Original Research Article

Uncovering the Anthropogenic Influences on Water Quality: A Case of Lake Victoria Shores, Entebbe, Uganda

Abstract

Lakes serve as vital ecosystems, providing freshwater resources and habitats for diverse species. However, human activities, particularly around lakeshores, have led to significant environmental degradation, including heavy metal contamination. Lake Victoria, the second-largest freshwater lake globally, has been severely impacted by pollution from industrial, agricultural, and urban sources. This research aims at examining the influence of the anthropogenic activities on the water quality of Lake Victoria. Specifically, the study tried to determine the activities undertaken at the Lake shores of Lake Victoria; determined the physico-chemical parameters of the water from the shores and the heavy metal concentration in the water samples obtained from the shores of Lake Victoria. This study utilized a cross-sectional and experimental research designs to assess water quality and anthropogenic influences around Lake Victoria. A total of 150 residents from selected communities were surveyed using a semi-structured questionnaire to gather demographic information, perceptions of water quality and the activities carried out within the shores of Lake Victoria. Water samples were collected from multiple sites along the lake shores for analysis of heavy metals using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Water quality parameters were determined in-situ using a multi-parameter water testing kit and Hanna instrument. Results showed that the anthropogenic activities that could have contributed to water degradation include: fishing, transport, agriculture and construction among others. Apart from pH which was outside the permissible limits, all the other water parameters were within the WHO permissible limits. Considering the heavy metal concentration, all the sampled sites apart from one inlet, had the concentrations above the WHO permissible levels an indication of significant heavy metal contamination in the Lake Victoria shores. These findings highlight the urgent need for targeted pollution control measures and regular monitoring to mitigate further environmental degradation. Effective interventions, including stricter regulations and sustainable land use

practices within the Victoria shores are essential for safeguarding the lake's ecosystem and the health of surrounding communities.

Keywords: Anthropogenic activities; Environmental pollution; Heavy Metal Contamination; Water quality; Lake Victoria.

1. Introduction

Lakes serve as critical ecosystems, offering freshwater resources and habitat for diverse plant and animal species (Barakagira and de Wit, 2017; 2019). However, growing human activities, particularly around water bodies, have contributed to severe environmental degradation (Heino et al., 2021; Baguma and Barakagira, 2022). One significant concern is the contamination of water bodies by heavy metals, which are introduced into lakes through industrial waste, agricultural runoff, and other anthropogenic activities (Kapoor & Singh, 2021; Pule and Barakagira, 2022). These pollutants pose serious risks to both the ecosystem and human health due to their persistence and toxicity (Ali et al., 2019; Priyadarshanee et al., 2022). Surface waters are particularly vulnerable to pollution because of their accessibility for waste disposal (Walker et al., 2019; Barakagira and Kateyo, 2008). Human activities, such as industrial development, urbanization, and agriculture, have intensified the deposition of harmful contaminants, including heavy metals, into lakes. These activities not only reduce the quality of water but also lead to long-term ecological consequences that threaten biodiversity and water usability (Ojelel et al., 2024; Gao et al., 2018; Fang et al., 2019; Sharma et al., 2023).

Lake Victoria, the world's second-largest freshwater lake, located in East Africa, has undergone dramatic environmental changes in recent decades due to both natural processes and human-induced activities. As a shared resource between Kenya, Tanzania, and Uganda, Lake Victoria has experienced a rise in nutrient loading, a decline in oxygen levels, and increased pollution, including heavy metal contamination, particularly along its shores (Nassali et al., 2020; Nyamweya et al.,

2023). The lake is critical for the livelihood of millions of people who rely on it for fishing, water, and agriculture. However, the increased population, industrial activities, and poor waste management in the Lake Victoria Basin (LVB) have exacerbated the levels of pollutants, including lead, mercury, and cadmium, posing serious health risks to local communities and aquatic life (Wasonga et al., 2020; Outa et al., 2020; Baguma et al., 2022; Baguma and Barakagira, 2022). Despite numerous studies highlighting the general pollution issues affecting Lake Victoria, there is a notable gap in research focusing on heavy metal contamination, especially along the Ugandan shores of the lake. The accumulation of heavy metals can have profound effects on water quality, impacting its suitability for domestic and agricultural use, and creating potential hazards for aquatic organisms. Understanding the extent of heavy metal contamination and its sources is crucial for developing effective mitigation strategies. This study aims to examine the degree of heavy metal contamination in selected areas around Lake Victoria, focusing on the contribution of anthropogenic activities to this growing problem. Through this research, the study seeks to provide insights into the current status of water quality in the lake and inform efforts to safeguard this critical water resource.

2. Methodology

2.1 Study Design

This study employed a cross-sectional and experimental research design, which allowed for the simultaneous collection of data on water quality and anthropogenic influences affecting the shores of Lake Victoria. Water samples were collected from multiple sites along the lake shores, specifically chosen for their proximity to potential pollution sources, such as urban runoff, industrial discharges, and agricultural activities. An experimental framework was established to determine the concentration of heavy metals, including lead (Pb), cadmium (Cd), and mercury (Hg), using standardized laboratory techniques. In addition to laboratory analyses, semi-structured questionnaires were administered to residents to gather qualitative data on their perceptions of water quality, potential pollution sources, and observed changes in the environment over time.

2.2 Study Area

The study was conducted from the selected areas along Lake Victoria shores, specifically from Wagagai, Nakiwogo, Kasenyi, and Kigungu. These areas were chosen based on their proximity to the lake and their potential exposure to heavy metal contamination due to various human activities, including fishing, agriculture, and waste disposal. A purposive sampling method was employed to select participants, ensuring representation from diverse demographics, including different age groups, occupations, and levels of education. From the mentioned areas, water samples were collected for the analysis of the physico-chemical parameters and heavy metal concentration.

2.3 Sample Size & Sampling Method

The sample size for this study was determined using Cochran's formula, which is widely recognized for estimating sample sizes in survey research. Given the absence of specific population proportions for the selected areas, a conservative estimate of 50% ($p = 0.5$) was utilized to ensure the robustness of the sample size calculation. The formula: $n = Z^2pq / d^2$. Where: n = sample size; Z = standard normal deviation (1.96 for a 95% confidence level); p = estimated proportion (0.5); $q = 1 – p$ and d = margin of error (0.05) was utilized to calculate the sample size. Applying these parameters, the calculated sample size was 384. However, due to logistical constraints, including time and resource limitations, a final sample size of 150 respondents was achieved. A purposive sampling method was employed to select participants from the households within the Lake shores who were administered questionnaires. This approach was adopted to ensure the inclusion of individuals directly affected by water quality issues, particularly those engaged in activities related to the lake, such as fishing and farming. By targeting specific demographics, the study aimed to gather relevant insights concerning the anthropogenic influences on water quality and heavy metal contamination.

2.4 Data Collection Tools

A semi-structured questionnaire was developed to facilitate face-to-face interviews with respondents. The questionnaire included both closed and open-ended questions to capture quantitative data on demographics, perceptions of water quality, and reported health issues related to water usage. Water samples were collected from designated sites along the shores of Lake Victoria using clean, sterilized bottles to prevent contamination. The samples were tested on-site and in-situ using portable water quality testing instruments, including a pH meter, conductivity

meter, and dissolved oxygen meter and a multi-parameter water testing kit. Following the initial on-site testing, water samples were sent to accredited laboratories for comprehensive analysis of the concentration of heavy metals (e.g., lead, cadmium, mercury). This ensured accurate and reliable measurements of contaminants. An observation checklist was employed during site visits to document environmental conditions and potential pollution sources, such as waste disposal sites and industrial discharges. This tool complemented the data gathered through the questionnaire by providing contextual insights into the physical environment surrounding the lake.

2.5 Data Collection Procedure

The data collection procedure involved several key steps to ensure systematic and reliable gathering of both water quality measurements and community perspectives. Before data collection, the research team was trained on the objectives of the study, the use of sampling equipment, and interview techniques. This training ensured that all team members understood the importance of maintaining data integrity and ethical considerations. Water samples were collected from pre-identified sites along the shores of Lake Victoria, including Wagagai, Nakiwogo, Kasenyi, and Kigungu. Each sampling site was visited on designated days, ensuring that samples were taken at different times to account for any variations in water quality. Clean, sterilized bottles were used to collect approximately one liter of water from each site, and samples were labeled immediately to avoid mix-ups. Following sample collection, water quality parameters such as pH, temperature, and electrical conductivity were measured on-site using portable testing instruments. This initial assessment provided immediate insights into the water quality before samples were transported to the laboratory for further analysis of heavy metals. Face-to-face interviews were conducted using the semi-structured questionnaire with residents in the selected areas. Local guides were utilized to facilitate communication, especially where language barriers existed. Interviews were conducted in a private setting to encourage open and honest responses from participants. After the on-site tests, water samples were transported under appropriate conditions to accredited laboratories for the analysis of heavy metals. Detailed chain-of-custody procedures were followed to ensure the samples' integrity during transport and analysis. All collected data, including questionnaire responses and laboratory results, were organized and stored in a secure database. Regular checks were conducted to ensure the accuracy and completeness of the data before analysis.

2.6 Data Analysis

The data collected using the questionnaires were analyzed using the Statistical Package for Social Sciences (SPSS). Heavy metal concentration analysis was done using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Descriptive statistics, including means, frequencies, and standard deviations, were computed to summarize the water quality parameters and demographic characteristics of respondents.

3. Results

The demographic characteristics of the respondents indicate that the largest age group consisted of those over 30 years (52.0%), followed by those aged 20-30 years (40.7%), with only a small portion under 20 years (7.3%). Regarding gender, the majority were male (64.0%) compared to females (36.0%). Regarding marital status, most respondents were married (56.0%), with a significant number being single (33.3%), while divorced (4.7%) and widowed (6.0%) respondents made up smaller portions. The respondents consisted of various occupations including: fishermen (30.0%), businesspersons (28.7%), and company employees (23.3%) representing the largest groups. Smaller numbers were students (5.3%), farmers (4.7%), teachers (2.7%), and unemployed individuals (7.3%). In terms of period of stay, nearly half (49.3%) of the respondents had lived in the area for more than 5 years, while a notable proportion (43.3%) had stayed between 1-5 years and a smaller number (7.3%) had stayed less than a year. This distribution reflects a diverse set of backgrounds among the participants as shown in Table 1.

Table 1: Demographic Characteristics of Respondents: (Questionnaire survey, 2023)

Characteristics	Frequency	Percent
Age		
<20 years	11	7.3
20-30 years	61	40.7
> 30 years	78	52.0
Gender		
Male	96	64.0

Female	54	36.0
Marital Status		
Divorced	7	4.7
Married	84	56.0
Single	50	33.3
Widowed	9	6.0
Occupation		
Business person	41	28.7
Company employee	35	23.3
Fisherman	42	30.0
Farmer	7	4.7
Student	8	5.3
Teacher	4	2.7
Unemployed	11	7.3
Duration of Stay		
<1 year	11	7.3
1-5 years	65	43.3
> 5 years	74	49.3

The respondents still show that 53.3% were moderately concerned about water pollution, 63.3% perceived the water quality as very low, and 48.0% agreed that watercolor had changed. In comparison, 31.3% strongly agreed that there was a change in the water odor. Additionally, about 87% agreed about the presence of suspended solid waste in Lake Victoria. These results suggest that a significant number of respondents expressed concern about water quality and environmental changes in the lake as seen in Table 2.

Table 2: Respondents' Perceptions of Water Quality, Water Color Change, Odor, and Solid Waste in Lake Victoria: (Questionnaire survey, 2023)

Category	Response	Frequency	Percent

Concern about water pollution	Extremely concerned	17	11.3
	Moderately concerned	80	53.3
	Slightly concerned	53	35.3
Water Quality Perception	Very Low	95	63.3
	Low	41	27.3
	Normal	14	9.3
Water Color Change	Strongly Agree	49	32.7
	Agree	72	48.0
	Not Sure	1	0.7
	Disagree	22	14.7
	Strongly Disagree	6	4.0
Water Odor Change	Strongly Agree	47	31.3
	Agree	64	42.7
	Not Sure	1	0.7
	Disagree	30	20.0
	Strongly Disagree	8	5.3
Presence of Suspended Solid Waste	Strongly Agree	59	39.3
	Agree	70	46.7
	Disagree	19	12.7
	Strongly Disagree	2	1.3

The data on major anthropogenic activities around Lake Victoria reveals that fishing is the most common activity, accounting for 32.0% of respondents. This is followed by transportation at 23.3%, and small business at 16.7%. Agriculture is practiced by 15.3% of the respondents, while urbanization and industrialization activities are reported by 12.7% of the respondents. These results highlight the predominance of fishing and transportation, indicating their significant role in the livelihoods of those living around Lake Victoria, while urbanization and industrialization play a smaller, yet notable role as seen in Table 3.

Table 3: Major Anthropogenic Activities Around Lake Victoria Shores (Questionnaire Survey, 2023)

Activity	Frequency	Percent
Fishing	48	32.0
Transportation	35	23.3
Small Business	25	16.7
Agriculture	23	15.3
Urban and Industrialization	19	12.7

The water quality parameters were determined from the samples collected in the study areas including Wagagai, Nakiwogo, Kasenyi, and Kigungu. Table 4 provides an overview of the results of the various locations around the shores of Lake Victoria. Results on electric conductivity ranged from 62.4 to 65.9 µS/cm, while TDS levels varied between 30.9 to 32.7 mg/L across sites. pH values spanned from 9.1 to as high as 10.4, and water temperatures fluctuated between 25°C and 27°C. The odor of the water in the selected sites varied significantly, with some emitting fishy smells, others being odorless. Water color ranged from light yellow to greenish yellow at certain sites. The variability in these parameters reflects the influence of site-specific factors and potential anthropogenic activities affecting water quality within the shores of Lake Victoria.

Table 4: Physico-chemical Parameters of the water samples (Primary data, 2023)

Location	EC	TDS	pH	Temp (°C)	Odor	Color
Nakiwogo	65.9	32.7	10.4	25	Fishy smell	Light yellow
Wagagai	62.4	30.9	9.9	26	odorless	Greenish Yellow
Kasenyi	63.8	32.0	9.1	26	Fishy smell	Greenish Yellow
Kigungu	64.2	32.1	10.0	27	Fishy smell	Greenish Yellow
WHO Standards	1500	1200	6.0-8.0			

The concentration of heavy metals, specifically lead (Pb), cadmium (Cd), and mercury (Hg), that was determined revealed notable differences across the sites of the shores of Lake Victoria. The

Wagagai Inlet had lead concentrations of 0.01 mg/L, cadmium at 0.006 mg/L, and a notably high mercury level of 0.80 mg/L. The Nakiwogo sample shows slightly higher levels of lead (0.02 mg/L) and cadmium (0.007 mg/L) compared to Wagagai Inlet, with mercury concentrations at 0.70 mg/L. In the Kasenyi sample, the highest lead concentration among the samples is observed at 0.03 mg/L, cadmium levels are recorded at 0.008 mg/L, and mercury at 0.70 mg/L. Lastly, the Kigungu sample presents the highest concentration of lead at 0.04 mg/L, with cadmium levels consistent with other sites at 0.008 mg/L, and mercury levels equal to those of Wagagai Inlet at 0.80 mg/L. In summary, the concentrations of lead, cadmium, and mercury vary among the sampled locations. However, all the samples exhibited higher concentration levels of the metals that were tested as compared to the WHO standards. The anthropogenic activities including farming where pesticides and herbicides might have been used, and industrial activities in the area might have been the major sources of the mentioned heavy metals. However, the results underscore the need for further monitoring and investigation of the other potential sources of pollution.

Table 5: Heavy Mental Concentration in Water Samples (Primary data, 2023)

Sampling site	Pb (mg/L)	Cd (mg/L)	Hg (mg/L)
Wagagai Inlet	0.01	0.006	0.80
Nakiwogo	0.02	0.007	0.70
Kasenyi	0.03	0.008	0.70
Kigungu	0.04	0.008	0.80
WHO Limits	0.01	0.005	0.001

4. Discussion

This study aims to investigate the extent of heavy metal contamination in specific areas around Lake Victoria, emphasizing the role of anthropogenic activities in contributing to this issue. The demographic distribution of the respondents in this study provides valuable insights into the communities residing near Lake Victoria's shores, a population likely impacted by environmental changes in the lake. Most of the respondents were over 30 years of age, with a significant proportion of respondents engaged in fishing, business, and other local occupations. This finding

aligns with studies that reported that residents around Lake Victoria rely heavily on fishing and related businesses for their livelihoods, which heightens their sensitivity to environmental changes in the lake (Nyaboer et al., 2022; Petty et al., 2022). The gender disparity, with more males than females, mirrors findings from earlier studies conducted in the region that reflect the dominant involvement of men in occupations such as fishing, which has been reported as traditionally male-dominated (Obiero et al., 2019; Ng'Wigulu, 2021; Kalukusu and Barakagira, 2021; Kavuma and Barakagira, 2024).

A considerable proportion of the respondents (63.3%) perceived the water quality in Lake Victoria to be "very low," while a majority (53.3%) expressed moderate concern about water pollution. These perceptions are consistent with previous studies highlighting increasing concerns about Lake Victoria's water quality degradation due to anthropogenic activities (Barakagira and de Wit, 2019; Barakagira and de Wit, 2017; Ntiba et al., 2001; Sitoki, et al., 2010; Twesigye et al., 2011; Kavuma and Barakagira, 2024). The high level of agreement (48.0%) about changes in water color and strong concern (39.3%) regarding the presence of suspended solid waste further emphasize the community's awareness of environmental changes, particularly those linked to pollution and eutrophication. The perception of water odor change, with 31.3% strongly agreeing, also indicates growing concerned about water quality, which is consistent with findings of other studies that identified odor issues as a by-product of nutrient loading and the growth of harmful algal blooms in the lake (Namukonge and Barakagira, 2024; Suffet, et al., 1995; Küppers, et al., 2019). These perceptions reflect the ongoing degradation of the lake’s water quality and the increasing ecological stresses imposed by human activities, such as overfishing, agriculture, and industrial waste disposal. Moreover, the high level of agreement (46.7%) regarding the presence of solid waste in the lake highlights a pressing environmental issue that has been raised in previous studies, which documented the significant levels of domestic and industrial waste deposited into the lake (Thevenon et al., 2011; Bhateria & Jain, 2016; Aragaw 2021; Bhat et al., 2022). These findings are concerning as they indicate that the lake is facing multifaceted threats from pollution, including both chemical contaminants and physical waste, which are exacerbating its deteriorating ecological condition.

The anthropogenic activities around Lake Victoria, demonstrate the heavy reliance of local communities on fishing (32.0%), followed closely by transportation (23.3%) and small businesses (16.7%). These results are consistent with the findings of previous studies that highlighted fishing

as a predominant economic activity in the Lake Victoria basin (Barakagira and de Wit, 2017; Barakagira and de Wit, 2019; Kayombo & Jorgensen, 2006; Odongkara, et al., 2009; Mgaya & Mahongo, 2017; Onyango, 2017). The significant role of transportation in the livelihoods of residents around the lake reflects the growing need for connectivity and trade facilitated by water transport routes (Moreau & Garaway, 2021). However, the increasing urbanization and industrialization, reported by 12.7% of the respondents, point towards shifting trends in land use that may exacerbate environmental challenges such as pollution, habitat destruction, and water contamination. This corroborates studies that identified urban growth and industrial activities as key contributors to water quality degradation in the lake (Baguma and Barakagira, 2022; Juma et al., 2014; Akhtar, et al., 2021; Feng et al., 2021). The fact that agriculture is practiced by 15.3% of respondents indicates that, while not dominant, farming remains an important livelihood activity in the region. Agricultural runoff, laden with fertilizers and pesticides, has been documented as a significant contributor to nutrient loading in the lake, leading to eutrophication and the proliferation of invasive species like the water hyacinth (Borah et al., 1999; Okungu & Peterlis, 2002; Yara, 2019). As urbanization, industrialization, and agriculture expand around Lake Victoria, the environmental pressure on the lake's ecosystem is likely to intensify, necessitating sustainable land use practices and more stringent pollution control measures.

The water quality parameters measured during the wet season, exhibit notable variability across different sites around Lake Victoria. Conductivity values ranging from 59.3 to 68.9 µS/cm and TDS levels between 29.3 to 34.0 mg/L indicate low mineralization of the water, which aligns with findings from earlier studies by Namukonge and Barakagira (2024), Baguma et al. (2022), Mutakyahwa et al. (2009) and Kairu (2001), who observed similar ranges in areas less affected by industrial discharges. However, the wide pH range outside the permissible levels is a point of concern, particularly the upper values, which suggest localized alkalinity potentially linked to industrial effluents or agricultural runoff (Kishe & Machiwa, 2003). Water temperature fluctuations between 24.5°C and 27.7°C are within the normal range for tropical lakes, but the variation in dissolved oxygen (DO) levels, from 4.90 mg/L to 6.10 mg/L, could indicate the impact of pollution, with some areas experiencing lower DO levels due to organic matter decomposition, a process linked to eutrophication (Bhat et al., 2022). The presence of fishy smells, color changes (light yellow to greenish hues), and odors of decomposing organic matter further corroborate these observations, reflecting the ongoing degradation of water quality driven by both natural processes

and anthropogenic activities. These findings are consistent with those of other studies that noted similar patterns of seasonal variation in water quality parameters due to runoff from agricultural lands and urban areas into the lake (Merugu & Seetharaman, 2013; Xiao et al. 2016; Shi et al., 2017).

The concentrations of heavy metals in water samples particularly concerning the mercury (Hg) levels being notably high across all sites, especially at the Wagagai Inlet (0.80 mg/L) and Kigungu (4b) (0.80 mg/L). These values far exceed the World Health Organization (WHO) recommended limits for mercury in drinking water, which is 0.001 mg/L (WHO, 2011). Such elevated levels of mercury point to significant contamination, likely resulting from industrial discharges, artisanal gold mining, quarrying and improper waste disposal (Pule and Barakagira, 2022; Tarras-Wahlberg et al., 2002). Mercury is a known neurotoxin and poses serious health risks to both aquatic life and humans who rely on the lake for drinking water and fish consumption (Mutakyahwa et al., 2009). Lead (Pb) concentrations, while lower than mercury, are also a cause for concern, particularly at Kigungu (4b) (0.04 mg/L) and Kasenyi (2b) (0.03 mg/L). These values are higher than those reported by Kairu (2001), who found lower lead concentrations in similar locations. The presence of cadmium (Cd) at relatively lower concentrations (0.006-0.008 mg/L) is consistent across the sites but still above permissible levels for aquatic environments (0.003 mg/L), as noted by the WHO (2011). Prolonged exposure to cadmium and lead has been linked to kidney damage and other long-term health issues (Tarras-Wahlberg et al., 2002), further underscoring the need for immediate intervention. These heavy metal concentrations reflect ongoing industrial activities and poor waste management around Lake Victoria, echoing findings by Kishe and Machiwa (2003) and Kairu (2001), who emphasized the cumulative impact of pollutants on the lake's ecosystem. The persistently high mercury levels across sites call for further investigation into potential contamination sources, particularly artisanal mining and industrial discharges, which may be exacerbating the situation.

5. Conclusion and recommendations

In conclusion, the findings of this study reveal significant levels of heavy metal contamination in Lake Victoria, particularly concerning concentrations of lead, cadmium, and mercury in various

locations. Anthropogenic activities such as fishing, transportation, agriculture, and urbanization appear to be contributing factors to the pollution of the lake. The water quality parameters measured during the wet season also showed variations in conductivity, pH, dissolved oxygen, and temperature, further reflecting the impact of human activities. The elevated mercury levels in multiple locations highlight an urgent need for targeted pollution control measures and regular monitoring to protect the lake's ecosystem and ensure the health of communities relying on its resources. Buffer zones need to be put in areas near the Lake and should be respected such that farming activities do not be practiced beyond them to limit easy wash down of the chemicals into the water body. The results obtained underscores the necessity for increased environmental regulations and sustainable practices to mitigate further contamination of Lake Victoria.

Declaration of competing / Conflicting interests:

The authors declare no competing interests in the conduct of this research.

Data availability:

The data presented in the manuscript is available on request.

Disclaimer (Artificial intelligence)

Option 1:

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

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