation.

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Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Author has declared that no competing interests exist.

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