Status of Trace Elements' Concentrations in Lake Baringo's Catchment in Kenya: A Review

ABSTRACT

Lake Baringo is one of the two shallow freshwater rift valley lakes characterized by a topographically closed basin, alkaline waters, turbidity, high evaporation rates and seasonal water level changes. The lake water is an important water source, and it sustains a small fishery and high biodiversity. The lake basin is located at a relatively lower altitude in a semi-arid area, along the floor of the rift valley, and therefore it is greatly influenced by materials derived from the steep gradient landscape of the catchment area, anthropogenic activities and geological formations. Cadmium, lead, arsenic's inorganic species, and mercury are the heavy metals which are considered to be the most toxic amongst the non-essential trace elements to humans, animals and plants in the environment. During the "Anthropocene" epoch there have been growing concerns as regards metal pollution sources due to increased generation of electronic wastes, uncontrolled solid waste disposal and untreated wastewater, abandoned and active mining operations. Additionally, the remote areas in Kenya and other countries are also exposed to transboundary atmospheric deposits, leaching of terrestrially applied agrochemicals and increased mineral weathering processes which contribute variable loads of metallic contaminants into surface and underground water sources. Potential sources, occurrences and accumulation of trace elements in the aquatic environmental samples are of concerns worldwide due to their known toxicities. Trace elements such as Cd, As, Cu, Fe, Hg, Cr, Mn, Ni, Zn, Sn, and Pb are contaminants known to cause severe toxicity to aquatic organisms and fish species. Increased exposure of toxic trace elements to humans emanates mainly from drinking water, consumption of aquatic species and food intake which leads to accumulation of elevated trace elements, and hence the need or stringent regulation of toxic elements in water, food and other products. Although varying and low levels of trace elements are often reported for most natural lake waters, and appreciably higher amounts in sediments, the bioavailability is what determines actual toxic effects. Therefore, being a Ramsar site, there is need to develop information and database for monitoring water quality changes and understanding anthropogenic impacts on the river and lake ecosystem. This report reviews information on the status of trace elements concentrations in the different lake compartments from previous studies, and the potential implications on water quality, ecosystem health and sustainability.

Keywords: *Lake Baringo; Aquatic ecosystem; Trace elements; Metals; Sediments; Water quality; Fish species.*

1.INTRODUCTION

Lake Baringo is a freshwater lake, among the several great East African rift valley lakes, which are located in the floor of the eastern arm of the rift valley which extends northwards from Lake Natron to L. Turkana, in the southern and northern national boundaries of Kenya respectively. The lake lies at 965 meters above sea level (Aloo 2002). It is a relatively shallow and topographically closed basin (Nyakeya et al. 2018ab; Odada et al. 2006; Britton and Harper 2005) which deepens towards the north. Lake Baringo in Kenya (East Africa) is a Ramsar site (Ramsar 2002), famous for its high bird diversity, hippopotamus and crocodile populations. The lake once supported a substantial fishery, and it also represents a precious source of freshwater in a semi arid area (Wahlberg et al. 2003). Small-scale fisheries contribute to food security and the eradication of poverty by providing food, income and employment to millions of people (FAO 2016). The fishery of Lake Baringois currently based on four species including *Orecochromisniloticusbaringoensis, Barbusgregori, B. lineomaculatus,* *Clariasgariepinus*and*Protopterusaethiopicus* (Nyamweya 2011; Aloo 2006; Mageria and Kibwage

2009).

Water resources management has often focused on satisfying increasing demands for water, without adequately accounting for the need to protect water quality and preserve ecosystems and biodiversity. Today, there is increased awareness on anthropogenic impacts and pollution threats on the surface water quality of natural lakes, rivers and underground waters sources, with many national standards and guidelines on solid waste management, air pollution, wastewater and effluent discharges, as tools for sound water resources management. Certain metals and metalloids are essential for plant growth and for animal and human health. With respect to plants, these are referred to be as micronutrients (Broadley et al. 2012) and include B, Cu, Fe, Zn, Mn, and Mo. In addition, As, Co, Cr, Ni, Se, Sn, and V are essential in animal nutrition. Micronutrients are also referred to be as trace elements since they are required in only small quantities, unlike major nutrients such as N, P, and K. In excess, trace elements can be toxic to plants (Broadley et al. 2012 Ganvir and Papadkar 2022), microbes, animals, and humans. Problems also arise when there is a deficiency in essential elements. Important trace elements in the environment are As, Ag, B, Ba, Be, Cd, Co, Cr, Cu, F, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Tl, V, and Zn. Trace elements in natural media are present at concentrations of less than0.1%. In biochemical and bio-medical research, trace element concentrations in plant and animal tissues are normally less than 0.01%. In food nutrition, a trace element is one that occurs at concentrations less than 0.002% (Adriano 2001).

Thirteen trace metals and metalloids are considered priority pollutants and they canbe derived from both natural (geogenic) and anthropogenic sources (Adriano 2005, 2001; Sparks 2005). (Table 1). Natural sources include parent rocks (Singh et al. 2023) and metallic minerals (metalliferous ores). Anthropogenic sources include agriculture (fertilizers, animal manures, pesticides), metallurgy (mining, smelting, metal finishing), energy production (leaded gasoline, battery manufacture, power plants), microelectronics, and sewage sludge and scrap disposal (Adriano 2001). Atmospheric deposition is a major mechanism for metal input to plants and soils. This is particularly true in forest ecosystems, where metal contamination of soils is almost totally due to atmospheric deposition. Volatile metalloids such as As, Hg, Se, and Sb can be transported over long distances in gaseous forms or enriched in particles, while trace metals such as Cu, Pb, and Zn are transported in particulate phases (Adriano 2001; Adriano et al. 2005). In terrestrial ecosystems, soils are the major recipient of metal contaminants, while in aquatic systems sediments are the major sink for metals. These contaminants can then impact freshwater and groundwater systems (Ganvir and Guhey 2023). Freshwater systems are contaminated due to runoff and drainage via sediments or disposal, while groundwater is impacted through leaching or transport via mobile colloids (Adriano 2001; Adriano et al. 2005).Micro contaminants (essential and non-essential elements; persistent organic pollutants and microbiological contaminants) are of great concerns to the public health sector as they have known toxic effects in exposed aquatic organisms and humans, and result in a lowered water quality. In the environment, natural concentrations can be magnified through accumulation in soils, sediments and biota, leading to levels above allowed thresholds for different environmental compartments (Poste Papadkar et al. 2024; 2023; Jeong et al. 2023; Yang et al. 2018; Poste et al. 2015). Total mercury, methyl mercury, cadmium, lead, arsenic, PCB, DDT and metabolites, organochlorines (e.gdieldrin) and dioxins are among the most regulated industrial

Table 1. Inputs of trace metals from various anthropogenicsources (Adriano 2001).

Element	Natural source or metallicmineral	Anthropogenic sources	Common forms in wastes
Ag	Freemeat (Ag) chlorargyrite(AgCl) acanthite(Ag_2S), copper, lead, zinc	Mining, photographic industry	Agmetal, Ag–CN complexes; Aghalides; Agthiosulfates
As	Metal arsenidesand arsenates, sulfide ores (arsenopyrite), arsenolite(As_2O_3), gases,geothermal springs	Pyrometallurgicalindustry,spoil heaps and tailings, smelting, wood preserving, volcanic fossil fuel combustion, poultrymanure,pesticides, landfills	As oxides (oxyanions) organo-metallic forms, $H_2AsO_3CH_3$ (methylarsinicacid), $(CH_3)_2$-AsO_2H (dimethylarsinicacid) (methylarsinicacid), $(CH_3)_2$-AsO_2H (dimethylarsinicacid
Be	Beryl (Be3Al2Si6O18), phenakite(Be2SiO4)	Nuclear industry,electronic industry	Be alloys,Bemetal, $Be(OH)_2$
Cd	Zinccarbonate and sulfide ores, copper carbonate and sulfide	Miningand smelting, metal finishing, plastic industry, microlectronics, batterymanufacture, landfillsand refusecomplexes, disposal, phosphate fertilizer, sewagesludge metal scrapheaps	Cd^{2+}ions, Cd halidesand oxides, Cd–CN complexes; $Cd(OH)_2$, sludge
Cr	Chromite($FeCr_2O_4$), eskolaite(Cr_2O_3)	Metal finishing, plasticindustry, wood treatment refineries, pyrometallurgical	Cr metal, Cr oxides (oxyanions), Cr^{3+}

		industry, landfills, scrapheaps	complexes with organic/inorganic ligands
Cu	Nativemetal (Cu), chalcocite(Cu_2S), chalcopyrite($CuFeS_2$),	Miningand smelting, metal finishing, microelectronics,wood treatment, refuse disposal and landfills, pyrometallurgical industry, swinemanure,pesticides scrapheaps, mine drainage	Cu metal, Cu oxides Cu humiccomplexes, alloys, Cu ions
Hg	Nativemetal (Hg), cinnabar(HgS), degassed from Earth's crust and oceans.	Miningand smelting,electrolysisindustry, plastic industry, refusedisposal/landfills, paper/pulp industry,fungicides	Organo-Hg complexes, Hghalides and oxides, Hg^{2+}, $(Hg2)^{2+}$, Hg^0
Ni	Ferromagnesian minerals, ferrous sulfideores, pentlandite	Iron and steel industry,miningand smelting, metal finishing, microelectronics, batterymanufacture	Ni metal, Ni^{2+}ions, Ni amines, alloys
Pb	Galena(PbS)	Miningand smelting, iron and steel industry, refineries, paintindustry, automobile exhaust, plumbing, battery manufacture, sewagesludge,refuse disposal/landfills, pesticides, scrapheaps	Pb metal, Pboxides and carbonates Pb-metal–oxyanioncomplexes
Sb	Stibnite(Sb_2S_3), geothermal springs.	Microelectronics, pyrometallurgical	Sb^{3+}ions, Sb oxides andhalides
Se	Free element(Se), ferroselite $FeSe_2$), uranium deposits, black shales, chalcopyrite-	Smelting, fossil fuel combustion, irrigation waters	Seoxides (oxyanions), Se-organiccomplexes

	pentlandite-pyrrhotite deposits		
Tl	Copper, lead, silverresidues	Pyrometallurgicalindustry microelectronics,cementindustry	Tl halides Tl–CN complexes
Zn	Spharelite(ZnS) willemite(Zn2SiO4), smithsonite(ZnCO3)	microelectronics,cementindustry textile, microelectronics, refusedisposal and landfills, pyrometallurgicalindustry, sewagesludge, pesticides, scrapheaps	Zn metal,Zn^{2+}ions, Zn oxides, carbonates and alloys.

Source: Adriano(2001);mineral nomenclature after MandarinoandBack(2004) and environmental contaminants, with tolerance and critical limits in fish and fish products set to protect consumers (EC 2001; FDA, 1998).

Increasing amounts of chemicals may be found in predatory species as a result of biomagnification, which is the concentration of the chemicals in the higher levels of the food chain. Or, they may be there as a result of bioaccumulation, when increasing concentrations of chemicals in the body tissues accumulated over the life span of the individual (Huss et al. 2003).

There is increasing awareness and concern over the environmental and biological effects of elevated concentrations of toxic and bioavailable heavy metals and residues of persistent organic substances in most natural aquatic ecosystems. Even in relatively remote lake ecosystems located in hot and arid climates, such as L. Baringo, the inputs from two permanent rivers traversing rich upper agricultural areas and key towns, and lower steep areas under sparsely vegetation cover, with highly degraded soils are thought to contribute significant amounts of materials into the lake. In most countries, soils have been used as a repository for all types of industrial and chemical solid wastes and obsolete pesticides disposal. Also increasing use of banned and persistent organic chemicals within the lake catchment area causes increased uptake and accumulation in aquatic organisms in rivers and lakes. Such data on accumulated organic residues concentrations in sediments, biota and fauna, surface and underground waters, is still inadequate due to lack of continuous monitoring in these ecosystems. Also, concerns about factors influencing the metal aqueous concentrations, speciation and toxicity, bioavailability have not been well addressed in some natural waters. The area is known for its huge fluoride deposits and other minerals. The extent of the metals elements modification by anthropogenic activities has been explored in many studies. In volcanic formations and areas known to contain geothermal energy sources, like Lakes Baringo and Bogoria, metal sulphides can released from geothermal fluids, although such assessmentdata is only for geothermal development and consequences in adjoining aquatic ecosystems need to be prioritized. Usage of Hg in gold amalgamation and recovery techniques is also of concerns in increasing exposure hazards to artisanal gold miners, immediate ecosystems and atmospheric emissions. Anthropogenic transport and deposition are important processes in the global cycling of trace metals. Although the atmospheric flux of tracemetals is a major component of both marine and terrestrial environments, very studies report on these sources around lake ecosystems.

Elsewhere and in other natural waters (Poste et al. 2015; Orata et al. 2008; Oluoch-Otiego, et al. 2016; Omwoma et al. 2015; Nnamuyomba, 2014; Orata et al. 2008; Igwegbe et al. 2014), evidence of low levels of priority metal (cadmium, mercury, Methyl Hg, lead, Arsenic) and organic residues (Dichlorodiphenyltrichloroethane and metabolites; polychlorinated biphenyls, dioxins; organochlorines; organophosphates) accumulated along aquatic food chains exists. However, only few data is available for L. Baringo (Campbell et al. 2003) and neighboring natural aquatic ecosystems (Mungachia et al. 1992; Muohi 2007; Jirsa et al. 2013; Bonzongo et al. 1996; Bettinetti et al. 2011; Lincer et al. 1981; Ogendi et al. 2014) and fish culture systems (Omwenga et al. 2016). Other organic contaminant residues that can potentially accumulate along the trophic levels in inland water bodies and cause toxic effects and stress to aquatic species. Lindanewas found to have the highest frequency of occurrence amongst other organochlorines studied in fish from pond culture systems (Omwenga et al. 2016) with a mean concentration of 0.723±0.011 μg/kg (muscle tissue); 0.013±0.033 μg/kg (liver tissue); 0.169±0.45 μg/kg (gonad tissue); 0.022±0.046 μg/kg (brain tissue) in Machakos county. Lesser flamingos (*Phoeniconaias minor* Geoffrey) which are associated with nearby alkaline saline rift lakes are specialized consumers of *Arthrospira fusiformis* (Voronichin) Komarek& Lund (formerly called *Spirulina platensis* (Voronichin), a cyanobacteria (Codd et al. 2003; Krienitz et al. 2003). Being the main diet of Lesser flamingos (Owino et al. 2001) these birds tend to migrate in response to changes in Arthrospira biomass in Lakes Nakuru and Bogoria (Nasirwa 2000), and nutritional composition and quality of phytoplankton community influence their temporal and spatial abundance (Kaggwa and Gruber 2013).

Using biological indicators such as plants for monitoring both air and water pollution has also been recognized and used to a limited extent over the years. Aquatic macrophytes showed higher concentration factors of accumulated Cd, Zn, Pb, and Cu than sediments from the same site (Fayed et al., 1985). Mosses and lichens strongly sorb metals ions from the air and water and are useful in detecting atmospheric and aquatic lead and other metal contamination (Goodman et al. 1971; MacLean and Jones 1975; Tyler 1976). Leaves and twigs of woody plants have also been used to indicate atmospheric pollution (Smith 1972). On the other hand, responses of macro-invertebrates assemblages (Kobingi et al. 2009), as bioindicators of biological integrity of effects of different land uses, especially urbanization, in inflowing rivers and streams provide valuable information on organic pollution and other impacts. Currently, urban domestic and industrial wastewater effluents are sources of concern of trace organic and inorganic residues some of which are toxic, persistent, carcinogens, and endocrine disruptors, which are included in water quality assessments (Kimosop et al. 2016; Chirikona et al. 2015). Their discharge into the environment results from the ubiquity of use in medical, veterinary, and agricultural practices. Some of the effects of antibiotics include development of antibiotic-resistant bacteria, making it difficult to treat diseases, variation in natural microbial communities, and enzyme activities. In the interests of safe and clean water sources, safe fish for direct human consumption and for non-food products, stringent hygiene measures have been adopted at national and international trade levels.

Therefore, the determination of metals and organic residues distribution and monitoring in lake ecosystem and other environmental samples is valuable because of the known and documented toxicity effects. Currently economically exploited fish species from L. Baringo includes *Clariasgariepinus, Oreochromisniloticusbaringoensis, Protopterusaethiopicus, Labeocylindricus,* and*Barbusintermediuslineomaculatus* (Kembenya et al. 2014; Omondi et al. 2013). Recent studies link the reducing catches of the endemic *O. niloticus*with increasing turbidity of the lake over time, although spatially, environmental variables exhibited a small difference which was attributed to the lakes small size and shallowness, and also the daily mixing of the lake water by wind action (Omondi et al. 2014). Aquatic species serve as good indicators of metal contamination. Some of the priority pollutants that have been found in variable levels in the main compartments of Lake Baringo ecosystem includes Cd, Cr, Al, Fe, Mn, Pb, F, Se, Cu, and organic pesticide residues. Therefore, the primary objective of this report was to review data on distribution and any trends of heavy metals in L. Baringo ecosystem.

2. LOCATION AND GEOLOGICAL SETTING OF LAKE BARINGO BASIN

Study area and geological formations

Lake Baringo (Fig. 1), a freshwater lake in the eastern arm of the great rift valley in Kenya, and lies in the rift floor, at an altitude of about 965 meters above sea level, between latitude (00˚30’N and 00˚45’E) and longitude (36˚00’E and 36˚10’E). The Lake is a wetland of international importance, and wasdesignated a Ramsar Wetland in 10th Jan 2002 (Ramsar Wetland).

The lake is a topographically closed basin. Recent hydrogeological evidence confirms the original assumption that some lake water is lost by underground seepage through the fractured lake floor (Beadle 1932; Onyando et al. 2005). Dunkley et al. (1993) estimated that this outflow could exceed 10^8 m^3/year. Scientific findings from several studies have associated the rift geological formations with high fluoride contents in underground water sources (Olaka et al. 2016), which compromises the desired natural water quality for human consumption.

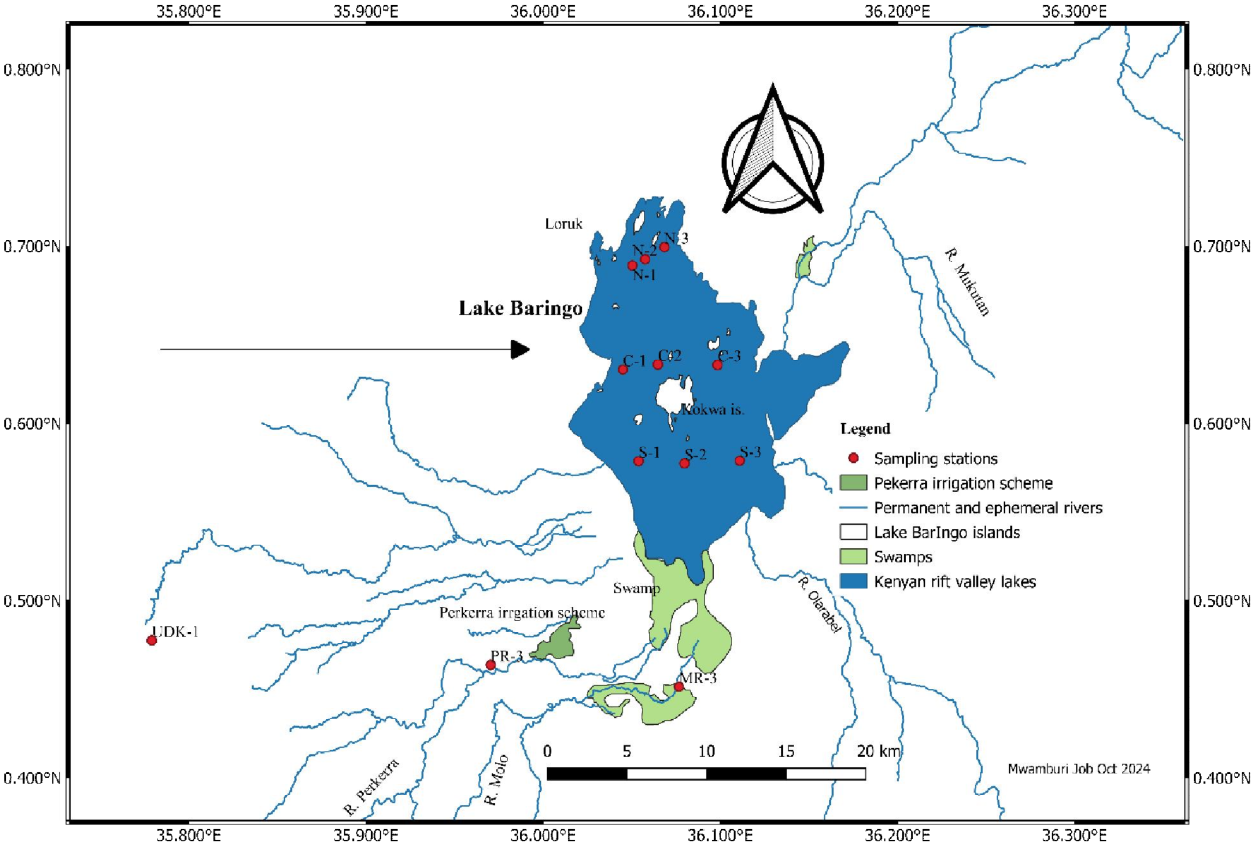

Fig. 1. Map of Lake Baringo showing the catchment area and the river drainage system.

The catchment area is 6820 Km2. Lake Baringo has five islands, the biggest being the Volcanic Kokwa. The Island is a remnant of a small volcanothat belongs petrogenetically to the Korosi volcano. This erupted during the Middle Pleistocene, approximately 2.6 million years ago (Cl’ement et al. 2003). On Kokwa island alkaline hot springs discharge into the lake (Beadle1932). The lake has a surface area of between 130 $Km^2$and 160 Km^2, with a variable waterdepth and physico-chemical characteristics, reflecting the high dry and wet seasonal influences in the semi arid climatic zone. Paleolimnological studies) have also been used to generate paleogeographic information and records of the past climatic conditions and variability in Lake Baringo (Kiage and Liu 2009; Renaut et al. 2000). The stratigraphic record from Lake Baringo reveals tow abrupt dry episodes at ca. AD 1650 and AD 1720 in East Africa led to drying up of the lake.

River drainage system and soils

Soils are clay and clay loams and the risk of soil erosion is high because of the soil properties (clay fills pores or seals the surface giving low infiltration capacity). Forty-six percent of the land in the district is too steep or too dry for agriculture and pastoralism is the main source of family income (Hickley et al. 2004). High water turbidity is also cited as a major contributorto reduced water quality. Although detrital sediment is washed into the lake throughout the year, the maximum influx occurs in August following the heavy rains. Winds then mix the loose sediments on the shallow lake floor generating very high turbidity (Oduor et al. 2003). Late Holocene to modern sedimentation in Lake Baringo is dominated by fine grainedsilicicclastics (Renaut et al. 2000). Most of the lake floor is covered by detrital muds and feldspathic silts that reflect the very high soil erosion rates in the catchment (Snelder and Bryan 1995; OostwoudWijdenes and Bryan 2001; Aloo 2002). The two permanent rivers dissect the highland agricultural areas and drier valleys before entry into the lake on the southern side, north of Loboi swamp and the hypersaline L. Bogoria, with known hotsprings. In their upper reaches, these rivers drain thick series of basalts, phonolites and trachytes of Mio-pliocene age, while downstream they flow across Pleistocene trachyphonolites, pyroclastic deposits, and siliciclastic fluvial sediments. The eastern part of the Baringo watershed, drained by the rivers Mukutan and OlArabel , is formed by a succession of basalts and phonolites of Miocene age, several hundreds of metresthich, which form the Laikipia fault escarpment. Although detrital sediment is washed into the lake throughout the year, the maximum influx occurs in August following the heavy rains. Winds then mix the loose sediments on the shallow lake floor, generating very high turbidity (Oduor et al. 2003).

Climatic conditions

Lake basinShallow lakes (< 5m deep) are characterized by varied environmental constraints (Talling2001). Water levels in L. Baringo fluctuates with time and responds to alternating wet and dry periods. This is reflected in changes in water characteristics (Ouma and Mwamburi2014; Omondi et al. 2014; Oduor et al. 2003; Schagerl and Oduor 2003) as rains normally lead to increased water inflows and lake surface area, sometimes accompanied by lakeshore flooding. The most recent rise in water levels was reported in 2011. The impact of the flooding in L. Baringo has seen the area under water rise from 143,6 Km^2 in January 2010 to a high of 231.6Km^2 in September 2013, an increase of 88 Km^2 (61.3% increase by area). In December 2010, the lake level had risen by 28.8 Km^2 (Onywere et al., 2013). The mean depth of L. Baringo is reported to have been 5.6m in the 1960s (Ssentongo 1995), over 8m in the late 1970s (Meyerhoffunpubl.), decreasing to just below 3m in 1994, but reaching 4.5m again in 1998 following El Nino rains. At the time of 2003 bathymetric survey, the mean depth was 2.65 m (Hickley et al.2004). Between April 2008 and March 2013, Omondi et al. 2014 reported a mean depth of 3m with the deepest point being 7m at high water levels. The mean (±SE) lake water depth ranged from 5.31±0.13 m to 6.35±0.12 m, (Omondi et al. 2014), which is close to the maximum depth of 8m reported by Schulter (1993) and Odour (2000). The annual rainfall is between 500 mm and1000 mm in the catchment and is highly variable (Odour 2000). Lake Baringo experiences very high annual evaporation rates of 1650 to 2300 mm (Odada et al. 2006) and its survival depends on theinflows from rivers originating from the hilly basin where rainfall varies from 1100 to2700 mm. The lake is fed by several ephemeral rivers including OlArabel, Mukutan, Endau, andChemoron, while Molo and Perkerra are permananet rivers.

Catchment landuse and impacts

The freshwater from the lake and rivers is used for irrigation and domestic uses. Dams and irrigation infrastructure support these uses along the river drainage basin and at lower edges of the lake respectively. However, it is not well established how changes in flow impacts on the riverine ecology, especially fish species. The type of local geology, topography and meteorology (Onyando et al. 2005) coupled with anthropogenic activities; especially overgrazing and deforestation expose the Lake Baringo catchment to high erosion. According to Lwenya and Yongo (2010), livelihoods of communities around the lake are centered on livestock keeping, cultivation and charcoal burning, factors which enhance land and water degradation. Sedimentation and turbidity have been found to be significant contributors to declining population of aquatic organisms (Henley et al. 2000). The resulting sediments and suspended solids inflow influence the lakes's depth and substratum. The muddy substratum in the south of the lake is not suitable for benthopelagicpotamodramous*Labeocylindricus* that prefers rocky habitats (Nyamweya et al. 2012).

3. MATERIALS AND METHODS USED

The review presented used an approach for systematic literature review to search for documented information in scientific journals using the common search engines (Science direct, google scholar and scopusetc); and those used for analysis were evaluated according to table 2.

Table 2. A table showinghow theinternet searched and retained publication information was extractedfor analysis.

No.	Criteria	Categories	Justification
1.	Publication year	Between 1980-2021	Studiesbefore1980notused.Studiesbeforeand aftergazettementas aRamsarwetland
2.	Name of publication	Scientific journal articles /Technical reports	Distribution ofthe work
3.	Location of studyarea	Watershed/basin name	LocationofsystemwithinL.Baringo basin/watershed
4.	Types of data sources	Primarydata	Field orsurveydata
		Mixed or otherdata	Otherdatareadilyavailableinexternaldatasets and not verified in thefield
5.	Method	Distribution	Spatial and temporal patterns
		Mapping	Visualization offield data
		Models	Predictive analyses
6.	Scale ofstudy	Patchy	10 - 10^2Km^2
		Local	10^2-10^3Km^2
		Regional	10^3-10^5Km^2
		National	10^6Km^2
		Global	. >10^6Km^2
7.	Modeof assessment	Qualification	Reportingon the status andchanges on the environmental/chemical qualityandecological health.
		Quantification	Reportingconcentration levels in each specific media/species in universallyaccepted / conventional standard

		Mapping	Studies with spatial visualization offield data and futureprediction
		Modelling	
		Combined	Used morethan oneof the above
8.	Types of ecosystem services	Cultural ecosystem services	Both tangible and intangible benefits derived from the ecosystem (recreation; aesthetics;
		Provisioning ecosystem	Products obtained from ecosystem(e.gwater, wetland
		Regulating ecosystem services	Silt &sediment trapping;Pollutant control; Flood control;Climatemitigation/rainfall; Hydrological recharge/discharge
		Supporting ecosystem	Basicecosystem servicesthat maintain the generation ofallotherecosystem

			(nutrient cycling; soil formation buffering; pollination e.t.c)
9.	Number of elements /or groupof elements assessed	Essential elements	Climatic and anthropogenic impacts; Water, air, soiland sediment qualityregulation; Waste management ;water purification; health risks
		Non-essential elements	
		Radioactive elements	
		Major elements	
10.	Expansion of sitespecific knowledge	Studies	Cleaner technologies /Environmental friendly waste treatment, material recyclingoptions at source; Siterehabilitation and future management / alternatives cost effective
11.	Methodological development	To develop new methods or check	Advanced morereliableand sensitive environmentallyand userfriendly, simple, and cost effectivemeasurement
12.	Purposeof publication	Management option	To recommend management options to sustain ecosystem services
		Policysupport	Discussed futurepolicyissues
13	Difficulties mentioned	Methodological	Uncertainties on theresultdueto application of unclear / orless developed method.Lack of implementingrobust QC/QAmeasures; Sample
		Other	Uncertainties linked withlack of conceptual clarity
		Data	Primaryand secondarydata sourcequalityand scarcitythat challenges

The resultsdiscussedinthis reportwereobtainedfromseveralsurveysconductedbetween2007and 2021 inL.Baringo basin. Thesampling andanalysismethodsusedforthedeterminationofmetalsfromdifferentstudies andenvironmentalsamplesare shownintable3.Differentanalyticalprocedures,techniquesand analysisequipmentswereemployedingeneratingtheconcentrationlevels,butinmostcases AASwas the main analytical equipment.Watersampleswerecollectedfromthesurfaceandbottomusing apre- cleaned watersampler.In most of the surveys, the bottomlakesediments were retrievedusing apre-cleanedEkmangrab sampler as is the case for most of the documented shallow lacustrine sediment studies.

Table 3. Procedures used in digestion and extraction oftrace elements from differentenvironmental samples.

Surfacewater

Elements **Equipment** **Sources**

1.Surfacewater (Trace elements (Cr, Cd,Hg,Zn,Ni, Pb, As, Cu). -Yanget al. 2017.

2.Filtered surfacewater,acidified, filtered; 50mlevaporated to 20ml; Traceelements (Cu, Fe,Zn, Cd, Pb). (FAAS). Nyingi et al. 2016.

3. Filtered surfacewater(0.45µm). (AAS). Mbuthiaet al. 2014.

4. Filtered surfacewater(0.2 µm filters); Major ions&traceelements (K, Ca, Mg, Na, Al,Fe, Sr, Ba-ICP-AES); (Cd, Cu, Cr, Al, Pb, Zn). (Perkin ElmerElan 5000ICP-MS) Tarits et al. 2006.

5. Filtered surfacewater500ml(0.45µm Milliporefilters); Digestedusing5ml11.1MHNO3; 10ml 16.3MHCl.; Trace elements (Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb,Sn, Zn) .(FAAS-Perkin Elmer) Ochienget al. 2007.

6. Surfacewater(Traceelements Cd, Cu, Hg) ChepkorirK. J. 2015.

Surfacelakesediments

1. Surfacesediments Trace elements (Cr, Cd,Hg,Zn,Ni, Pb, As, Cu) Yanget al. 2017.

2. Surfacesediments (Traceelements Cd, Cu, Hg) ChepkorirK. J. 2015

3. Digested with using5ml11.1MHNO$_3$;at 95Cfor1hr; centrifuged; supernatant analysedfor trace elements (Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn, Zn); (FAAS-Perkin Elmer) Ochienget al. 2007

Samples of fishtissues

1. Fish tissuedigested in10mlmixtureHNO andHClO$_4$, ratio 3:1v/v); Trace elements (Cu,Fe,Zn, Cd, Pb) (FAAS) Nyingi et al. 2016.

2. Fish tissuedigested usingHNO3; HFmixture(THg, Cu, Cd,Zn); (AAS) Mbuthiaet al. 2014

3. Fish muscle tissue; AFS&purgeprocedure; (Total THg) Campbell et al. 2003.

4. RESULTS AND DISCUSSION

METALS IN LAKE SEDIMENTS AND SOILS

There are few documented studies on soil metal concentrations, but with an increase in studies on the metal contents within the freshwater lakes (Lakes Baringo and Naivasha) and other rift valley saline alkaline lakes ecosystem.Eleshwere, studies show that contaminated mine soils are important sources of trace metals in the environment (Ahmad et al. 2021; Dusengemungu et al. 2022). However very few studies report on these environmental samples, similar to the areas around Lake Baringo basin.

TRACE ELEMENTS IN LAKE WATER

The lake water is characterized by high pH and conductivity. The distribution of trace elements in lake water, for both dissolved and total concentrations shows wide range for most elements (Table 4). Aqueous contamination represents a crucial environmental issue, especially when elements are in high concentration in the bioavailable forms. WHO health based limit guideline values for drinking water are shown in table 5 for some of the regulated elements, and reference made on the NEMA guideline values (NEMA 2006).The mean and range values of Cd, Pb and Cr reported in diferent studies appear slightly above some of the guideline levels.

Toxic inorganic elements concentrations (Hg, As, Be, Ba, Pb, Ni, Sn, Cu, Cr, Cd, Ag, Se) in water are more prioritized due to the potential long term human health hazards and when in excessive levels tend to interfere with many beneficial uses of the water, while excess concentrations of some trace metals (Al, Fe, Mn, Zn) are regulated in drinking water due to aesthetic properties (FAO). The concentration of Zn in tap water can be considerably higher than that in surface water owing to the leaching action of Zn from galvanized pipes, brass and other Zn alloys. Zinc imparts to water an undesirable astringent taste and in concentrations in excess of 5ppm. The water may appear opalescent and develop a greasy film on boiling (FAO). Macrophytes such as water hyacinth are considered good accumulators of metals, and useful in phytoremediation of wastewaters containing high levels of metals. Such information on lake macrophytes is lacking, but could also be prioritized in future studies.

In comparison, most of the surface water in rivers ,lakes and reservoirs is exposed to trace metals contamination through their use as dilutants of different types of treated and untreated waste water sources besides the natural inputs from the surrounding areas and different anthropogenic sources (Kinuthia et al. 2022; Prasad et al. 2022). The lack of effective reuse of wastewaters is associated with the transfer of metal loads to soils and recipient rivers and other drainage systems. Mercury and thallium levels in waste water around Nairobi industrial area were found above the USEPA limits and in soils samples from the open drainage channels recorded high Hg, Pb, Cr, Cd and Ni levels (Kinuthia et al. 2022). Elevated levels of Cd and Pb and lower Mn, Cu and Ni were recently reported for the hot springs of the saline-alkaline Lake Bogoria which is located on the southern basin of the Lake Baringo (Sunguti et al., 2024). The mean Pb and Cd concentrations were 0.06±0.04 ppm and 0.05±0.02 ppm respectively, hence the need for frequent monitoring of the ecosystem to protect the bird species, commonly associated with the saline lakes. High levels Iron (2.71 ± 0.5 mg/L), Mn (0.49 ± 0.06 mg/L), Pb (0.05 ± 0.04 mg/L) and Cr (0.06 ± 0.03 mg/L) in Mid-Cross river (Nigeria) water were found to be above permissible limits for drinking water, and the heavy metals concentration in fish tissue decreased from Tilapia zillii > Mormyrusrume > Clariasanguillaris > Chrysichthysnigrodigitatus except for Pb contents (Okogwu et al. 2009).

FLOURIDE ION CONCENTRATIONS IN THE LAKE BARINGO BASIN

Flouride mineral deposits occur in the Kenyan rift region, and presence of high F in rocks are often the source of high F contents in underground and surface water. Lake Baringo, being a water scarce area, the surface water of rivers, lake, together with other underground water sources are the common sources of F exposure to the surrounding communities. Fish are also exposed to F from the habitat. Although there is no much information on the fish F contents in L. Baringo and other lakes, Gikunju et al., 1992 and Gikunju 1992 reported on F levels (ranging from 1.3 mgKg^{-1} to 2.0 mgKg^{-1} wet weight) in fillets of tilapiine fish and *Micropterussalmoides* from Lake Naivasha. According to a study (Ganta et al., 2015), in a high fluoridated belt area, the amount of F present in the fishes is directly related to the severity of flourosis amongst fish consuming population suggesting fishes as contributing factor to flourosis depending upon dietary consumption. The mean F content of various river and sea fishes (bone, muscle and skin) ranged from 0.22 ppm to 151 ppm (river fishes) and 0.83ppm to 4.22ppm (sea water fishes). F showed more affinity towards the hard calcified tissues resulting in higher concentrations of F in the bones. In the Naivasha basin underground waters were found to contain highly variable F concentrations (0.22 mgL^{-1} to 74.98 mgL^{-1}), an indication of geochemical F enrichment in regional groundwaters (Olaka et al., 2016). This implies that the total contribution in human F intakes can vary greatly when other sources of intake such as food are taken into account. In general, long-term use of drinking water with F significantly above 1.5 mgL^{-1} can have serious effects on health. Dental and skeletal flourosis are associated with exposure to high F concentrations in drinking water (Fawell et al., 2006; Scher 2011). This observation is evident elsewhere, within the East African rift valley. In most areas of the Ethiopian rift valley, water is epidemiologically the most important source of F (75% - 90% of the daily intake) flourosis not only affects the people’s health, but also has serious economic and social consequences (Tekle-Haimanot et al., 2006; Tekle-Haimanot and Haile 2014).

TRACE METALS IN SUSPENDED AND BOTTOM SEDIMENTS

Accumulation and variations of metals in sediments shows most of the metal concentrations are below the freshwater sediment levels of potential biological impacts to aquatic organisms based on the consensus based SGQ values, although Pb, Cd and Ni exceeded the lower limit which recommends more site investigations. (Table 6).

Consensus based metal sediment quality guideline (SQG) values are often used to indicate probable sediment metal negative effects on the aquatic environment. Using existing SQG from other areas (Table 5), Cd, Pb, Zn and Ni levels were all above the TEC values but below the PEL, indicating that there are no signs of adverse effects to aquatic organisms.

Elsewhere, trace metal sources in sediments have been assessed using different sequential extraction procedures in order to try and understand how metals were bound on lake sediments and their potential bioavailability within the aquatic environment. Lake Victoria shoreline sediments were found to contain accumulated and elevated levels of Cr, V, Mo, Cu and Ti mainly from diverse anthropogenic sources (Ribbe et al. (2021). Near Jinja, industrial wastewaters caused particularly elevated contents of Cu in the sediments (70–121 mg/kg) which were about 3.5 to 6 times the geogenic background concentrations. Significant spatial and temporal variations were found in sediments of the Lake Togo-Lagoon of Aného complex (Ouro-Sama et al. 2021) in Southern Togo. The average trace elements in sediments during the dry and wet seasons 0.75 - 0.46 (Cd), 13.26 – 9.50 (Pb), 50.63 – 27.43 (Cr), 36.05 – 21.36 (Ni), 10.90 – 9.61 (Cu), 0.04 – 0.05 (Hg), 3.88 – 5.23 (As), 47.38 – 39.21 (Zn) and 766.74 – 910.08 (Mn) mg/Kg. These concentrations showed a strong spatial and seasonal variation for Cd, Pb, Cr, Ni, Hg and As.

TRACE ELEMENTS IN FISH SPECIES

Very few studies report on trace elements levels in lake flora and fauna. The concentration levels of Cd and Hg found in fish tissues (Table 7) were below critical limits for fish and fishery products. Lead levels were above these limits (0.2 to 1.7 ppm). There is no data on MeHg concentrations in the lake compartments. Mercury is known to be transformed to other methyl forms within the aquatic environment, but only total concentrations values are available. Although the fraction of methylmercury in sediments is small, the majority of Hg that accumulates in biota is in the methylated form (Langston 1982; Bernhard and George 1986) which is also the most toxic form.

Fish utilized for food provide consumers with several health benefits from the high levels of nutrient elements and fatty acids. One 30 gram serving of dried Silver cyprinid can provide a large fraction of the recommended daily intake for vitamin B12, the sum of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), calcium, zinc, and iron and could therefore contribute greatly to improve micronutrient status for many malnourished people. (Wessels et al. 2023). Utilizing the whole potential catch of Silver cyprinid would provide a significant daily source of vitamin B12, Ca, Zn and Fe to the roughly 33 million people living in the Lake Victoria basin (Wessels et al. (2023). However, fish species also accumulate non-essential trace metals. Dry and wet samples of the endemic silver cyprinid fish (Rastrineobolaargentea, Pelegrin, 1904) a commercial species from Lake Victoria was analyzed for Cd and Hg using the Atomic Absorption Spectrophotometer (AAS) Inductively Coupled Plasma – Mass Spectrophotometer ICP-MS techniques respectively (Mwirigi et al. 2022). The average whole body contents of Cd and Hg ranged from 0.008 – 0.028 Cd ppm and 0.093 – 0.339 Hg ppm respectively, but the levels were below the permissible limits of fish set by WHO (2010) and EC (2001). In another study, the mean concentration (mean ± SD) for Cd, Hg, Pb and As in the sun-dried Silver cyprinid from L. Victoria (Kenya) was 0.04 ± 0.01 mg/Kg (Cd), 0.03 ± 0.01 mg/Kg (total Hg), 0.07 ± 0.06 mg/Kg (Pb), and 0.52 ± 0.16 mg/Kg (total As) respectively (Wessels et al. 2023). The levels of Cd and Pb appear lower in Dagaa (except for total Hg) than in the fishes of L. Baringo. The results of bioaccumulated trace elements in fish tissue from different studies reveals a wide variation in the fish body burdens (Omar et al. 2013; Sobhanardakani et al. 2011; Okogwu et al. 2009; Shaaban et al. 2021; Wessel et al. 2023). The trace elements revealed species specific patters of accumulation which is attributed to the differences in fish size, habitat environmental conditions, trophic level and food sources types consume. Feral and cultured fish species (Nile tilapia, Oreochromisniloticus and Mullet Mugilcephalus in an inland lake, Egypt) accumulated different levels in the external and internal body organs; with much lower levels in M. cephalus liver, kidney and muscle tissues than those of Nile tilapia (Omar et al. 2013),

Trace metals and other organic residues from applied pesticides may potentially accumulate in cultured fish species through uptake during feeding and direct uptake from the ambient waters if the feed sources are not well monitored for chemical contaminants and other mycotoxins. However, in the study area fishing activities are mainly support by the capture fisheries when compared to the thriving cage aquaculture in Lake Victoria (Kenya).

Table 4. Metal (±SD) concentrations in water(µg/l)
SurfacewaterofL. Baringo(Total &dissolved concentration)

Cd	$2.0\pm0.01-5.0\pm0.60^{\&\&}$	$^{k}0.0216\pm0.00-0.0327\pm0.0242^{k}$	$0.01\pm0.001-0.19\pm0.003^{y}$
	nd-0.07^{v}		

Cu	5.0±0.11-20.2±1.20$^{\&\&}$	0.0157±0.00-0.0313±0.0213^{k} 0.02±0.01-0.15±0.02^{y} 3.09-5.89^{v}
Pb	nd-65.1±5.44$^{\&\&}$	nd-0.31±0.04^{y} 0.16-0.48^{v}
Zn	45.0±4.44-105.0±8.94$^{\&\&}$	-0.01±0.002-0.31±0.02^{y} 1.98-94.31^{v}
Hg	-	0.0019±0.0011-0.0031±0.00153^{k}
Cr	nd-188.0±10.2$^{\&\&}$	0.47-2.28^{v}
Ni	nd-38.0±7$^{\&\&}$	
Co	5.0±0.11-25.1±0.26$^{\&\&}$	
Ag	nd-185.0±10.1$^{\&\&}$	
Sn	nd-301.0±16$^{\&\&}$	
Mn	50.0±9.64-280.0±21.2$^{\&\&}$	
Al	317.2 - 1,562^{v}	
Fe	112.9 - 476.1^{v}	
Mg	2,400 - 2,900^{v}	
Ca	8,100 - 11,800^{v}	

Ochiengetal.2007dissolvedlevelsforfiveriftlakesNaivasha,Nakuru,Baringo,Bogoria,Elementeita= &&;Nyingietal.2016, dissolved values =y; Mbuthia et al. 2014, dissolved mean±SE values =k;Tarits, et al. 2006, dissolved =v;

Table 5. Guideline values of some of the regulated inorganic chemical element species in drinking water associated with significant health related effects (mg/L) (WHO 1984;2022; USEPA 2024 National primary drinking water regulations and NEMA 2006water quality regulations for domestic source water)

	WHO	**NEMA**	**USEPA (MCL)**
Hg	0.006	-	0.002
Cd	0.003	0.01	0.005
As	0.01	0.01	0.01
Cu	2	0.05	-
Pb	0.01 (P)	0.05	0.015 (TT)
Zn	-	1.5	-
Se	0.04 (P)	0.01	0.05
Cr (Total)	0.05	-	0.1
F-	1.5	1.5	4.0
Ni	0.07 (P)	-	-

P=Provisional value; MCL = Maximum contaminant levels; TT -=Treatment technique is required if the level is above this value;

Table 6. Metal (±SD) concentrations in suspended and bottomsediments (values in µg/gdrywt. unless specified)

Surficial sediments ofL. Baringo			**CBSQG**	
			TEC	PEL
Cd	3.5±1.6[m]	0.57±0.02 - 0.76±0.14[&&]	0.99	4.98
Pb	49.9±22.9[m]	16.57±1.44-21.83±1.08[&&]	35.8	128
Zn	127±20[m]	171.5±14.3 - 207.1±12.4[&&]	121	459
Cr	2.17 - 4.87[&&]		43.4	111
Ni	25.70±2.55 - 39.72±13.11[&&]		23	49
Co	0.69±0.04 - 1.38±0.12[&&]		-	-
Ag	nd-0.35±0.12[&&]		1.6	2.2
Mn	942±100-1,464±110[&&]		460	1100
Cu	15.12±1.44-20.95±1.56[&&]		31.6	149
Sn	23.39±0.84-43.41±1.34[&&]		-	-
Suspendedsediments ofL. Baringo[v]				
Al	102,626-132,250[v]			
Fe	93,086.7-102,885.3[v]			
Mn	1,548-1857.6[v]			
Cr	48,000-75,000[v]			

Ochiengetal.2007forfiveriftlakesNaivasha,Nakuru,Baringo,Bogoria,Elementeita=&&;Mwamburi2015=m;Tarits,etal.2006,suspendedsediments=v.;CBSQG=consensusbasedSQG(MacDonaldetal.,2000;TEC=Thresholdeffectconcentration; PEL=Probable effectconcentration

Table 7. Metal (±SD) concentrations infish species (µg/g wet wt.)

Fishspecies ofL. Baringo(muscle tissue, wwt=wet weight or dwt = dryweight)		
Cd	0.1±0.04-1.9±0.30[y]	3.565±0.06289[k]
Cu	nd-8.5±0.47[y]	0.4728±0.12455[k]
Pb	4.17±0.39-6.11±1.02[y]	nd[k]
Zn	17.1±4.36-29.5±4.28[y]	24.398±3.26165[k]
Fe	53.0±2.14-125.6±55.07[y]	-
Hg	[r]5.3-111.3 ng/g;	nd[k]

Nyingi et al. 2016, Tilapia, catfish, lungfish =y;Mbuthiaet al. 2014,Oreochromisniloticusbaringoensis, Clariasgariepinus, Protopterusaethiopicus=k; Campbell et al. 2003, fish species ofL.Baringo (Protopterusaethipicus, Labeocylindricus, Barbusintermediusaustralis, Orecohromisniloticusbaringoensis, Clariasgariepinus),values ofTHgin ng/gwwt.=r

METAL POTENTIAL HEALTH RISKS EVALUATION

Target Hazard Quotient (THQ) was used to assess non-carcinogenic health risks of metals to consumers. Calculated risks were made using assumed parameters and reference dose for each element (USEPA 2012).

THQ = {(EFr x EDr x IRfa x C) / (RfDo x BWa x AT)}; where
EFr = exposure frequency (365 days/yr);
EDr = exposure duration;
IRfa = food item consumption per day; For fish in Kenya 5.2 kg/yr per capita;
C = metal concentration in food item mg/kg;
BWa = body weight average 60-70kg for adults;
RfDo = reference dose mg/kg bdwt/day (USEPA, 2012)
AT = average time for non-carcinogen 365 days per year.

According to the THQ evaluation calculation a THQ of ≤1 indicates that there is no significant risk to health of consumer; whereas, a value greater than 1 indicates a possible health risks associated consumption of respective elements.There is a need to to develop a better database and factor in all the potential routes of toxic metal exposure for a more reliable exposure risk evaluation.

CONCLUSION

The protection of water resources is one of the main challenges for most lake managers due to the different uses of lake water, fluctuating water levels and high evaporation in a closed basin area, with increasing water demands for safe and clean water, especially in a water scarce semi- arid area such as Lake Baringo. Anthropogenic activities have significant impacts on trace elements in the basin, due to the agricultural activities and natural erosion,transport and loading of external aerial and surface runoffs in to the lake. Very few studies report on trace elements levels in lake flora and fauna. The concentration levels of Cd and Hg found in fish were below critical limits for fish and fishery products but lead levels were above these limits. There is no data on MeHg concentrations in the lake compartments. but only total concentrations values are available. The high alkaline pH and complexation of metal ions in the lake water could probably be a significant control in availability of most metals from the aqueous environment. Occurrences of the toxic elements (As, Cd, Pb, Hg) and F ions need to be monitored more frequently (surface and underground water, soils, sediments, aerial dust, fish, water hyacinth) to improve on the database on concentrations and loadings, and develop a sediments background levels data. The study report recommends detailed studies and frequent monitoring to update the trace metal database and allow comprehensive risks evaluation.

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DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

REFERENCES

Adriano, D. C., Bolan, N. S., Vangronsveld, J. & Wenzel, W. W. (2005). Heavy metals, In: D. Hillel (ed.) Encyclopedia of soils in the environment, Elservier, Amsterdam, pp. 175 - 182

Adriano, D. C. (2001). Trace elements in the terrestrial environment, 2nd Edition, Springer, Verlag,New York.

Ahmad, W., Alharthy, R.D., Zubair, M. Ahmed, M., Hameed, M. &Rafique, S. (2021). Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk. Scientific Reports, 11, 17006

Aloo, P. A. (2002). Effects of climate and human activities on the ecosystem of Lake Baringo. In: Odada, E. O., Olago, D. O., (Eds.), The East African Great Lakes: Limnology, Paleolimnology and Biodiversity. Advances in Global Research 12. Kluwer Academic Publishers. Dordrecht. pp.335-348.

Aloo, P. A. (2006). Fishery industry in Kenya: Towards the development of a National policy. Food and Agricultural Organization of the United Nations (FAO), Nairobi, 110pp.

APHA (1985). Standard methods for the examination of water and wastewater. 16th Edition. American Public Health Association (APHA) American Water Works Association, (AWWA) Water Pollution Control Facility. (WPCF), USA.

Beadle, L. C. (1932). Scientific results of the Cambridge expedition to the East African lakes, 1930-1-4. The waters of some East African lakes in relation to their fauna and flora. *Journal of the Linnaeus Society of Zoology,* 38: 157 – 211.

Bettinetti, R., Quadroni, S., Crosa, G., Harper, D., Dickie, J., Kyalo, M. et al. (2011). A preliminary evaluation of the DDT contamination of sediments in Lakes Natron andBogoria (Eastern rift valley, Africa) *Ambio,* 40 (4): 341-350.

Bonzongo, J. C., Ojiambo, B. S., Lyons, W. B., Wilder, S. &Welch, K. (1996). Mercury concentrations in waters of Lake Naivasha watershed, Kenya. *Geophysical Research Letters*,23:1581 – 1584.

Britton J. R. & Harper D. M. (2005). Assessing the true status of the fish species *Labeocylindricus* (Peters 1868) (Teleostei: *Cyprinidae*) in Lake Baringo, Kenya. *African J. Aquatic Science,30:203-205.*

Broadley, M., Brown, P., Cakmak, I., Rengel, Z. & Zhao, F. (2012). Functions of nutrients: Micronutrients. Marchner's Mineral nutrition of higher plants (3rd Ed.). p. (191 – 248). Academic Press.

Campbell, L. M., Osano, O., Hecky, R. E.& Dixon, E. G. (2003). Mercury in fish from three rift valley lakes (Turkana, Naivasha and Baringo), Kenya. East Africa, *Journal of Environmental Pollution,* 125: 281-286.

Codd, G. A., Metcalf, J. S., Morrison, L. F., Krienitz, L., Ballot, A.Pflugmacher, S. et al.(2003). Susceptibility of Flamnigos to cyanobacterial toxins via feeding, *The Verterinary Record*, 152: 722-723.

Chirikona, F., Filipovic, M., Ogoko, S. &Orata, F. (2015). Perfluoroalkyl acids in selected wastewater treatment plants and their discharge load within the Lake Victoria basin in Kenya, *Environ.Monit.Assess*.,187: 238. doi:10.1007/s10661-015-4425-6.

Cl'ement, J. P., Caroff, M., H'emond, C., Bollinger, J. J. C., guillou, H. &Cotton, J. (2003). Petrogenesis of alkaline lavas from Baringo-Bogoria basin, central Kenya rift, *Canadian Journal of Earth Science,* 40:1239 – 1257.

Dsikowitzky, L., Mengesha, M.,Dadebo,E., de Carvalho, C.E.V. &Sindern, S. (2012). Assessment of heavy metals in water samples and tissues of edible fish species from Awassa and Koka Rift Valley Lakes, Ethiopia, *Environmental Monitoring and Assessment*, 185 (4):Doi:10.1007/s10661-012-2777-8.

Dunkley, P. N., Smith, M., Allen, D. J.&Darling, W. G. (1993). The geothermal activity and geology of the northern sector of the Kenya rift valley. British Geological Survey Research report SC/93/1, KeyworthNorttingham.

Dusengemungu, L., Mubemba, B. &Gwanama, C. (2022). Evaluation of heavy metal contamination in copper mine tailing soils of Kitwe and Mufulira, Zambia, for reclamation prospects. Scientific Reports, 12, 22143

EC (2001) Commission Regulation (EC) No. 466/2001 of 8 March 2001: Setting maximum levels for certain contaminants in foodstuffs. Accessed from: https://op.europa.eu/en/publication-detail/-/publication/52b2484d-39e0-4aa9-ba19-4b13a887bb1c

FAO. (2016). The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Rome, 200pp.

Fawell J., Bailey, K., Chilton, J., Dahi, E., Fewtrell, L.&Magara, Y. (2006). Flouride in drinking water. Bailey, K., Chilton, J., Dahi, E., LennonM.,Jackson, P. &Fawell J. (Eds.) London, WHO and IWA Publishing, Inc. 15 – 35pp.

Fayed, S. E., Abd-El-Shafy, H. I., (1985). Accumulation of Cu, Zn, Cd, and Pb by aquatic macrophytes*, Environmental International*, 11: 77- 87,

Ganta, S., Yousuf, A., Nagaraj, A., Pareek., S., Sidiq, M., Signh, K. et al. (2015). Evaluation of fluoride retention due to the most commonly consumed estuaries fishes among fish consuming population of Andhra Pradesh as a contributory factor to dental fluorosis: A cross sectional study. *Journal of Clinical Diagnostics Research*, 9:ZC11 – ZC15.

Ganvir, P. S. &Papadkar, J. N. (2022). Hydrogeochemistry and human health: A briefreiew.*Int. J. of Food and Nutritional Sciences,* 11(11):223 - 227.

Ganvir, P.S. and Guhey, R. (2023). Implication of Enhanced Rock Weathering on the Groundwater Quality: A Case Study from Wardha Valley Coalfields, Central India. Weathering and Erosion Processes in the Natural Environment, 2023:215-242. https://doi.org/10.1002/9781394157365.ch9

Gikunju, J. K., Maitho, T. E., Birkeland, J. M. &Lokken, P. (1992). Fluoride in fish from lakes of great rift valley, Kenya. *Ecology of Food and Nutrition,* 27:85 – 90.

Gikunju, J. K. (1992). Fluoride concentration in tilapia fish (*Oreochromisleucostictus)* from Lake Naivasha Kenya. *Flouride,* 25:37 – 43.

Goodman, G. T. &Roberts, T. M., (1971). Plants and soils as indicators of metals in the air, *Nature,*231:287.

Hakan T-W., Everard M., &Harper D. M., (2002). Geochemical and physical characteristics of river and lake sediments at Naivasha Lake, Kenya. *Hydrobiologia*488 (1/3): 27 – 41.

Henley, W. H., Patterson, M. A., Neves, R. J., Lemly, A. D., (2000). Effects of sedimentation and turbidity on lotic food webs. A concise review for natural resource managers, *Review Fish. Sci.*,8: 125 – 139.

Hickley, P., Muchiri, M., Boar, R., Britton, C., Adams, C., Gichuru, N., (2004). Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya, *Ecohydrology and Hydrobiology*, 4:503 – 517.

Huss, H. H., Ababouch, L., Gram, L. (2003). Assessment and management of seafood safety and quality. FAO Fisheries Technical Report, No. 444, FAO Rome.

Igwegbe, A. O., Negbenebor, C. A., Chibuzo, E. C., Badau, M. H., (2014). Effects of season and location on heavy metal contents of fish species and corresponding water samples from Bornostate of Nigeria, Global Advanced Research journal of Medicine and Medical Science 3 (3): 64-75. http://garj.org/garjmms/index,htm

Jeong, H. Lee, Y. Moon, . B. & Ra, K. (2023). Characteristics of metal pollution and multi-isotopic signatures for C, Cu, Zn, and Pb in coastal sediments from special management areas in Korea. *Marine Chemistry*, 188: 114642.

Jirsa, F., Gruber, M., Stojanovic, A., Omondi, S. O., Mader, D., Korner, W., Schagerl, M., (2013). Major and trace element geochemistry of Lake Bogoria and Lake Nakuru, Kenya, during extreme drought, *Chemie Der Erde*, 73 (3): 275 – 282. Doi:10.1016/j.chemer.2012.09.001. (PMCID: PMC4375630)

Kaggwa, M. N., Gruber, M., (2013). A detailed time series assessment of the diet of *Lesser Flamnigos*: further explanation of their itinerant behavior. *Hydrobiologia,* 710: 83 – 93.

Kallqvist, T.(1987). Primary production, and phytoplankton in Lake Baringo and Naivasha, Kenya. Norwegian Institute for Water Research report Blinden, Oslo 59pp.

Kamau, J. N., Gachanja, A., Ngila, C., Kazungu, J. M., Gatagwu, J., 2007. The seasonal and spatial variations of labile copper, iron manganese, lead and zinc sediment fractions in Lake Naivasha, Kenya. *Lakes & Reservoirs: Research and Management*, 12: 303-313. DOI: 10.1111/j.1440-1770.2007.00342.x.

Kembenya, E. M., Ogello, E. O., Githukia, C. M., Aera, C. N., Omondi, R. &Munguti, J. M. (2014). Seasonal changes of Length-weight relationship and condition factor of five species in Lake Baringo, Kenya*. International Journal of Sciences: Basic and Applied Research,*14 (2): 130-140. http://gssr.org/index.php.?journal=JournalOfBasicAndApplied.

Kimosop, S.J., Getenga, Z.M., Orata, F., Okello, V. A. &Cheruiyot, J. K., (2016). Residue levels and discharge loads of antibiotics in wastewater treatment plants (WWTPs), hospital lagoons, and rivers within Lake Victoria Basin, Kenya, *Environmental Monitoring and Assessment,* 188:532. doi:10.1007/s10661-016-5534-6.

Kinuthia, G.K., Ngure, V., Beti, D., Lugalia, R. Wangila, A. &Kamau, L. (2020). Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. *Scientific Reports* 10, 8434

Kobingi, N., Raburu, P. O., Masese, F. O. &Gichuki, J., (2009). Assessment of pollution impacts on the ecological integrity of the Kisian and Kisat rivers in Lake Victoria drainage basin, Kenya. *African Journal of Environmental Science and Technology*, 3 (4): 97-107.

Kosgey, J., Koech, J., Bunyasi, S., Bett, K., Muthoka, T. M. &Nyabaro, O. M. (2015). Determination of heavy metal pollutants in sediments along the banks of AthiriverMachakos county Kenya. *International journal of Science and Technology,* 5 (7): http;//www.ejournalofscience.org (ISSN 2224-3577)

Kiage, L. M. &Liu, K-B. (2009). Paleoenvironmental changes in the lake Baringo basin, Kenya, East Africa since AD 1650: evidence from the paleorecord. *The Professional Geographer*, 61 (4):438 – 458.

Krienitz, L., Ballot, A., Kotut, K., Weigand, C., Putz, S., Metcalf, S., et al. (2003). Contribution of hot spring cyanobacteria to the mysterious deaths of Lesser Flamnigos at Lake Bogoria, Kenya, *Fens Microbiology Ecology*, 43: 141-148.

Lincer, J. H., Zalkind, D., Brown, L. H. &Hopcraft, J. (1981). Organochlorine residues in Kenya's rift valley lakes. *The journal of Applied Ecology*, 18: 157 -171.

Lwenya, C. &Yongo, E. (2010). Human aspects of siltation of Lake Baringo: causes, impacts and interventions, *Aquatic Ecosystem and Health Management Society,* 13 (4): 437 – 441.

Mageria, C. &Kibwage, J. (2009). Current status of Rift Valley fisheries. In: The status and potential of fisheries of the Rift Valley lakes (Aloo-Obudho P. (ed.), pp. 7 – 11. Intermass Printers & stationers, Nairobi.

Magu, M. M., Kareru, P. G. &Chege, C. W. (2016). Burdens of selected heavy metals in common fish species from specific Kenyan freshwaters, *International Journal of Fisheries and Aquatic Studies,* 4(3):173 – 179.

Mandarino, J. A. &Back M. E., (2004). Fleischer's Glossary of Mineral Species 2004. The Mineralogical Record, Tucson, AZ.

Mbuthia, J. W., Ogendi, G. M., Moturi, W. N., Koskey, J. C. &Maina, G. M. (2014). Heavy metal concentrations in tissues of commercially exploited fish (*Oreochromisniloticusbaringoensis, Protopterusaethipicus, Clariasgariepinus*) from Lake Baringo, Kenya, *Journal of Environmental Science, Toxicology and Food Technology*, 8 (11): 55 - 63.

McLean, R. O. &Jones, A. K. (1975). Studies of tolerances to heavy metals in the flora of rivers. Ystwyth and Clarach, Wales, *Freshwater Biology*, 5: 431.

Mungachia, J. C., Kanja, L. &Gitau, F. (1992). Organochlorine pesticide residues in fish from Lake Naivasha and Tanariver, Kenya. *Bulletin of Environmental Contamination and Toxicology*, 49:207 – 220.

Muohi, A. W. (2007). Bioaccumulation of trace metals in biota (algae and chironomids) from Kenyan saline Lakes (Bogoria and Nakuru): Evaluation and verification of two compartment toxicokinetic models. Oldenburg:Carl von Ossietzky Universitat Oldenburg, Germany, Institut fur Chemie und Biologie des Meeres (ICBM).

Mutia, T. M., Virani, M. Z., Moturi, W. N., Muyela, B., Mavura, W. J. &Lalah, J. O. (2012). Copper, lead and cadmium concentrations in surface water, sediment and fish species *Cyprinuscarpio* samples from Lake Naivasha: effect of recent anthropogenic activities. *Environ. Earth Sci*., 67 (4): 1121 – 1130.

Mwamburi, J. (2015). Comparative evaluation of the concentrations of lead, cadmium and zinc in surficial sediments from two shallow tectonic freshwater lake basins, Kenya. *African Journal of Science and Technology,* 9(6):531-544.

Mwamburi, J. (2008). Trace metals. Chapter 3. In: Muli J., Gichuki, J., Getabu, A., Wakwabi, E., Abila, R. (Eds.), Lake Baringo Research Expedition LABRE: Fisheries and Environmental impact KMFRI/LABRE/Technical Report 3, 109p. pp. 33 – 57.

Mwirigi, N., Aura, C., Owili, M., Otuo, P., Mrombo, N. &Odoli, C. (2022). Concentrations of mercury and cadmium in small pelagic fish from Lake Victoria, Kenya: The case of dagaa fishery. Kenya Aquatica, 7:33 – 37.

Okogwu, O.I., Nwonumara, G.N. &Okoh, F.A. (2009). Evaluating heavy metals pollution and exposure risk through the consumption of four commercially Important fish species and water from Cross River Ecosystem, Nigeria. Bull Environ ContamToxicol 102, 867–872

Nasirwa. O. (2000). Conservation status of Flamingos in Kenya. *Waterbirds* 23: 47 – 51.

NEMA (2006). Water quality regulations. Water quality monitoring or sources of domestic water. Second schedule (r.9) and Quality standards for sources of domestic water (r.5). Accessed: 25 Nov. 2024; https://www.nema.go.ke;

Nnamuyomba, P., Mbabazi, J. &Ntale, M. (2014). 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane (DDT) and its derivatives in marketed Clariaswerneri caught from Uganda’s major urban wetlands. *Journal of Toxicology and Environmental Health Sciences*, 6 (5): 113 – 119. http://www.academicjournals.org/JTEHS

Njogu, P. M., Keriko, J. M., Wanjau, R. N. &Kitetu, J. J. (2011). Distribution of heavy metals in various lake matrices; water, soil and sediments: A case study of the Lake Naivasha basin, Kenya. *Journal of Agricultural Science and Technology, JAGST,* 13 (1):91-106.

Nyakeya, K., Kipkorir, K. K., Nyamora, J. M. Odoli, C. O. &Kerich, E. (2018a). Dynamics of hydrology on the physico-chemical water quality parameters and trophic state of Lake Baringo, Kenya. *Africa Environmental Review Journal,* 3(1): 94 – 107.

Nyakeya, K., Kipkorir, K. K., Nyamora, J. M. &Kerich, E. (2018b). Assessment of the fisheries status in River Molo to guide the Management on its fisheries. *African J. Education, Science and Technology*, 4(4): 10 – 20.

Nyamweya, C. S. (2012). Fish eggs and larvae juvenile survey in Lake Baringo. In: Lake Baringo Research Expedition, 13 – 19 December 2010. A report on the Physico-chemical parameters KMFRI, pp. 55-65.

Nyamweya, C. S., Mlewa, C. M., Ngugi, C. C., Kaunda- Arara, B., Njiru, M., Gichiuki, J. W. et al. (2012). Aspects of the biology of *Labeocylindricus* (Pisces: Cyprinidae) in Lake Baringo, Kenya, *Lakes & Reservoirs: Research and Management,* 17 (3):225 – 229.

Ochieng, E. Z., Lalah, J. O. &Wandiga, S. O. (2007). Analysis of heavy metals in water and surface sediments in five rift valley lakes in Kenya for assessment of recent increase in anthropogenic activities. *Bulletin of Environmental Contamination and Toxicololgy*, 79 (5): 570–576.

Odada, E.O., Onyando, J. O.&Obudho, P. A. (2006). Lake Baringo: Addressing threatened biodiversity and livelihoods, *Lakes & Reservoirs: Research and Management,* 11: 287 – 299.

Oduor, S. O., Schagerl, M. &Mathooko, J. M. (2003). On the limnology of Lake Baringo (Kenya): I. Temporal physico-chemical dynamics. *Hydrobiologia* 506-509: 121-127.

Odour, S. O., (2000). Diel physico-chemical dynamics, primary production and algae of Lake Baringo, Kenya. MSc. Thesis, 83p. International Institute for Infrastructural hydraulic and Environmental Engineering (IHE), Delft.

Ogendi, G. M., Maina, G. M., Mbuthia, J. W., Koech, C. M., Ratemo, C. M. &Koskey, J. C. (2014). Heavy metal concentrations in water, sediments, and Common carp (*Cyprinuscarpio*) fish species from Lake Naivasha, Kenya, *Research Journal of Environmental and Earth Sciences* 6 (8): 416 – 423.

Olaka, L. A., Wilke, F. D. H., Olago, D. O., Odada, E. O. &Musolff, A. (2016). Groundwater fluoride enrichment in an active rift setting: Central Kenya rift case study, *Science of the totalEnvironment,* 545-546: 641-653. https://doi.org./10.1016/j.scitotenv.2015.11.161.

Olal, F. O. (2015). Assessment of the impact of urban runoff from Migori town on the concentration levels of selected heavy metals in Migori river, Kenya, *Journal of Environmental and Earth Science,* 5 (20): 2015. ISSN2224-3216 (Paper) ISSN 2225-0948 (ONLINE). www.iiste.org.

Oluoch-Otiego, J., Oyoo-Okoth, E., Kiptoo, K. K., G.,Chemoiwa, E. J., Ngugi, C. C. &Simiyu, G. et al. (2016). PCBs in fish and their cestode parasites in Lake Victoria, *Environmental Monitoring and Assessment,* 188:483, doi: 10.1007/s10661-016-5483-0.

Omar, W.A., Zaghloul, K.H., Abdel-Khalek, A.A. et al. (2013). Risk assessment and toxic effects of metal pollution in two cultured and wild fish species from highly degraded aquatic habitats. Arch. Environ. Contam. Toxicol. 65, 753–764

Omondi, R., Yasindi, A. W. & Magana, A. M. (2013). Food and feeding habits of three main fish species in Lake Baringo, Kenya, *Journal of Ecology and Natural Environment,* 5 (9): 224 – 230.

Omondi, R., Kembenya, E., Nyamweya, C., Ouma, H., Machua, S. K. &Ogari, Z. (2014). Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya. *Journal of Ecology and Natural Environment,* 6 (5): 154 – 163.

Omwoma, S., Lalah, J. O., Virani, M., Schramm, K. W. &Henkelmann, B. (2015). Dioxin-like PCBs and PCDD/Fs in surface sediments near the shore of Winam gulf, Lake Victoria, *Chemosphere,* 118: 143-147.

Omwenga, I., Kanja, L., Nguta, J., Mbaria, J., &Irungu, P., (2016). Organochlorine pesticide residues in farmed fish in Machakos and Kiambu counties Kenya, *Cogent Environmental Science,* 2: 1153215, http://dx.doi.org/10.1080/23311843.2016.1153215.

Onyando, J. O., Kisoyan, P. &Chemelili, M. C. (2005). Estimation of potential soil erosion for river Perkerra catchment in Kenya, *Water Resources Management*, 19: 133 – 143.

Onywere, S. M., Shisanya, C. A., Obando, J. A., Ndubi, A. O., Masiga, D., Irura, Z. et al. (2013). Geospatial extent of 2011 - 2013 flooding from the Eastern African Rift Valley lakes in Kenya and itsimplicationonthe ecosystems. 18pp. www.ku.ac.ke/schools/environmental /images/stories/research/Geospatial_Extent_20011-2013.pdf

Oostwoud, W. D. J. &Brayan, R. (2001). Gully - head erosion processes on a semi-arid valley floor in Kenya: a case study into temporal variation and sediment budgeting. *Earth surfaces Processes Landforms,* 26: 911 – 933. DOI:10.1002/esp.225.

Orata, F., Quinete, N., Maes, A., Werres, F. &Wilken, R. D. (2008). Perfluorooctanoic acid and perfluorooctane sulfonate in Nile perch and tilapia from gulf of Lake Victoria, *African Journal of Pure and Applied Chemistry*, 2 (8): 75 – 79. http://www.academicjournals.org/AJPAC (ISSN1996-0840)

Otachi, E. O., Korner, W., Avenant-Oldewage, A., Fellner-Frank, C. &Jirsa, F. (2014). Trace elements in sediments, blue spotted Tilapia *Oreochromisleucostictus* (Trewavas, 1933) and its parasite *Contracaecummultipapillatum* from Lake Naivasha, Kenya, including a comprehensive health risk analysis. *Environmental Science and Pollution Research*, 21 (12):7339-7349.

Ouma, H. &Mwamburi, J. (2014). Spatial variations in nutrients and other physicochemical variables in the topographically closed Lake Baringo freshwater basin (Kenya). *Lakes & Reservoirs: Research & Management,* 19:11–23.

Owino, A. O., Oyugi, J. O., Nasirwa, O. O. &Bennun, L. A. (2001). Patterns of variation in waterbird numbers on the four rift valley lakes in Kenya, 1991-1999, *Hydrobiologia*, 458:45-53.

Papadkar, J. N., Ganvir, P. S., Nimbarte, G. R., Patre, P. P., Barsagade, A. U. &Chandekar, R. D. (2023). A review over the causal relationship between hydro-geochemistry and bioaccumulation in special reference to coalfields. *European Chemical Bulletin*, 12(4);15288-15297.

Papadkar, J. N., Ganvir, P. S., Nimbarte, G. R., Patre, P. P., Pusala, S. V., Sakhare, S. K., &Ghagargunde, P. G. (2024). Implications of Coalfield Dynamics on Associated Ecosystems: A Tangential Review. *Uttar Pradesh J. Zoology,* 45(20), 34-43. https://doi.org/10.56557/upjoz/2024/v45i204563

Poste, A. E., Muir, D. C. G., Guildford, S. J. &Hecky, R. E., (2015). Bioaccumulation and biomagnification of mercury in African lakes: the importance of trophic status, *Science of thetotal Environment,* 505-507: 126 – 136. https://doi.org./10.1016/j.scitotenv.2015.11.161.

Ramsar (2002). Inormation sheet on Ramsar wetlands (RIS). Accessed: 02 October 2024. http:www.ramsar.orgris_kenya_baringo1.htm

Renaut, R. W., Tiercelin, J. J.& Owen, R. B.(2000). Lake Baringo, Kenya rift valley, and its Pleistocene precursorsc. In: Gierlowski-Kordesch, E. H., Kelts, K. K. (eds.), Lake Basins through space and time. AAPG Studies in Geology series, no. 46. American Association of Petroleum Geologits: Tulsa; 561 – 568.

Schagerl, M. &Oduor, S. O. (2003). On the limnology of Lake Baringo (Kenya): II. Pelagic primary production and algal composition of Lake Baringo, Kenya.*Hydrobiologia*506-509:297-303.

Schulter, T. (1993). Comparison of the mineral composition of the lakes of the East African rift system (Gregory rift and western rift). In: U. Thorweihe and H. Schandelmeier (Eds.) Geoscientific Research in Northeast Africa, pp. 657-662.

SCHER (2011). Scientific Committee on Health and Environmental Risks (SCHER). Opinion of critical review of any new evidence on the hazard profile, health effects, and human exposure to fluoride and the fluoridating agents of drinking water. Brussels Belgium: Directorate General for Health and Consumers, European Commission, 16 May, 2-4pp.

Singh, V. B., Madhav, S., Pant, N. C., &Shekhar, R. (Eds.). (2023). Weathering and Erosion Processes in the Natural Environment. John Wiley & Sons.

Smith, W. H. (1972). Lead and mercury: burden of woody plants Science, 176: 1237.

Snelder, D. J. &Bryan, R. B. (1995). The use of rainfall simulation tests to assess the influence of vegetation density on soils loss on degraded rangelands in the Baringo district, Kenya. *Catena*25: 105 – 116. DOI: 10.1016/0341-8162(95)00003-B.

Sparks, D. L. (2005). Toxic metals in the environment: The role of surfaces, Elements vol. 1, pp. (193 – 175), Department of plant and soil sciences, University of Delaware, Newark, DE, USA. Sparks, D. L., 2002. Environmental soil chemistry, Academic Press, San Diego.

Ssentongo, G. W. (1995). Report on the present fisheries situation of Lake Baringo, FAO. Rome. Snelder DJ, Bryan RB (1995). The use of rainfall simulation tests to assess the influence of vegetation density on soils loss on degraded rangelands in the Baringo district, Kenya. *Catena*25: 105 – 116. DOI: 10.1016/0341-8162(95)00003-B.

Talling, J. F. (2001). Environmental controls on the functioning of shallow tropical lakes. *Hydrobiologia*, 458: 1-8.

Tarits, C., Renaut, R. W., Tiercelin, J.-J., Le Hérissé, A., Cotton, J. &Cabon, J.-Y. (2006). Geochemical evidence of hydrothermal recharge in Lake Baringo, central Kenya Rift Valley. *Hydrological Processes,* 20:2027 – 2055.

Tekle-Haimanot, R., Melaku, Z., Kloos, H., Reimann, C., Fantaye, W., Zerihun, L. et al. (2006). The geographic distribution of fluoride in surface and groundwater in Ethiopia with an emphasis on the rift valley. *Science of the total Environment,* 367: 182-190.

Tekle-Haimanot, R. Haile, G. (2014). Chronic alcohol consumption and the development of skeletal flourosis in a fluoride endemic area of the Ethiopian rift valley. *Journal of Water Resources Protection,* 6:149-155.

Tyler, G. (1976). Metal concentration in moss, leaves and other indicators of metal exposure in the environment. International Conference on Environmental Sensing and assessment, Vol. 1, Institute of Electrical and Electronics engineering, New York, 1976.

USEPA (2024) National primary drinking water regulations Updated October 2024. Accessed: 25 Nov 2024. https://www.epa.gov/groundwater-and–drinking-water/national-primary-drinking-water-regulations.

WHO (2022). Guidelines for drinking water quality: fourth edition incorporating the first and second addenda.583p.

WHO (2010) Evaluation of certain food additives and contaminants. seventy-third report of the Joint FAO/WHO Expert committee on food additives. Geneva, Switzerland.

WHO (1984) Guidelines for drinking water quality (Volume 1) Recommendations, WHO Geneva.

Prasad, M., Aswal, R. S., Joshi, A., Kumar, A. &Ramola, R. C. (2022). A systematic study on occurrence, risk estimation and health implications of heavy metals in potable water from different sources of Garhwal Himalaya, India. Scientific Reports, 12, 20419.

Ribbe, N., Arinaitwe, K., Dadi, T., Friese, K. & Wolf, V. T. (2021). Trace-element behaviour in sediments of Ugandan part of Lake Victoria: results from sequential extraction and chemometrical evaluation. Environ Earth Sci., 80, 323

Shaaban, N.A., El-Rayis, O.A. &Aboeleneen, M.S. (2021). Possible human health risk of some heavy metals from consumption of tilapia fish from Lake Mariut, Egypt. Environ SciPollut Res 28, 19742 – 19754.

Sobhanardakani, S., Tayebi, L. &Farmany, A. (2011). Toxic metal (Pb, Hg, and As) contamination of muscle, gill and liver tissues of Otolithesruber, Pampus argenteus, Parastromateusniger, Scomberomoruscommerson and Onchorynchus mykiss. World Applied Sciences Journal 14(10), 1453–1456.

Sunguti, A.E., Kibet, J.K., Kinyanjui, T.K. Oyugi, A.M. &Muhizi, T. (2024). The analysis of potentially toxic heavy metal contamination in the Lake Bogoria geothermal springs. Discover Toxicology, 1, 3.

Wahlberg, H. T., Harper, D. &Wahlberg, N. T. (2003). A first limnological description of Lake Kichiritith, Kenya: a possible reference site for the freshwater lakes of the Gregory rift valley. *South Africa Journal of Science*, 99:494-496.

Wessels, L., Kjellevold, M., Kolding, J. Odoli, C., IngerAakre, I., Reich, F. &Pucher, J. (2023). Putting small fish on the table: the underutilized potential of small indigenous fish to improve food and nutrition security in East Africa. Food Sec. 15, 1025–1039

Yang, Q., Li, Z., Lu, X., Duan, Q., Huang, L. & Bi, J. (2018). A review of soil heavy metal pollution from industrial and agricultural regions in China: pollution and risk assessment. *Science of the Total Environment,* 642: 690 – 700.

Yang, Y., Wei, L., Cui, L., Zhang, M.& Wang, J. (2017). Profiles and risk assessment of heavy metals in great rift lakes, Kenya. *Clean Soil Air Water*, 45: n/a, 1600825. doi:10.1002/clen.201600825.