https://doi.org/10.4314/rjeste.v3i2.3

Heavy Metal Concentrations in Water Samples from Lake Kivu, Rwanda

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ABSTRACT

Heavy metals are among the pollutants threatening the living organisms including human beings. The presence of heavy metals in water is of great concern due to their toxicity to aquatic organisms, humans and ability to accumulate in food chains. Thus, there is a need to regularly monitor heavy metal levels in aquatic medium. The present study was conducted to assess heavy metal concentrations in Lake Kivu water. Water samples from Lake Kivu were taken from three sites, namely: Rusizi, Karongi and Rubavu. Heavy metals in the samples were analyzed using Atomic Absorption spectro-photometer (SHIMADZU AAS-6800) and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).Copper, lead, cadmium, chromium, manganese, mercury and arsenic concentrations were determined. Copper ranged from 3.24 to 10.01 µg/l, lead varied from 8.81 to 37.44 µg/l, cadmium ranged from 5.01 to 14.01 µg/l,chromium was between 139.5 and 226.6 µg/l, manganese varied from 598.3 to 795.7 µg/l, mercury ranged from 0 to 0.047 µg/l, while arsenic was not detected in any of the analyzed water samples. Except for arsenic, all the other heavy metals exceeded the EPA (US Environment Protection Agency) maximum permissible limit for class III surface water intended for fish consumption and recreation. Thus, there is a need to establish the sources of lake water pollution by heavy metals in order to design further strategies limiting the amounts of heavy metals entering Lake Kivu.

Keywords: Cadmium, chromium, copper, lead, manganese, mercury

1. INTRODUCTION

Lake Kivu is situated at 1,463 m altitude and maximum depth of 485m in the Western part of the East African Rift zone between Rwanda and Democratic Republic of Congo. An estimated two million people use Lake Kivu water for drinking water without any treatment (Olapade and Omitoyin, 2012). The lake has accumulated a huge amount of methane and carbon dioxide(Schmid and Wüest, 2012; Bärenbold et al., 2020), and itis characterized by significant nutrient inflow from soil runoff from surrounding steep slopes (Muvundja et al.,2009). Lake Kivu is also located in a volcanic region and surrounded with active volcanoes (Nyamuragira and Nyiragongo). The active volcanoes may contaminate the lake with mercury and other heavy metals (Bagnato et al., 2015).

Heavy metals are chemical elements with a density greater than 5g/cm^3(Al-najjar et al., 2016.) They are also called trace elements as they are found in biological systems in low concentrations (Al-najjar et al., 2016). Heavy metals can be present naturally in aquatic environment (Sani,2011), however, anthropogenic activities marking the recent development such as modern agriculture, industrialization, construction and mining have contributed to the increase of heavy metals and other pollutants in different environments(Mensoor and Said, 2018).Heavy metals are persistent in the environment as they are not eliminated by biodegradation or chemical processes (Ashraf et al., 2012). Lead, cadmium, arsenic and mercury have no biological role in the metabolism of human being and aquatic organisms and are very toxic (Shah, 2017). Apart from toxic heavy metals, other metals can be classified as essential. Copper, manganese and chromium are essential for the metabolism of living organisms including human being; however, they are toxic if present at high quantities (Aliyu et al., 2015).

Assessing the level of heavy metals in lake could be an important aspect of environmental protection and a tool that influences the policy makers in decision making on environmental issues. Among the sources of heavy metals presence in the lake could be the discharge of untreated effluents from various sources into the lake (Thangamalathi and Anuradha, 2018), and soil erosion. The erosion, landslides and seismicity result in the transport of the neighboring soil into the lake and may contain heavy metals (Bagalwa et al., 2015). Limited studies have been conducted on water pollution in Lake Kivu, while major research attention was focused on methane gas resources (Bärenboldet al., 2020; Roland et al.,2017; Wüest et al., 2012, Pasche et al., 2011; Jannasch, 1975; Deuser et al., 1973).However, recent urban growth of cities located on lake borders, limited soil protection and expansion of open mining sites in the lake zone might pose risks for increased water pollution in the lake. Therefore, the present study aimed to assess the concentrations of heavy metals in water in major fishing sites of the Rwandan part of Lake Kivu.

2. METHODS

Water samples were taken in Northern, Easternand Southernparts of Lake Kivu, which represent the major fishing sites near the settlements/cities - Rubavu, Karongi and Rusizi, respectively (Fig. 1). Thecoordinates were taken for water stations at Rusizi (28.89341, -2.48202); Rubavu (29.25512, -1.73278) and Karongi (29.31138, -2.06042) using GPS Garmin 60. Water samples were taken at surface and 40 m depth using a NISKIN bottle, repeated three times, on which an RBR 620 CTD (Conductivity, Temperature and Depth) probe was attached to record the depth and physical properties of the water. Samples were transported in a cool box to the laboratory and stored at 4^{o}C. A Method 3005, which is an acid digestion procedure, was used to prepare water samples for analysis by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Water samples were acidified at the time of collection with HNO_3 (5 mL/L).

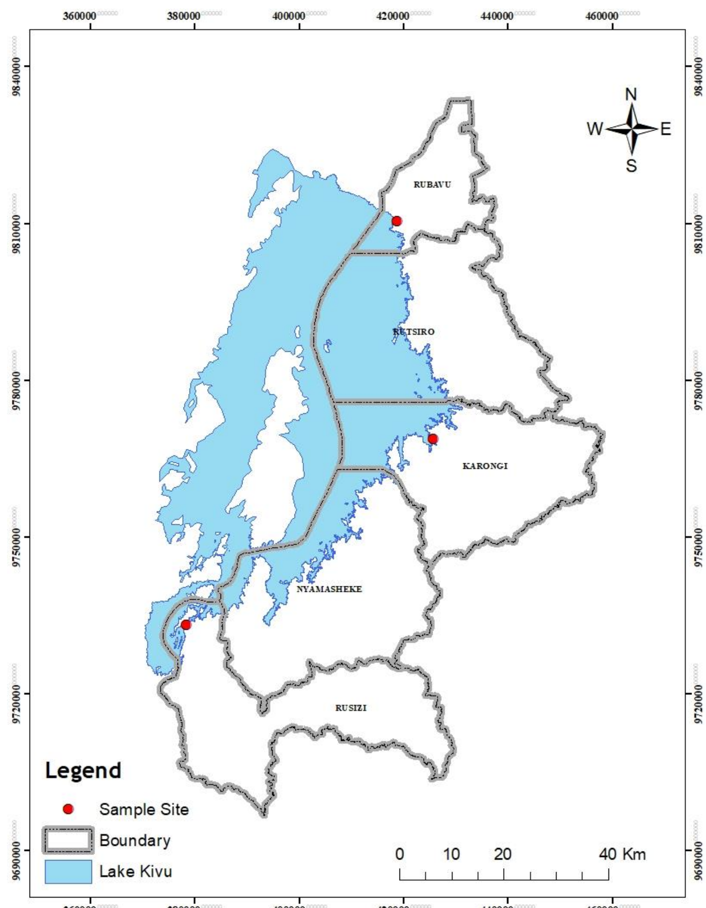

Fig.1 Map showing the sampling points on Lake Kivu (The map was prepared using ArcGIS version 10.6)

At the time of analysis, the water samples were heated with acid and substantially reduced in volume. The obtained volume was filtered and diluted. A 100-mL aliquot of well-mixed sample was transferred to a beaker and 2 mL of concentrated HNO_3 and 5 mL of concentrated HCl were added. Each sample was covered with a ribbed watch glass and heated on a hot plate at 90 ^oC until the volume has been reduced to 15 ml. The beaker was then removed from the hot plate and allowed to cool, washed with water and sample filtered to remove silicates and other insoluble material that could clog the nebulizer. Thereafter, the volume was adjusted to 100 ml with reagent water.

The observed heavy metal concentrations were compared with the available maximum permissible limits for heavy metals from the US Environment Protection Agency for surface water intended for fish consumption, recreation, propagation and maintenance of a healthy, well balanced population of fish and wildlife (EPA, 2018).

3. RESULTS

The concentrations of most of the heavy metals analyzed in water samples from Lake Kivu exceeded the US Environment Protection Agency (EPA) maximum permissible limitintended for fish consumption, recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife across all sites and both depths: at water surface and at 40m depth (Table 1).The concentration of lead in water samples varied from 11.02 µg/l to 35.24 µg/l, which exceeded up to 3 or 4 times the EPA maximum permissible limit of 8.5 µg/l. This was consistent at both, surface water and 40m depth and all sites (Table 1). Cadmium ranged from 6.01 to 12.51 µg/l. Cadmium concentration exceeded EPA maximum permissible limit of 8.8 µg/l in three samples out of six in Rubavu and one sample out of six in Rusizi, while its concentration was below 8.8 µg/l in Karongi (Table 1).

Table 1. Heavy metals concentrations (µg/l) in water samples from Lake Kivu (water depths at 0 and 40m)

Depth (m)	Replicate	Pb	Cd	Cu	Cr	Mn	As	Hg
Location: Rusizi								
0	1	35.24	12.51	7.28	203.13	751.07	ND	0.015
0	2	24.23	6.01	8.65	191.41	781.70	ND	0.0055
0	3	25.33	8.01	5.01	207.04	687.23	ND	0.026
40	1	25.33	7.51	6.83	183.60	683.40	ND	0.0135
40	2	33.04	6.01	9.56	214.85	683.83	ND	0.0085
40	3	11.02	9.51	7.23	218.75	653.19	ND	0.018
Location: Karongi								
0	1	28.85	8.40	4.03	151.40	738.59	ND	ND
0	2	30.93	7.39	3.45	153.19	628.54	ND	0.0028
0	3	25.63	6.80	5.83	176.95	675.10	ND	0.0008

40	1	25.98	6.59	5.06	166.82	751.20	ND	ND
40	2	27.33	7.15	4.83	141.18	615.38	ND	0.0021
40	3	27.67	8.23	4.75	151.96	684.09	ND	ND
Location: Rubavu								
0	1	23.42	10.67	5.94	193.41	620.52	ND	0.0335
0	2	30.71	7.92	7.20	149.13	600.37	ND	0.030
0	3	27.33	10.56	7.16	186.92	614.01	ND	0.021
40	1	19.56	11.37	5.71	160.33	638.98	ND	0.027
40	2	23.37	8.65	8.35	164.63	609.87	ND	0.046
40	3	22.00	7.89	8.68	171.75	620.39	ND	0.0125
MPL*		8.5	8.8	3.7	50	NR	50	0.025

* MPL – Maximum Permissible Limit set by the United States Environmental Protection Agency for Class III surface water intended for fish consumption, recreation, propagation and maintenance of a healthy population of fish and wildlife (EPA, 2018). ND: Not Detected; NR – Not Regulated.

Copper in water samples ranged from 3.45 to 9.56 µg/l, which exceeded the EPA maximum permissible limit of 3.7 µg/l up to 2 times in all sites and both depth, except one sample out of 6 at Karongi where it was below the EPA maximum. Chromium concentration in water samples was between 141.2 µg/l and 218.8 µg/l, which was 3-4 times higher than the EPA maximum permissible concentration of 50 µg/l. This was in all sites and both, surface water and 40m depth. Manganese concentration varied from 609.9 µg/l to 781.7 µg/l. This was higher than for any other heavy metal, however, no EPA maximum permissible limits were recommended for chromium. Arsenic was not detected in any of the samples, while mercury concentration ranged from 0 to 0.046 µg/l.One sample out of six in Rusizi, and four out of six in Rubavu exceeded the EPA maximum permissible limits for mercury, which was 0.025 µg/l (Table 1). In Karongi site, mercury was not detected in three samples out of six, and it was present at low concentrations not exceeding the EPA limits in the remaining three samples.

4. DISCUSSION

In the whole East African region, lakes constitute an important source of fishing for surrounding population, while water pollution may threat human health. Contamination of water and fish resources by heavy metals and pesticides was the subject of recent research: for the lakes Victoria (Ogwok et al., 2009; Nakuru (Mavura and Wangila, 2003); Ethiopian lakes Koka and Awassa (Dsikowitzky et al., 2013); Rwandan lakes Muhazi (Mupenzi et al., 2009) and South Cyohoha (Bazimenyera et al., 2014), where contamination of water and fish by different heavy metals was described. Yabe et al. (2010) review described water and fish contamination by heavy metals as pertinent but scarcely studied problem for the whole Africa.

Among the factors contributing to increased presence of heavy metals in water, the following were described: anthropogenic activities around the lake (Aderinola et al., 2009), mining, industrial waste water, municipal waste water and agricultural activities (Aprile and Bouvy, 2010), mineral composition of underlying rock and soil around the surface water (Shehu et al., 2015).

Excess concentration of heavy metals in surface water has an effect on both, water organisms and human beings (He et al., 2018). It is possible that heavy metals in water bodies could have an effect on primary productivity in aquatic ecosystem (Jamal et al., 2013).Copper, Manganese and Chromium are essential for the metabolism of living organisms including human being, they are toxic at high level (Olapade and Omitoyin, 2012) causing anemia in fish, kidney and liver damage in human being (Thangam et al., 2014). Excessive manganese may cause brain damage in invertebrates (Baden and Eriksson, 2006). Chromium in aquatic environment is derived from a discharge of waste from metallurgical, electroplating, paints, pigments, tanning, wood, chemicals and paper industries (Saha et al., 2011).

Lead, Cadmium, Arsenic and Mercury have no biological role and are very toxicto both, human beingand aquatic organisms (Shah, 2017). Lead is very toxic and accumulates in aquatic food chains (Afshan et al., 2014). High level of cadmium in water can decrease egg production thereby reducing the offspring's which results in a population decline and thus leading to low productivity (Cherif et al., 2015). The sources of cadmium and lead in water include the use of phosphate fertilizers, discharging waste water from the industries producing alloys, pigments and batteries (Tchounwou et al., 2012). Other sources of lead include metal plating, waste from battery industries, exhaust from automobiles, smelting of ores and factory chimneys (Jaishankar et al., 2014). Mercury may be originated from the erosion of the upland soil (Obrist et al., 2018), the discharge of waste and chemical production facilities (Pacyna et al., 2009), volcanic eruptions and emissions (Hansell et al., 2006), mining (Wang et al., 2004).

Although Lake Kivu and surrounding areas are known by the lack of big industries and most of human activities are related to agro-pastoral occupation and fisheries, the main findings of our study reveal wide contamination of surface and deep water in Lake Kivu by a range of heavy metals. Thus, it is the first report for Lake Kivu. Although our study was not based on extensive sampling as it was exploratory, the fact that the range of heavy metals in the collected water samples exceeded the US EPA maximum permissible levels by 2-4 times across all three sites and at both, surface water and 40m depth would be the indicator that the contamination of water by heavy metals may be widespread. Further studies are needed definitely: (i) with more extensive sampling to investigate the pertinence of the problem; (ii) to develop health standards with recommendations limiting drinking of water from the lake and (iii) to conduct further research to establish contamination levels by heavy metals in fish. The last is particularly important with the recent expansion of cage farming (Kampayana et al., 2016; RAB, 2018).

5. CONCLUSION

The results from the conducted assessment of heavy metals in Lake Kivu revealed that the concentration of Copper, Lead, Cadmium, Chromium, Manganese and Mercury in water were above the EPA maximum permissible limit for surface waterintended for fish consumption, recreation, propagation and maintenance of a healthy, well balanced population of fish and wildlife. Thus, there is a need to establish the sources of lake water pollution by heavy metals in order to design further strategies limiting the amounts of heavy metals entering Lake Kivu.

Acknowledgments

The authors would like to thank the scientific committee of the 2nd Springer EMCEI (www.emcei.net) for evaluation of this manuscript. This study was financially supported by the Ordinary Research Grant under the University of Rwanda and Sweden Collaboration.

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