

A Review on water and sedimentary Lead concentrations in Kenya's surface water bodies

Cornelius Ngandu¹ 

¹Egerton University, Kenya.

*Correspondence: cornelius.ngandu@egerton.ac.ke

Keywords: water; lead; reviewed; water concentration; sediment concentration

Abstract: Proper management, monitory and pollution controls measure should be maintained, for limited water resources, so as to reduce human health risks. Lead pollution can negatively affect human health. This study reviewed concentrations of lead in water and sediments of water bodies in Kenya, from samples or publications conducted between 1990 and 2021. Information on quantitative concentration values, locality, allowable standards, general methodology and possible pollutant sources for lead pollution in water and sediment were gathered. Based on the review, 71 concentration values (23.94%) for water, where above or similar to the Republic of Kenya (2006), maximum allowable value, with higher pollution levels in Kenya's major urban areas. The 43 sedimentary concentrations, were in the range of 198.7 mg/kg to 5.9 mg/kg. Lead concentration varied with weather patterns, in some reviews. Lead and heavy metals pollution was mainly attributed to human, industrial or agricultural activities and poor waste management. There was variation in method used by different studies. More experimental researches and modeling techniques, should be considered, for accurate methodologies, within Kenya's context. There should be proper treatment and monitoring of effluent, also human and industrial activities should be avoided near water body's banks through enforcement of riparian areas protection.

1. Introduction

Presence of high lead concentration in water resources could pose a public health risk. Lead is toxic and persistent in the environment and can accumulate in the body over time (Centers for disease control and prevention CDC). Young children, infants and fetuses are specifically vulnerable to lead and even at low lead levels in child's blood could lead to problems such as: behavior and learning; lower IQ and hyperactivity; hearing challenges; anaemia and reduced growth rate; and in adults' lead could result to: increased blood pressure; reduced kidney functioning and reproductive challenges (United States Environmental Protection Agency - EPA). According to Evens *et al.*, 2015 study, results clearly indicated that early childhood lead exposure has a negative effect on school performance, even at levels less than 5 µg/dl blood concentrations of lead. Since no safe levels in blood had been identified for young children, all lead exposure sources for children should be eliminated or contained (Centers for disease control and prevention- CDC). According to Obeng-Gyasi *et al.*, 2021, USA adults exposed to lead (Pb) were more likely to get higher levels of chronic stress. Trace elements could bio-accumulate and even bio-magnify in organisms, with serious health effect (Abubakar *et al.* 2015).

According to Sun *et al.*, 2020 study in Jiuzhen bay, China, given the Pb, As and Hg pollution in seawater and sediment in some of the studied sites, potential risks of those metals in living organisms to local ecology and human health requires more attention.

Mustapha *et al.*, 2021 study for Epe lagoon, Lagos, Nigeria, indicated Pb concentrations of between non-detectable level to 0.875 ± 0.01 mg/kg in fish samples, lower than WHO/FEPA recommended limit of 2 mg/kg, the Pb concentration for water and sediment were in the ranges non-detectable level to 0.13mg/l and non-detectable level to 2.427 mg/kg respectively, levels of Pb or other metals within the lagoon were attributed to industrial discharge, run-off from agricultural activities during rainy season and domestic waste dumped in water bodies. According to Li *et al.*, 2015 study in China, high accumulation of waste water discharge quantities could have persisted in environment and resulted to high water pollution levels of heavy metals (like arsenic, cadmium and lead) in 2011. According to Bhuyan *et al.*, 2019 study, for Old Brahmaputra river, Bangladesh, concentration of Pb ranged between 4.8 to 9.8 mg/kg in sediment, with the highest concentration (9.8 mg/kg) at Belanagor in post-monsoon and water Pb concentration were between 0.01 to 0.21 mg/l. After entry of natural acid mine drainage to Rongna river, heavy metal concentrations were significantly greater compared to Bolong river, control samples, with Pb concentrations were reported at 3 times for the former with relation to the latter, statistical analysis indicated the presence of Pb may have been due to rock weathering (Luo *et al.*, 2022). Astatkie *et al.*, 2021 study for Awatu watershed, Ethiopia indicated high concentration of sedimentary Pb, with mean value 2005.94 mg/kg, correlation analysis showed that heavy metals had common anthropogenic pollution sources due to rapid urbanization and discharging of water inappropriately. Study by Abubakar *et al.* (2015), samples for river Kaduna and Kakari-Makera drain, Nigeria were above the World health organization's (WHO) allowable limits, heavy metal pollutions was likely due to urban, municipal, industrial effluents and other anthropogenic sources, which discharged to the drains, subsequently to the river.

According to Republic of Kenya, Ministry of water and irrigation, Kenya faced enormous challenges in management of its water resources, which are limited and the water quality had been impacted negatively by the poorly controlled effluent discharged from industries and sewage and excessive nutrient and agrochemicals. There is therefore need to consistently monitor and maintain proper management strategies to ensure that water bodies in Kenya are free from harmful pollutants.

This study aimed at reviewing, lead concentration in water and sediments for water bodies in Kenya. Analysis were made, based on the review, of lead (Pb) concentrations and potential pollution sources.

1.1 Study Area

Kenya is a nation located in East Africa. It shares a border with Uganda on the west, Tanzania on the south, South Sudan, Ethiopia and Somalia to the north west, north and north east respectively, also it has a coastline to Indian ocean. The equator and the longitude 38°E cut through Kenya, according to Ntarangwi (Britannica). Major urban areas include Nairobi, the capital city, Mombasa, on the coast and Kisumu, adjacent to Lake Victoria, figure 1, shows the map of the study area, Kenya.

2. Review: Lead Concentrations

11 previous studies on lead concentration in various water bodies, focused on sediment and water concentration were reviewed and based on this, information was derived, as presented in *table 1*.

From those sources, 71 and 43 concentration values for water and sediment samples respectively were derived, for analysis, indicating lead (mean) concentrations in water of between 0 to 0.2522 mg/l, from some of the sources in *table 1*.

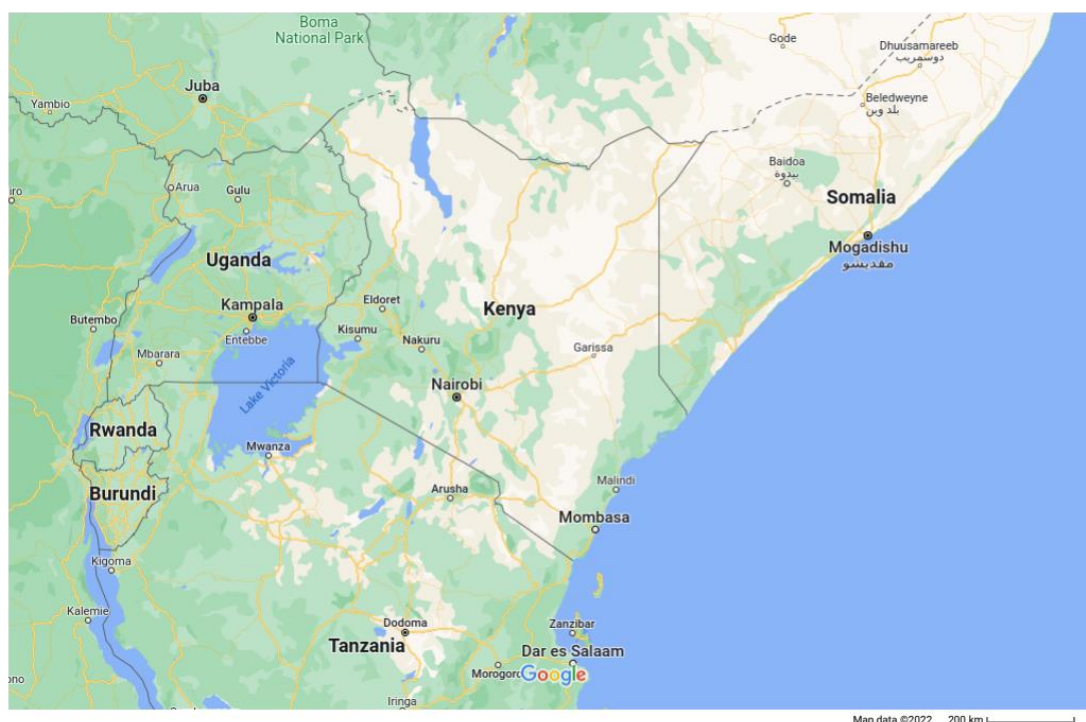


Figure 1. Map of Kenya (Source: Googles maps)

Table 1. Lead concentration based on reviews

Period & Place	Water / Sediment	Values/Ranges	Sampled time/Period /Method Brief	Source S/no
Nairobi/Ngong River basin (various points)	Water	Between 0 to 0.1 mg/l (1992), 0.03 to 0.07 mg/l (1998-2006)	Two periods: 1990 - 1992 & 1998 - 2006	Kithiia (2007)
Nairobi river sub-basin (Kamiti, Ngong, Kasarani)	Water	0.1 mg/l (4 stations), 0 (@ Museum)	Between 10/1990 and 5/1991	Kithiia and Ongwenyi (1997)
Tudor and Makupa creeks (four sampling point each)	Sediment	Mean values: 5.9 mg/kg in (at a Tudor creek site-dry) to 33.3 mg/kg (at a Makupa creek site-wet)	Dry and wet seasons, between 05/1997 & 03/1998. For water samples, extraction solution (1% ammonium pyrrolidine dithiocarbamate) & methyl isobutyl ketone were used. For sediment samples, residue was dissolved in perchloric acid, then evaporated to semi-dryness at 150°C, then dissolved in 3% hydrochloric acid, with blank digestion treated similarly.	Mwashote (2003)
	Water	highest mean concentration: 0.006 mg/l (at a Tudor creek site- wet season) & lowest, nd.		
Lake Victoria, in Winam gulf or main lake (5 sites)	Water	Between: 0.861 µg/l (Rusinga Island) & 1.21 µg/l, (Kisumu city)	Between 09/2016 to 07/2017 sampling. Water samples were acidified with HNO ₃ . For sediment samples, 34% HNO ₃ (Trace SELECT®Fluka) was added and also 30% H ₂ O ₂ , the samples were processed at 130°C for 2 h.	Outa <i>et al.</i> (2020)
	Sediment	Between 6.82 ± 3.4 mg/kg & 195 ± 273 mg/kg (Kisumu city)		

Period & Place	Water / Sediment	Values/Ranges	Sampled time/Period /Method Brief	Source S/no
Nairobi river (basin),	Water	mean concentration wet season & dry season between 0.2522 mg/l at KKK & 0 mg/l (6 sampling point)	Wet season (11/2013) & dry season (06/2013) sampling. Digestion in concentrated nitric acid Mbui <i>et al.</i> , 2016 as cited/ref. from Maiti, 2004, the AAS model SHIMADZU 6300	Mbui <i>et al.</i> (2016)
Nairobi river (basin),	Water	Dry season: range 0 to 158 µg/l; mean, 5.89 µg/l & SD, 29.82; Wet season: range 0 to 9 µg/l; mean, 1.17 µg/l & SD, 2.49 µg/l;	Rainy season (10/2015) and dry season (06/2016) sampling.	Njuguna <i>et al.</i> (2017)
7 stations along river Sosiani, Eldoret	Water	Ranged between 0.06 mg/l to 0.23 mg/l	Samples were boiled slowly at controlled temperature of 70°C, then addition of concentrated nitric acid and concentrated sulphuric acid.	Munene <i>et al.</i> (2021)
3 sites at Lini stream and Ikiwe river, Machakos municipality	Water	0.007 ± 0.01 mg/L (Lini); 0.0012 ± 00 mg/L (Ikiwe); 0.0062 ± 01 mg/L (Ikiwe)	Dry season, between June 2019 and October 2019 sampling. Samples were digested in tri acid mixture (HNO ₃ , HCl and HClO ₄ at ratio of 5:1:2 at 150°C for not less than 20 minutes Tomno <i>et al.</i> , 2020 as cited /ref. from Nazir <i>et al.</i> , 2015	Tomno <i>et al.</i> (2020)
Lake Naivasha basin (incl. Adjacent water bodies)	Water Sediment	Range: 36.41 + 5.1 µg/l (Shar canal) and 5.61 + 2.1 µg/l (Crescent shoreline) Range: 60.23+2.21 µg/g (R. Malewa highway bridge) & 26.13+0.99 µg/g (Sher Canal)	November and December, 2008 sampling. Sediment and water samples were acid digested with a mixture of nitric acid and perchloric acid (1:3).	Njogu <i>et al.</i> (2011)
Winam gulf, Lake Victoria, at within 100m from shoreline.	Sediment	Range (mean-all seasons): 198.7 µg/g (River Kisat inflow, shoreline) to 56.95 µg/g (river Kisian-100m from shoreline). Range (mean-considering): 183.25 µg/g wet seasons (river Kisat) to 60.20 µg/g dry season (river Kisian)	Wet season (April-June 2013) & dry season (January-March 2014) sampling. Digestion was done at 100°C for 3 hours, using HNO ₃ and HCl mixture (4:1).	Kiema <i>et al.</i> (2017)
Rungiri quarry reservoir	Water	No lead detected	January 2019 (dry seasons) sampling.	Kilonzo <i>et al.</i> (2019)

According to Kithiia and Ongwenyi, 1997), Ngong river at Embakasi had high levels of pollutant substances such as Mercury, Manganese & lead due to industrial activities at site's upstream. Study of Nairobi river (basin) by Mbui *et al.*, 2016, indicated higher concentration at Kileleshwa Kirichwa Kubwa (KKK), possibly due to effluent from garage and car wash near river. According to Njuguna *et al.*, 2017 study, the only site

that had concentrations greater than WHO limits for Pb, pollution was possibly due to lead acid batteries, detected adjacent to Dandora dumping site. According to Tomno *et al.*, 2020 study, mean Pb levels were lower than WHO standards, detected amounts could be due to metallic waste from open air garage, near Lini stream, sewage effluent, petroleum product from garage and disposition of airborne Pb. According to Njogu *et al.*, 2011 study for lake Naivasha basin, the most significant pollution sources, for heavy metals to the watercourse were attributed to flower farms, river Malewa and Naivasha municipal council. At Kihoto sewer point, high concentration for lead, zinc and nickel (sediment) was attributed to Naivasha municipal sewer treatment plant inflow and high heavy metals concentrations in L. Oloidien possibly due to bio-concentration by blue-green algae and the soda lake (Njogu *et al.*, 2011). According to Kiema *et al.*, 2017 study, area around river Kisat and coca-cola plant discharge, had more industrial activities that discharged waste water having heavy metals to the lake, hence sediment from site had higher concentration of heavy metals.

According to Mwashote, 2003 study, the Pb concentration levels were usually higher during the wet season as compared to the dry season, in areas that had higher Pb concentration in water and sediment. Njuguna *et al.*, 2017 study, on assessment of macrophyte, heavy metals and nutrients in Nairobi river/basin, indicated higher pollution in 2016 (dry season) as compared with wet season in 2015, the variation was attributed to prevailing weather. According to Kiema *et al.*, 2017, wet season had higher levels of Pb concentration, hence surface run-off after rainfall seemed to be the main method of washing heavy metals to Winam Gulf, Lake Victoria.

Kithiia (2007) study, for Nairobi and Ngong rivers, results indicated that some heavy metals, with serious health effects, not detected in 1990-1992 were recorded in 1998-2006 and an increase in water quality degradation and heavy metals.

2.1. Lead concentrations in water

The maximum allowable guiding value for lead in domestic water sources, in Kenya, according to Environmental management and co-ordination (water quality) is 0.05 mg/l (Republic of Kenya, 2006). The selected sources where for samples collected or publications between 1990 to 2021. Based on 10 sources, for 71 lead concentration values in water, 17 (23.94%) were above the Environmental management and co-ordination (water quality), maximum allowable value (Republic of Kenya, 2006). Majority of those (10) were from Nairobi river basin, and rivers or streams within Nairobi- the capital city- or adjacent areas. The rest (7), were from Munene *et al.*, 2021, study on River Sosiani, through Eldoret town. This shows that unacceptable levels of lead pollution in water were in urban areas. Some of those (mean) concentrations, were conducted or published in the 1990s' and others for post 2000 period. It was not indicated when Munene *et al.*, 2021 conducted his sample, from the publication.

Based on the review, for the 4 results within the Nairobi river basin, by (Kithiia, 2007; Kithiia and Ongwenyi, 1997; Mbui *et al.*, 2016; Njuguna *et al.*, 2017) the highest (mean) values were 0.1 mg/l in 1992 and 0.07 mg/l (1998-2006) by Kithiia, 2007, 0.1 mg/l (10/1990 – 5/1991) by Kithiia and Ongwenyi, 1997 and 0.2522 mg/l (2013) by Mbui *et al.*, 2016 and 0.158 mg/l (06/2016, dry season) by Njuguna *et al.*, 2017, for samples sites. Based on those, the critical concentration values for post 2010, for Nairobi river basin were higher, hence an indication of possible increase in pollution levels with time. Also, Kithiia, 2007 results for water, sediment and plant in Nairobi river basin suggested increasing pollution for heavy metals and pesticide residues. The maximum values in the 4 publications for Nairobi river basin were generally higher than Environmental management and co-ordination (water quality) regulation, Republic of Kenya, 2006.

With exception of Nairobi river basin, most of the other Pb concentration values were less than the allowable maximum, by Republic of Kenya, 2006. Based on this

review, outside Nairobi river basin, only river Sosiani, Eldoret, from Munene *et al.*, 2021 study, had at least some values above the required value.

2.2 Lead concentrations in Sediment

43 concentration values derived from 4 studies indicated that concentration values in sediments ranged between 198.7 mg/kg (Kiema *et al.*, 2017) to 5.9 mg/kg (Mwashote, 2003). Those 43 values included for Winam gulf, Lake Victoria, at within ≈ 100 m from shoreline, Lake Victoria (Winam gulf or main lake), Lake Naivasha basin (incl. Adjacent water bodies), Tudor and Makupa creeks based on studies by (Kiema *et al.*, 2017; Outa *et al.*, 2020; Njogu *et al.*, 2011; Mwashote, 2003) respectively. Based on the 43 values, Kiema *et al.*, 2017 study indicated comparatively higher Pb pollution levels for sediment.

Table 2, show the ranges of lead concentration in sediment, for some studies outside Kenya, which ranged between 2.15 mg/kg to 270 mg/kg, the upper values were higher as compared to those of studies within Kenya.

Table 2. Concentration of sedimentary lead concentration for other studies outside Kenya

Period & Place	Values/Ranges (mg/kg)	Source S/no
Tembi river, Iran (2011 & 2012, different seasons)	Range: 141 mg/kg (winter, 2011, upstream) & 270 mg/kg (summer 2011, downstream)	Shanbehzadeh et al. (2014)
Kabul river (or tributaries), Pakistan, 4 sites	Ranges: - 32.8 +18.2 mg/kg (reference site) & 54.6 + 4.3 mg/kg	Khan et al. (2018)
Lake Łebsko, Poland sampling 2014-2015	Ranges: Western part, 2.15 mg/kg to 91.73 mg/kg; Central part, 9.48 mg/kg to 99.84 mg/kg; Eastern part, 2.22 to 225.53 mg/kg	Mrozińska and Bąkowska (2020)
Main tributaries of Dongting lake (Rivers: Xiangjiang, Zishui, Yuanjiang & Lishui), China	Range: 19 mg/kg to 244 mg/kg	Xu et al. (2018)
Yi river, Beng river, Su river, at/near their junction point, China. Sampled: April 2017	Ranged: 8.50 mg/kg to 17.93 mg/kg	Li et al. (2019)

2.3 Methodologies Analysis

Mwashote, 2003 method for sediment sample included, perchloric acid, semi-dryness at 150°C and dissolving 3% hydrochloric acid, Njogu *et al.*, 2011 included acid digested with a mixture of nitric acid and perchloric acid (1:3), for sediment. Kiema *et al.*, 2017 methodology involved, digestion at 100°C for 3 hours, using HNO₃ and HCl mixture (4:1), for sediment samples. Outa *et al.*, 2020 method included, 34% HNO₃ (TraceSELECT® Fluka) added and also 30% H₂O₂, and the samples processed 130°C for 2 h, for sediment samples. This shows that the methods and reagents for sediment were not consistent. Based on Mwashote, 2003, Njogu *et al.*, 2011, Kiema *et al.*, 2017 and Outa *et al.*, 2020 studies in Kenya, reagents used and temperatures, for the sediment samples before analyzing, were generally not consistent. According to Outa *et al.*, 2020, the actual trace element sedimentary concentration indicated in their study could be as much as 10 – 30% underestimated.

Mwashote, 2003 method for water samples, included extraction solution (1% ammonium pyrrolidine dithiocarbamate) & methyl isobutyl ketone, in Outa *et al.*, 2020 study, water samples were acidified with HNO₃. Mbui *et al.*, 2016 digested water samples in concentrated nitric acid (Mbui *et al.*, 2016 as cited/ref. from Maiti, 2004 and

in Munene *et al.*, 2021 study, water samples were boiled slowly at controlled temperature of 70°C, then addition of concentrated nitric acid and concentrated sulphuric acid. Tomno *et al.*, 2020 water samples were digested in tri acid mixture (HNO₃, HCl and HClO₄ at ratio of 5:1:2 at 150°C for not less than 20 minutes (Tomno *et al.*, 2020 as cited/ref. from Nazir *et al.*, 2015). In Njogu *et al.*, 2011 study, water samples were acid digested with a mixture of nitric acid and perchloric acid (1:3).

Water sample studies for reviews, reagents used, for the water samples before analyzing, were not generally consistent, with a good number of those indicating using nitric acid solution or a mixture of the same.

3. Discussion

Based on the 71 water concentration values, most of those were within the allowable concentration levels. Majority of water concentrations equal or above the allowable value (10/17) based on Environmental management and co-ordination (water quality) regulations, were from or adjacent to Nairobi, the others 7 were for river in Eldoret according to Munene *et al.*, 2021 study. Hence, based on this review, generally, water bodies that are within major urban areas in Kenya are at higher risk for lead pollution.

The results varied for studies that conducted samples in different seasons. Njuguna *et al.*, 2017, study on assessment of macrophyte, heavy metals and nutrients in Nairobi river/basin, attributed variation in pollutant concentration to prevailing weather. According to Mwashote, 2003 study, the concentration levels were usually higher during the wet season. Njuguna *et al.*, 2017 study, for on assessment of macrophyte, heavy metals and nutrients in Nairobi river/basin, there were higher pollutions in 2016, dry season as compared with wet season in 2015. According to Kiema *et al.*, 2017 study, wet season had higher levels of Pb concentration, hence surface run-off after rainfall seemed to be the main method of washing heavy metals to Winam Gulf, Lake Victoria.

High concentration of pollution was attributed to industrial activities (Kithiia and Ongwenyi, 1997), possibly due to effluent from garage and car wash near river (Mbui *et al.*, 2016), possibly due to lead acid batteries, detected adjacent to Dandora dumping site (Njuguna *et al.*, 2017), Pb in samples could be from metallic waste from open air garage, near Lini stream, sewage effluent, petroleum product from garage and disposition of airborne Pb (Tomno *et al.*, 2020), most significant pollution sources, for heavy metals to the watercourse were reported to be flower farms, river Malewa and Naivasha municipal council, and in L. Oloidien could be due to bio-concentration by blue-green algae, also due to being a soda lake, in lake Naivasha basin (Njogu *et al.*, 2011) and industrial activities that discharged waste water having heavy metals (Kiema *et al.*, 2017). Hence, human, industrial and agricultural activities and poor waste management are possibly major sources of Pb or other metal pollution in water bodies.

Table 2, show the ranges of lead concentration in sediment, for some studies outside Kenya, which ranged between 2.15 mg/kg to 270 mg/kg, the upper range values were higher than those for studies in Kenya by Mwashote, 2003, Outa *et al.*, 2020, Njogu *et al.*, 2011 and Kiema *et al.*, 2017. Possibly, this could be due to longer period of pollution and accumulations, and proper pollution controls measure should be put in place to prevent accumulations, reduction or remediation.

Based on Mwashote, 2003, Outa *et al.*, 2020, Mbui *et al.*, 2016, Munene *et al.*, 2021, Tomno *et al.*, 2020 and Njogu *et al.*, 2011 studies, reagents used, for the water samples before analyzing, were not consistent, with a good number of those indicating using nitric acid solution or a mixture of the same. Also, based on Mwashote, 2003, Njogu *et al.*, 2011, Kiema *et al.*, 2017 and Outa *et al.*, 2020 studies, reagents and temperatures used, for the sediment samples before analyzing, were not consistent. Outa *et al.*, 2020 reported that the actual trace element sedimentary concentration

indicated in their study could have been as much as 10 – 30% underestimated. More experimental researches and appropriate modeling techniques, with consideration to local conditions should be conducted for laboratory method, with an aim of providing accurate and consistent methods.

Since a good number of studies used nitric acid for water samples, evaluation should be focused on the same reagent, with an aim to obtain suitable mixture proportions and improved results reliability. Research should be conducted, an evaluation and comparison of various methods for extraction reagents, concentrations, preparation and costs, including the temperatures and durations, so as to establish a cost-effective method that would appropriately provide accurate concentrations for Pb in water and sediment.

4. Conclusion

This study shows that lead pollution in water bodies was higher particularly within major urban areas in Kenya. Based on the 71 lead concentration values in water, 17 (23.94%), were above the maximum allowable values based on republic of Kenya (2006) regulation. Reviews indicated that there were variations in concentrations with weather patterns, an indication that run-off during the wet season either increase pollution or dilute the contaminants in water bodies. Lead and heavy metals pollution in water bodies in Kenya could be attributed mainly to human, industrial and/or agricultural activities and poor waste management.

There should be proper treatment and monitoring of effluent from industrial and municipal wastes. Also, human and industrial activities, that may result to lead pollution in water bodies should be prevented through enforcement of riparian protection. Proper risk management measures should be conducted for agricultural activities including inputs. All human, agricultural and industrial activities should be prevented in the riparian areas.

There was variation in method used by various reviewed studies. More experimental researches and appropriate modeling techniques, with consideration to local conditions should be conducted for laboratory methods, with an aim of providing accurate and consistent methods and standards.

Acknowledgments: Appreciations to the authors and contributors of the previous works used for this article

Author contributions: The authorship was entirely by Cornelius Ngandu.

References

1. Abubakar, A.J.; Yusuf, S.; Shehu, K. (2015) Heavy metals pollution on surface water sources in Kaduna metropolis, Nigeria. *SWJ*, 10 (2), 1-5. <https://www.scienceworldjournal.org/article/download/15478/9881>
2. Astatkie, H.; Ambelu, A.; Mengistie, E. (2021) Contamination of stream sediment with heavy metals in the Awetu watershed of Southwestern Ethiopia. *Front. Earth sci*, 9, 658737. <https://doi.org/10.3389/feart.2021.658737>
3. Bhuyan, M.S.; Bakar, M.A.; Rashed-Un-Nabi, M.; Senapathi, V.; Chung, S.Y.; Islam, M.S. (2019) Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra river, Bangladesh. *Appl. Water sci*, 9, 125. <https://doi.org/10.1007/s13201-019-1004-y>
4. Britannica. Available online: <https://www.britannica.com/place/Kenya> (accessed on 13/05/2022)
5. Centers for disease control and prevention- CDC. Available online: <https://www.cdc.gov/nceh/lead/prevention/sources/water.htm> (Accessed on 5/01/2022)

6. Evens, A.; Hryhorczuk, D.; Lanphear, B.P.; Rankin, K.M.; Lewis, D.A.; Forst, L.; Rosenberg, D. (2015) The impact of low-level lead toxicity on school performance among children in the Chicago public-schools: a population based retrospective cohort study; *Environ health*, 14, 21. <https://doi.org/10.1186/s12940-015-0008-9>
7. Googles maps. Available online: <https://www.google.com/maps/@-0.5551993,41.7989254,6z> (accessed on 13/05/2022)
8. Khan, M.I.; Khisroon, M.; Khan, A.; Gulfam, N.; Siraj, M.; Zaidi, F.; Ahmadullah; Abidullah; Fatima, S.H.; Noreen, S.; Hamidullah; Shah, Z.A.; Qadir, F. (2018) Bioaccumulation of heavy metals in water, sediments and tissues and their histopathological effects on *Anodonta cygnea* (Linea, 1876) in Kabul river, Khyber Pakhtunkhwa, Pakistan. *BioMed Research International*, 2018, 1910274. <https://doi.org/10.1155/2018/1910274>
9. Kiema, F.M.; Owour, P.O.; Kapiyo, R.J.A. (2017) Recent influences of anthropogenic activities and seasons on heavy metal distribution in shoreline sediments in Lake Victoria near Kisumu city Kenya. *J environ anal chem*, 4(2), 1000201. DOI:10.41722380-2391.1000201
10. Kilonzo, W.; Home, P.; Sang, J.; Kakoi, B. (2019) The storage and water quality characteristics of Rungiri quarry reservoir in Kiambu, Kenya, as a potential source of urban water. *Hydrology*, 6, 93; doi: 10.3390/hydrology6040093
11. Kithiia, S.K. (2007) An assessment of water quality changes within the Athi and Nairobi river basins during the decade. Water quality and sediment behaviour of the future: *Prediction for 21st century, Proceedings of symposium HS2005 at IUGG2007, 2007. IAHS Publ.*, 314, 2007, 205 – 212. <https://iahs.info/uploads/dms/14040.28-205-212-314-18-Kithiia.pdf>
12. Kithiia, S.M.; Ongwenyi G.S. (1997) Some problems of water quality degradation in the Nairobi river sub-basin in Kenya. *Fresh contamination, proceedings of Rabat symposium S4, Rabat, Morocco, April-May 1997; IAHS publ.*, 243, 1997, 121 – 127. <https://iahs.info/uploads/dms/10745.121-127-243-Kithiia.pdf>
13. Li, H.; Li, Y.; Lee, M.K.; Liu, Z.; Miao, C. (2015) Spatiotemporal analysis of heavy metal water pollution in transitional China. *Sustainability*, 7, 9067-9087; doi: 10.3390/su7079067
14. Li, X.; Shen, H.; Zhao, Y.; Cao, W.; Hu, C.; Sun, C. (2019) Distribution and potential ecological risk of heavy metals in water, sediments and aquatic macrophytes: a case study of the junction of four rivers in Linyi city, China. *Ijerph*, 16, 2861. doi: 10.3390/ijerph16162861
15. Luo, Y.; Rao, J.; Jia, Q. (2022) Heavy metal pollution and environmental risks in the water of Rongna river caused by natural AMD around Tiegelongnan copper deposit, Northern Tibet, China. *Plos one*, 17(4), e0266700. <https://doi.org/10.1371/journal.pone.0266700>
16. Mbui, D.; Chebet, E.; Kamau G.; Kibet J. (2016) The state of water quality in Nairobi River, Kenya; *Asia j of research in chem.*, 9(11), 579-586. doi:10.5958/0974-4150.2016.00078.X
17. Mrozińska, N.; Bąkowska, M. (2020) Effects of heavy metals in lake water and sediments on bottom invertebrates inhabiting the blackish coastal lake Łebsko on the southern Baltic coast. *Ijerph*, 17, 6848. doi: 10.3390/ijerph17186848
18. Munene, N.E.; Hashim, N.O.; Ambusso, W. (2021) Numerical modeling of heavy metals in riverine systems in Eldoret, Uasin-Gishu county, Kenya. *JAGST*, 20(2). <https://ojs.jkuat.ac.ke/index.php/JAGST/article/view/189/186>
19. Mustapha, A.M.; Ugya, A.Y.; Mustapha, Z. (2021) Assessment of heavy metal levels in fish tissues, water and sediment from Epe lagoon, Lagos, Nigeria. *SWJ*, 16(4), 464 – 469. <https://www.scienceworldjournal.org/article/download/22396/14370>

20. Mwashote, B.M. (2003). Levels of cadmium and lead in water, sediments and selected fish species in Mombasa, Kenya. *Western Indian ocean j. mar. sci.*, 2(1), 25-34, DOI: 10.4314/wiojms.v2i1.28426
21. Njogu, P.M.; Keriko, J.M.; Wanjau, R.N.; Kitetu, J.J. (2011) Distribution of heavy metals in various lake matrices; water, soil, fish and sediments: A case study of the lake Naivasha basin, Kenya. *JAGST*, 13 (1), 91-106. <https://ojs.jkuat.ac.ke/index.php/JAGST/article/view/144/146>
22. Njuguna, S.M.; Yan, X; Gituru, R.W.; Wang, Q; Wang, J. (2017) Assessment of microphyte, heavy metal and nutrient concentrations in the water of the Nairobi River, Kenya; *Environ monit assess.*, 189, 454. DOI:10.1007/s10661-017-6159-0
23. Obeng-Gyasi, E.; Ferguson, A.C.; Stamatakis, K.A.; Province, M.A. (2021) Combined effect of lead exposure and allostatic load on cardiovascular disease mortality- A preliminary study, *IJERPH*, 18, 6879. doi: <https://doi.org/10.3390/ijerph18136879>
24. Outa, J.O.; Kowenje, C.O.; Plessl, C.; Jirsa, F. (2020) Distribution of arsenic, silver, cadmium, lead and other trace elements in water, sediment and macrophytes in Kenyan part of Lake Victoria: Spatial, temporal and bioindicative aspects. *Environ sci and pollut res*, 27, 1485-1498. <https://doi.org/10.1007/s11356-019-06525-9>
25. Republic of Kenya, (2006) Environmental management and co-ordination (water quality) regulation, 2006, Republic of Kenya; Kenya, 2006; pp 9. https://www.nema.go.ke/images/Docs/water/water_quality_regulations.pdf (Accessed on 14/05/2022)
26. Republic of Kenya, Ministry of water and irrigation. The national water resources management strategy (NWRMS) 2006-2008; Kenya; pp 1-2. Available online: <https://waterfund.go.ke/watersource/Downloads/006.%20Water%20Resources%20Management%20Strategy.pdf> (Accessed on 7/01/2022)
27. Shanbehzadeh, S; Vahid Dastjerdi, M; Hassanzadeh, A; Kiyanizadeh T. (2014) Heavy metals in water and sediment: A case study of Tembi river. *Journal of environmental and public health*, 2014, article ID 858720. <https://doi.org/10.1155/2014/858720>
28. Sun, X.; Li, B.S.; Liu, X.L.; Li, C.X. (2020) Spatial variations and potential risks of heavy metals in seawater, sediments and living organisms in Jiuzhen bay, China. *Journal of chemistry*, 2020, 7971294, 13. <https://doi.org/10.1155/2020/7971294>
29. Tomno, R.M.; Nzeve J.K.; Mailu, S.N.; Shitanda, D.; Waswa F. (2020) Heavy metal concentration of water, soil and vegetables in urban streams in Machakos municipality, Kenya. *Scientific African*, 9, e00539 . <https://doi.org/10.1016/j.sciaf.2020.e00539>
30. United States Environmental Protection Agency- EPA. Available online: <https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water>
31. Xu, J.; Chen Y.; Zheng, L.; Liu, B.; Liu, J.; Wang, X. (2018) Assessment of heavy metal pollution in sediment of the main tributaries of Dongting lake, China. *Water*, 10, 1060. doi: 10.3390/w10081060

