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KMFRI

Editorial

Editorial: Kenya Aquatica Journal Vol 10(1) – A Showcase of KMFRI's Pioneering Research in Freshwater Ecosystems

The latest edition of Kenya Aquatica Journal, Vol 10(1) showcases pioneering research by KMFRI scientists on Kenya's freshwater ecosystems. This edition, supported by KMFRI and WIOMSA, covers ecological, socio-economic, and environmental challenges, providing valuable insights into sustainable management practices.

One notable study investigates disease surveillance and antimicrobial resistance in fish from lacustrine caged farms, emphasizing responsible antibiotic use to maintain fish health. Another study explores the impact of organochlorine pesticides on macroinvertebrates in Lake ecosystems, advocating for Rhagovelia spp. as a bioindicator for pesticide monitoring across food webs.

Research on Lake Baringo's small-scale fishery assesses the catch and effort composition, stressing the need for regulatory enforcement to avoid overfishing and advocating for capacity building among stakeholders for sustainable management. Additionally, a study on wild fish kills in Lake Victoria focuses on eutrophication and pollution, recommending integrated watershed management to protect the lake's fisheries and local livelihoods.

A comprehensive study on Lake Elementaita – one of Kanya's flamingos' sanctuaries, combines water quality, fisheries studies, and community surveys, calling for integrated watershed management, conservation, and sustainable agriculture. Research on fisheries co-management in Lake Baringo highlights the importance of local community involvement and sustained achievements in ecosystem management, despite challenges in law enforcement.

An article on the socio-economic dynamics of Lake Victoria proposes establishing a regulatory framework incorporating citizen science to manage the lake's resources for long-term sustainability. Addressing plastic pollution in Lake Turkana, a study recommends waste management solutions, public awareness, and better enforcement of regulations to tackle the issue.

The journal also features research on antimicrobial resistance (AMR), with a review exploring Kenya's aquatic biodiversity for potential novel antimicrobial agents. A genetic research study evaluates freshwater fish populations, identifying gaps and proposing future directions for conservation and management.

Lastly, the journal presents an evaluation of fish market dynamics in Lake Naivasha, recommending infrastructure development like fish markets and hatcheries to support the region's fishery sector.

This edition of Kenya Aquatica Journal provides crucial insights into Kenya's freshwater ecosystems, covering a wide range of research on sustainable management, environmental challenges, and the socio-economic factors influencing aquatic resources. The research highlights KMFRI's ongoing contributions to understanding and addressing these issues, fostering a deeper understanding of Kenya's aquatic biodiversity.

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About
Kenya Aquatica

Kenya Aquatica is the Scientific Journal of the Kenya Marine and Fisheries Research Institute (KMFRI). The aim of the Journal is to provide an avenue for KMFRI researchers and partners to disseminate knowledge generated from research conducted in the aquatic environment of Kenya and resources therein and adjacent to it. This is in line with KMFRI's mandate to undertake research in "marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography", in order to provide sci entific data and information for sustainable development of the Blue Economy.

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Featured front cover picture: Researcher sampling surface plankton in the Kerio River inlet to Lake Turkana. (Photo credit: Mr. John Malala)

Featured back cover picture: Chair of KMFRI Board of Management Amb. Dr. Wenwa Akinyi Odinga Oranga (seated middle), on her right, Ag. KMFRI CEO Dr. James Mwaluma, flanked by KMFRI Heads of Sections: Front (L-R) Dr. Victoria Tarus, Ms Caroline Mukiira, Dr. Jacob Ochiewo, Dr. Irene Githaiga, Mr. Abraham Kagwima. Back (L—R) Mr. Paul Waluba, Ms Jane Kiguta, Dr. Gladys Okemwa, Dr. Eric Okuku, Dr. Joseph Kamau, Mr. Isaac Kojo, Ms Joan Karanja, Mr. Milton Apollo. (Photo credit KMFRI)
Research Vessel MV Mtafiti in the background

Unravelling the causes of the current wild fish kills in Kisumu Bay fishery of Lake Victoria, Kenya

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Abstract

Recurrent fish kills in Kisumu Bay, Lake Victoria, Kenya, threaten both ecological stability and local livelihoods. This study investigates the drivers of recent fish mortality events through field surveys and water quality analysis across key stations, including Kisat River mouth, Coca-Cola discharge zones, and the control station. Results revealed severe hypoxia (dissolved oxygen [DO] < 2.5 mg L^{-1}), far below the 6–8 mg L^{-1} threshold required for fish survival, alongside hyper-eutrophic conditions marked by elevated ammonium (NH_4^+ > 1.5 mg L^{-1}), total nitrogen (TN > 40–50 µg L^{-1}), and phosphorus (TP >700 µg L^{-1}). Chlorophyll-*a* concentrations exceeded 100 µg L^{-1}, indicating prolific algal blooms linked to nutrient overloading, possibly from industrial effluents, agricultural runoff, and untreated sewage. Spatial-temporal analysis identified the lowest DO levels during algal decomposition phases, exacerbated by an oil layer near docking sites, which could have impeded gas exchange and coated fish gills, intensifying respiratory stress. Nitrite peaks (21.12 mg L^{-1}) and ammonium spikes signaled toxic pollution from wastewater, while Secchi depth measurements inversely correlated with algal biomass, confirming turbidity-driven hypoxia. The study attributes fish kills to possible synergistic effects of nutrient pollution, climate-driven temperature rises (27.26°C on average), and inefficient waste management. The study recommends enforcing industrial effluent regulations, expanding wastewater treatment infrastructure, and reclaiming wetlands to mitigate runoff. This work provides a framework for addressing eutrophication-driven fish mortality in tropical freshwater ecosystems, advocating for integrated watershed management to sustain Lake Victoria's fisheries and socio-economic resilience.

Keywords: fish kills, hypoxia, eutrophication, nutrient pollution, Lake Victoria, algal bloom

Introduction

Fish kills, defined as the sudden localized large-scale death of fish in either marine, estuarine or freshwater environments are a common occurrence (Meyer and Barclay, 1990) and can range from several individuals to millions of fatalities per incident (Holmlund and Hammer, 1999). While some fish kills may occur naturally, due to extreme seasonal temperatures, parasites and diseases, human-induced changes and pollution have amplified their frequency and scale globally. A majority of the fish kills are linked to human activities emanating from industrial, municipal, agricultural and transport-related processes. Specific causes include chemical spills, manure, pesticide application, sewage and nutrient enrichment, and harmful algal blooms (La and Cooke, 2011). Despite the widespread occurrence, very few countries have established regional or national frameworks to systematically track the prevalence, magnitude, and underlying causes.

Over the years, Lake Victoria has undergone drastic environmental changes mainly due to anthropogenic activities, which have likely contributed to recurring fish kills. The transformation began with the advent of the railway, establishing the region as a special economic zone engaged in global trade (Graham, 1929). A wave of settlers arrived, drawn by the Lake's resources and fertile catchment area, leading to the conversion of forests, natural vegetation, and wetlands into agricultural land for cash crop plantations (Balirwa *et al.,* 2003). As a result, population growth around the Lake surged, increasing from 8.7 million in 1960 to over 42 million (Nyamweya *et al.,* 2020). Over the years, poor land-use practices and the extensive use of agrochemicals (Peters and Meybeck, 2000) contributed to soil erosion, siltation, and declining water transparency (Sitoki *et al.,* 2010). Additionally, deforestation, sedimentation, and nutrient loading led to eutrophication and frequent algal blooms, further impacting water quality and fish populations. The first eutrophication event is suspected to have occurred as early as the 1950s in the Kenyan waters of Lake Victoria and later on spread into the Uganda and Tanzanian regions. Studies indicate that during this period there was a shift in phytoplankton composition from diatoms to cyanobacteria. This was accompanied by deep-water oxygen depletion (anoxia) which intensified around this time. (Lehman, 1998; Verschuren *et al.,* 2002; Stager *et al.,* 2009). Urbanization and industrialization have exacerbated pollution, with untreated sewage and industrial effluents further degrading water quality (Balirwa *et al.,* 2003). Additionally, climate change has intensified these impacts through altered rainfall patterns, stronger storm events, and rising water temperatures, affecting dissolved oxygen levels and increasing the frequency and severity of fish kills.

The Nyanza Gulf has a history of fish kills with a notable event documented in 1984 after a violent storm that resulted in mass mortalities exceeding 400,000 fish, which collectively weighed over 2,400 tons. The casualties were Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*). Several factors were attributed to this mass mortality event such as low dissolved oxygen, high levels of suspended matter in the form of detritus and algae which clogged the gills of fish, low pH and algal bloom (Ochumba, 1990). Other factors include oxygen depletion caused by agricultural runoff which may contain toxic chemicals due to poor farming practices, ammonia toxicity and heavy rainstorms which increase runoff into the water body (La and Cooke, 2011).

Persistent occurrence of this phenomenon poses significant economic risks, especially by depleting populations vital to commercial and recreational fisheries (Holmlund and Hammer, 1999). For example, the 2022 fish kill incident in Kisumu and Homa Bay resulted in nearly a billion shillings ($7.2 million) in losses (Odhiambo, 2023). Similarly, the 2024 fish kills at Mulukoba where approximately 50 tonnes of fish were lost, translated to over 5 million shillings in losses (Opanda, 2024).

The number of distress calls on fish kills from stakeholders has escalated in recent months, with three calls within November and January, which is quite unusual. It is against this backdrop that this study was undertaken to investigate the current wild fish kills in Kisumu Bay, Kisumu County, and demystify their underlying causes to provide applicable mitigation measures.

Materials and methods

Study Area

The study on fish kills was undertaken in the Kenyan waters of Lake Victoria consisting of the Nyanza Gulf (Winam Gulf) which forms the major portion of Kenya waters (Fig. 1). The Kenyan side of the Lake covers an area of 4,100 km^2, with a length of about 60 km and width varying between 6 and 30 km and lies between 34° 13' and 34° 52' East of latitude 0°, 0° 4' and 0° 32' South of the Equator. The Gulf has an average depth of 6-8 m and a maximum depth of 70 m (in the open waters) (Odada *et al.,* 2004; Aura *et al.,* 2018). Nyanza Gulf at irregular periods of the year experiences intermittent fish kills affecting either cage or wild fish. Sampled stations were determined at accessible points within areas affected by reported fish kills. Global Position-

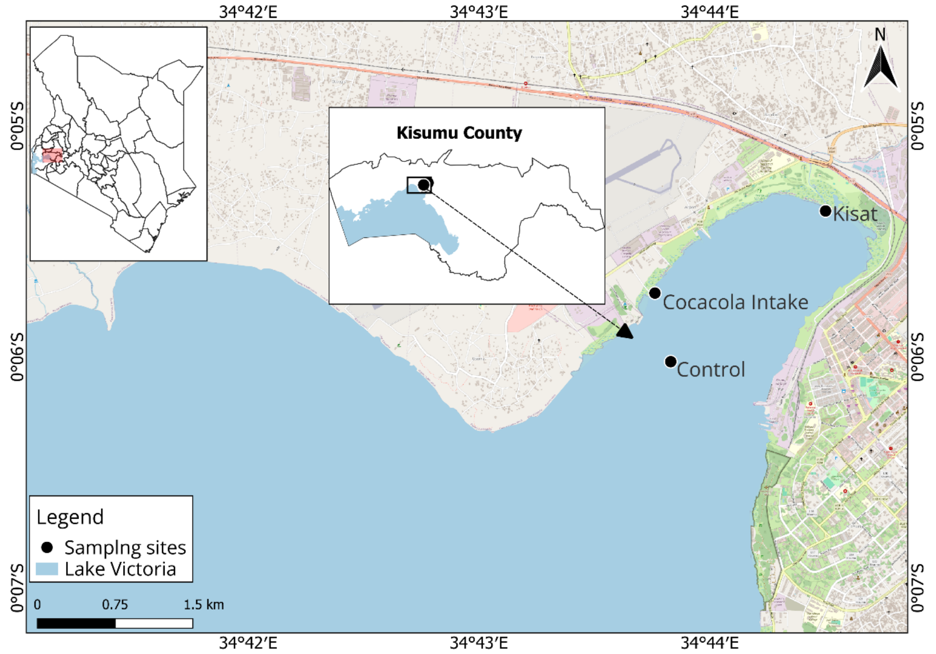

Figure 1. Map of Kisumu Bay, Winam Gulf, showing areas sampled for reported fish kills (Source: Owoko W., 2025)**.**

ing System (GPS) locations (GPS Coordinates) thereafter were marked using a hand-held GPS tool as waypoints and salient attributes of the sites recorded prior to sampling.

Physico-chemical parameters

After calibration, *in situ* physico-chemical water quality parameters of Temperature (°C) and Dissolved Oxygen (DO) (mg L^{-1}) measurements were achieved by use of a portable electronic YSI multi-parameter meter to log in water quality data down the depth of the water column. Acid-washed 500 ml plastic bottles were prepared for preservation of water samples for both soluble and non-soluble nutrients fractions of Soluble Reactive Phosphates (SRP), Nitrates, Ammonium, Nitrites and Silicates. Additionally, water samples for Chlorophyll-a, Total Nitrogen and Total Phosphorous were immersed in a cooler box at temperatures of about 4°C and transported for membrane filtration of a volume of lake water through Whatman® GF/C filters which were then used to determine the difference per unit volume of sample and digestion in KMFRI laboratory using methods adopted from APHA (2005) and Sasaki *et al.* (2005).

The analyzed nutrient compounds were Nitrates-N, Ammonium-N, Nitrites-N, Soluble Reactive Phosphorous (SRP) and Silicates. Secchi depth (m) measured with a standard Secchi disk of 20 cm diameter and with quadrants painted in black and white was recorded. Secchi depth is derived as the average of the depth at disappearance and that of reappearance of the disk in water. General environmental observations about the target stations like the maximum depth of the sampling site, time of sampling, weather conditions and station features, were documented. Water samples for chlorophyll-*a* data were filtered using GF/C filters, wrapped in aluminium foil and stored in a desiccator for onward seston solvent extraction and spectrophotometric analyses using methods described by Sasaki *et al.* (2005). Data was collected in response to distress calls on November 14th 2024 (1st sampling), January 16th 2025 (2nd sampling) and January 28th 2025 (3rd sampling).

Data Analysis

Inferential and quantitative methods were employed to assess spatial-temporal variations in water quality parameters and their linkages to fish mortality. Primary data collected from three sampling stations (Kisat River mouth, Coca-Cola, and Control site) during three periods (November 2024 to January 2025) were cataloged in Microsoft Excel 2010. The averages for dissolved oxygen (DO), temperature, nutrient concentrations (NH_4^+, NO_3^-, NO_2^-, TN, TP, SRP), chlorophyll-a, and Secchi depth were plotted using R software version 4.4.3.

Results and discussion

Trends in temperature (°C) and dissolved oxygen (DO, mg L^{-1}) levels across the different sampling stations over three sampling periods are illustrated in (Fig. 2). These parameters are essential for aquatic life; temperature affects metabolic rates, oxygen solubility due to its inverse relationship, and biochemical processes, whereas DO is critical for fish survival (Wetzel, 2001; Kalff, 2002). Though the DO levels fluctuate, there is a general trend of low concentrations across the sampling sites. Only the control sites exhibited desirable levels of 5 - 7 mg L^{-1}. The overall mean value for DO was 4.09 ± 2.05 mg L^{-1}, with a range of 5.21 mg L^{-1}, which is not desirable as fish generally require DO levels of between 6 – 8 mg L^{-1} to thrive (U.S. EPA, 1986; FAO, 2015). Coca cola intake point consistently exhibited anoxic conditions during the second and third sampling periods with average DO levels of 1.71 and 1.77 mg L^{-1} and 2.93 and 1.99 mg L^{-1} at the Kisat River mouth.

The mean temperature observed across the sites for the three periods was generally warm at 27.26 ± 0.66°C with a range of 1.96°C. This has an effect of reducing the solubility of oxygen in water and also accelerating microbial decomposition of organic matter, therefore consuming oxygen and exacerbating anoxia (Paerl and Huisman, 2009). The critically low DO levels at Coca cola and Kisat River mouth were likely due to a combination of the effects of high temperatures and nutrient pollution (phosphorus and nitrogen) from sewage, agricultural runoff, and industrial wastes (Dodds and Smith, 2016). Such low DO levels are stressful to fish and can cause mass mortalities (Diaz and Rosenberg, 2008).

Trends in nitrogen compounds (ammonium, nitrates, nitrites, and total nitrogen) and soluble reactive phosphorus (SRP), total phosphorus (TP), and silicate concentrations at three sampling stations over the three sampling periods are presented in Figure 3 and 4, respectively. A sharp increase in nitrate and nitrite levels was observed in the 2nd sampling, particularly at Kisat River mouth (82.03 µg L^{-1} and 21.12 µg L^{-1}) and Coca cola (94.15 µg L^{-1} and 19.91 µg L^{-1}). This increase was likely due to an influx if nitrogenous compounds, likely due to runoff, sewage and industrial discharge or sediment disturbance. These elevated nitrite levels may be toxic to fish by disrupting oxygen transport in the blood system, a condition referred to as methemoglobinemia, also known as "brown blood disease" (Jensen, 2003). This was followed by a

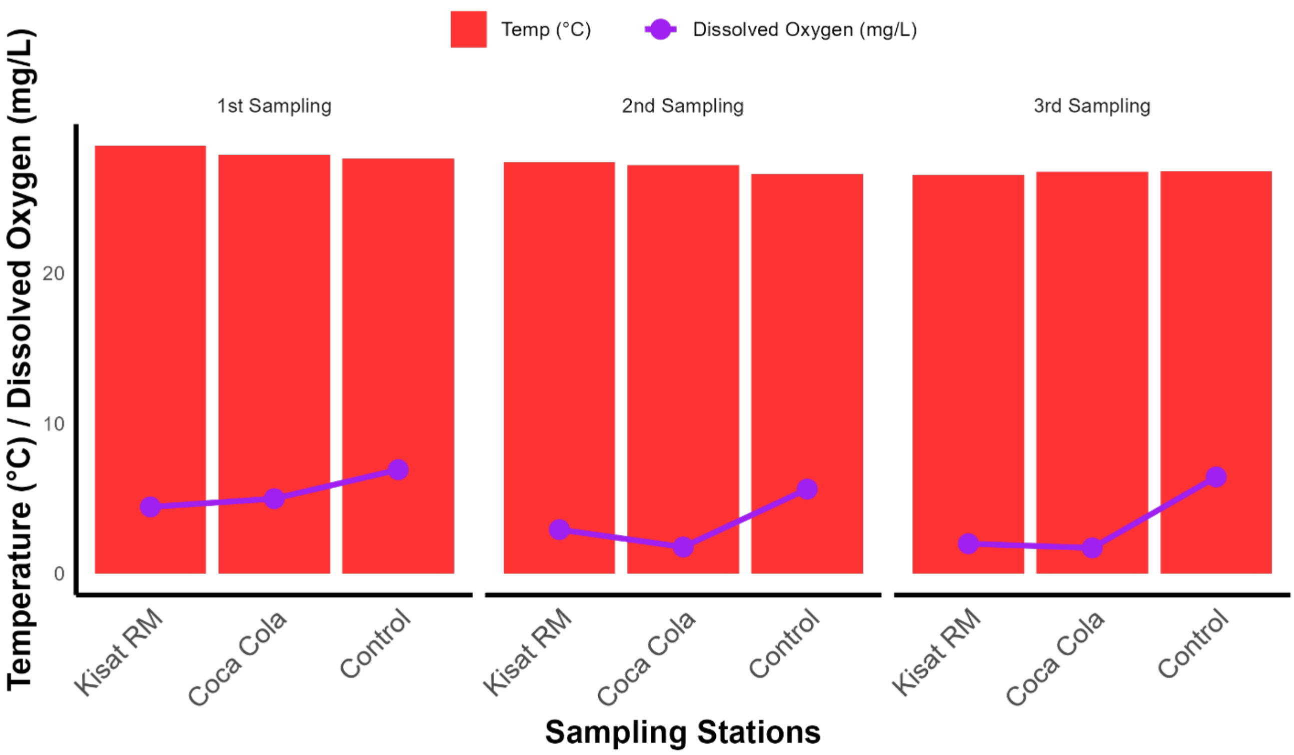

Figure 2. Dissolved Oxygen (mg L^{-1}) and Temperature (°C) trends across stations during the sampling of fish kills studies at the Kisumu Bay Lake Victoria, Kenya.

significant decline in nitrate and nitrite concentrations during the 3rd sampling session, presumably due to uptake by phytoplankton, and the dilution effect of water movement by currents. The control station exhibited much lower concentration across all the sampling periods, indicative of localized pollution at the Kisat River mouth and Coca Cola stations.

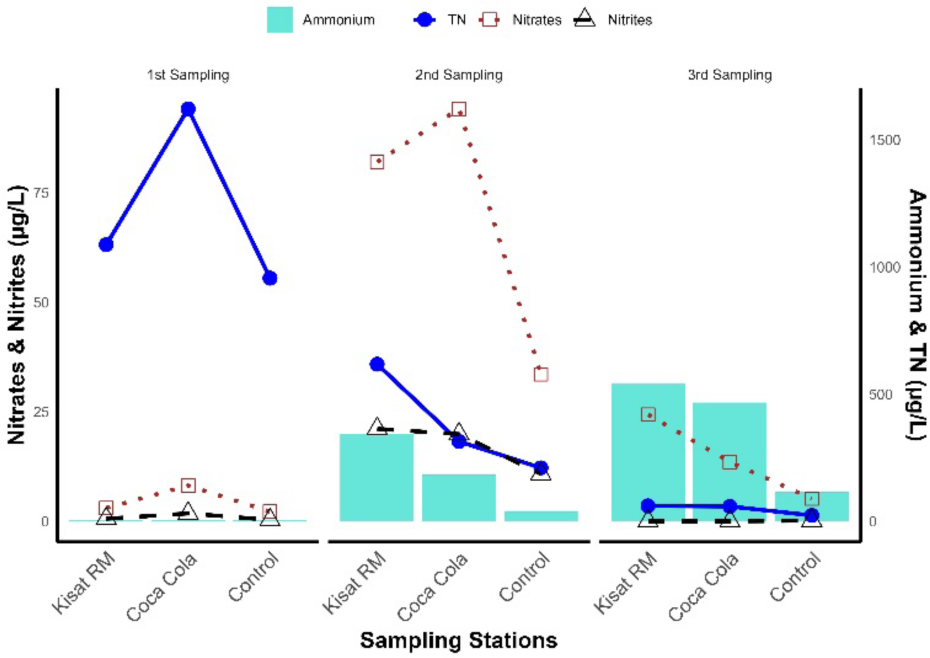

Figure 3. Trends in (Total Nitrogen, µg L⁻¹), Ammonium (µg L⁻¹), Nitrates µg L⁻¹) and Nitrites (µg L⁻¹) concentrations across stations during the sampling of fish kills studies at the Kisumu bay Lake Victoria, Kenya.

A significant peak was observed in Ammonium concentrations in the 2nd sampling at Kisat River mouth and Coca Cola stations. This coincided with high levels of total nitrogen (TN) indicating possible anthropogenic pollution emanating from sewage and waste water discharge (Camargo and Alonso, 2006), agricultural runoff from upstream containing ammonium and organic nitrogen-rich fertilizers (Carpenter *et al.*, 1998). The TN levels drastically dropped in the 3rd sampling presumably due to dilution or microbial uptake. However, the ammonium levels continued to increase, indicating incomplete nitrification, which is usually associated with anoxic conditions (Diaz and Rosenberg, 2008), synonymous with fish kills. Figure 2 shows that the DO levels were anoxic during these periods. Both ammonium and TN levels were way above the globally recommended standards of 1.5 mg L^{-1} (EPA, 2013) and 40-50 µg L^{-1}, respectively (U.S. EPA, 2013; OECD, 1982).

Soluble Reactive Phosphorus (SRP) varied across the sampling stations, with an increasing trend from the 1st to the 2nd sampling periods. The highest SRP values were recorded at the Control station in the 3rd sampling period. Total Phosphorus (TP) had more pronounced peaks in the first sampling period, suggesting anthropogenic sources from wastewater discharge and runoff from agricultural lands (Sitoki *et al.,* 2012). A decrease between the 2nd sampling and a further peak in the 3rd sampling period followed this. The decline experienced in the 2nd sampling, may hhave been due to dilution from increased water flow or biological uptake by phytoplankton (Paerl and Otten, 2013). Elevated phosphorus (TP and SRP) and TN levels are strongly associated with eutrophication in freshwater systems (Dodds and Smith, 2016). The levels recorded during the three sampling periods beyond the acceptable threshold (40-50 *µ*g L^{-1}). Such levels promote excessive growth of phytoplankton, resulting in algal bloom and as the organic matter from the bloom decomposes, it utilizes the already depleted dissolved oxygen, resulting in fish kills due to hypoxia (Randall and Tsui, 2002; Diaz and Rosenberg, 2008).

Figure 5 presents trends in alkalinity, hardness, Chlorophyll-a, and Secchi depth across different sampling stations over the three sampling periods. Chlorophyll-a exhibited fluctuating concentrations with the highest peak in the 3rd sampling period, particularly at Kisat and Coca cola sta-

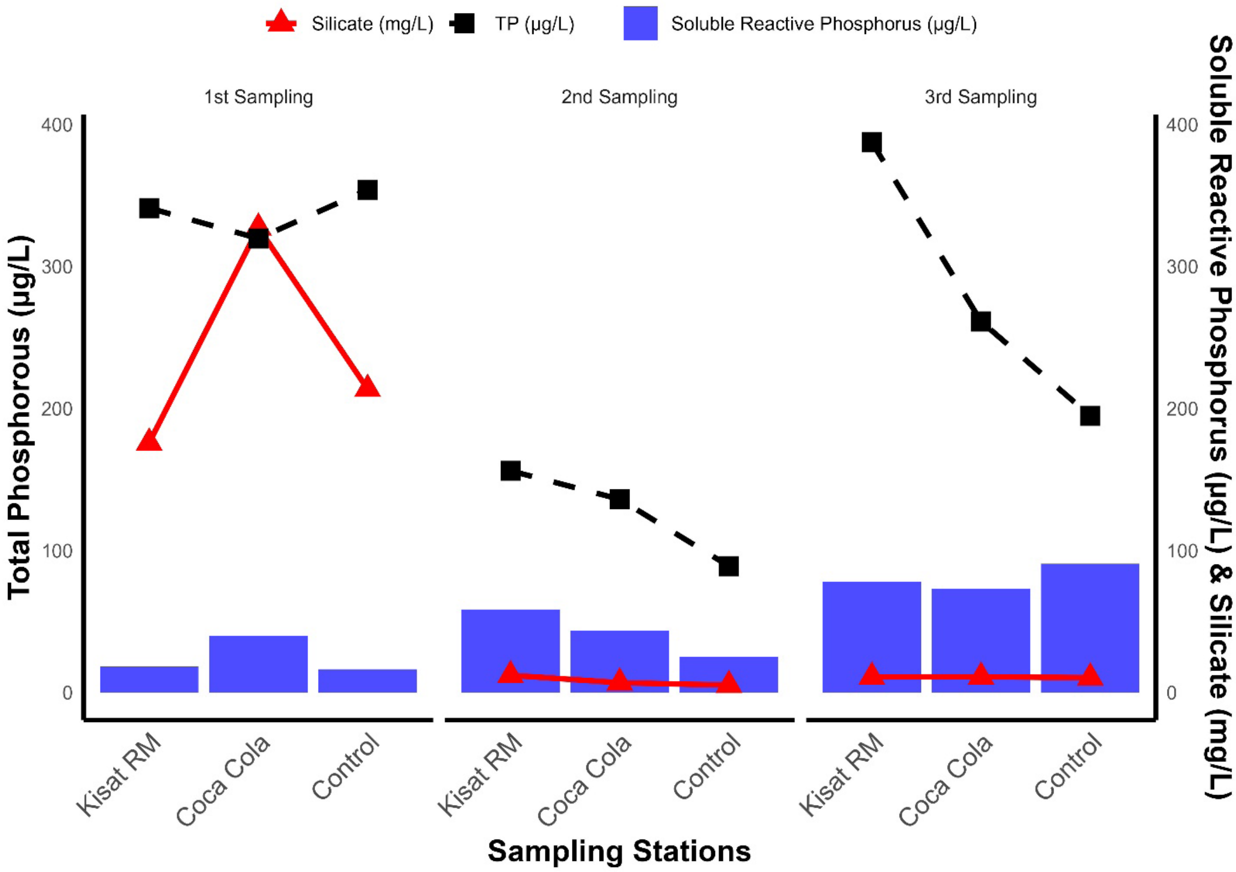

Figure 4. Trends in total phosphorous (µg L-1), soluble reactive phosphorus (µg L^{-1}); and silicates (mg L^{-1}) concentrations during the sampling for fish kills studies at the Kisumu Bay Lake Victoria, Kenya.

tions. These concentrations were beyond the acceptable standards of 1-2 µg L^{-1} (OECD, 1982; U.S. EPA, 2000) indicating eutrophication (Paerl and Otten, 2013). This increase in chlorophyll-a levels correlates with the high phosphorus levels observed as illustrated in Figure 3 during the same sampling periods, ascertaining that phosphorus is a key driver of phytoplankton growth (Smith *et al.,* 1999).

Secchi depth (m), a measure of water clarity, exhibited an inverse relationship with chlorophyll-a concentrations. Elevated chlorophyll-a levels corresponded to reduced Secchi depth readings, indicating greater turbidity caused by algal proliferation, particularly at Kisat and Coca Cola stations. Elevated chlorophyll-a levels alongside reduced Secchi depth measurements signal heightened primary productivity in the water column, a phenomenon strongly linked to nutrient enrichment (Paerl and Hall, 2016). This surge in phytoplankton biomass often drives excessive organic matter accumulation, which, upon decomposition, can deplete dissolved oxygen levels, resulting in hypoxic or anoxic conditions that threaten aquatic ecosystems (Diaz and Rosenberg, 2008).

Conclusion and recommendations

Most of the physico-chemical parameters in the sampled stations at the sampling times exceeded globally recommended standards, rendering the environment unsuitable for fish and aquatic life. Critically low dissolved oxygen indicated anoxic conditions likely driven by nutrient overloading and organic matter decay, a known precursor for fish mortality. High ammonia (NH3) levels further evidenced microbial decomposition of organic waste, pointing to potential wastewater contamination. The high total nitrogen (TN) and

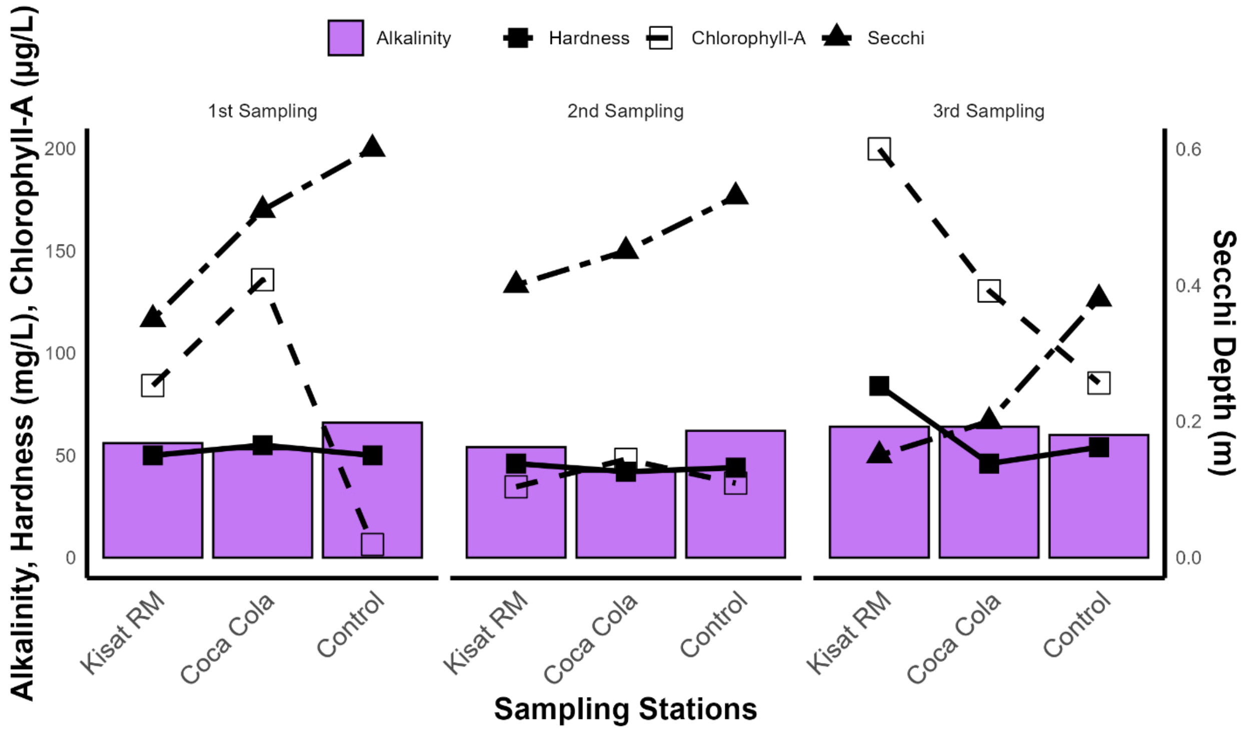

Figure 5. Trends in total alkalinity (mg L^{-1}), total hardness (mg L^{-1}), *chlorophyll-a* (µg L^{-1}) and *Secchi* depth (m) across stations during the sampling for fish kills studies at the Kisumu bay Lake Victoria, Kenya.

total phosphorus (TP) concentrations across all stations indicated nutrient pollution probably from industrial effluents, agricultural runoff, and sewage discharge. Concurrently, extreme chlorophyll-a levels signaled eutrophication and algal blooms, which deplete oxygen via nighttime respiration and post-bloom decomposition, forcing fish to surface for air. These conditions were worsened by an oil layer which was observed, which may have impaired gas exchange by forming a physical barrier and coated fish gills, intensifying respiratory stress and compounding the hypoxic stress caused by algal blooms. Collectively, these factors may have led to the fish kills. It is therefore recommended that:

1. associated companies periodically present and implement control measures that have been put in place to minimize oil spill and untreated sewage discharges;
2. periodical random visits be conducted by the relevant agencies for inspection of point sources of pollution into the Lake and assessing their efficiency and performance;
3. improved efforts in development of waste water treatment facilities be executed by associated companies;
4. implementation of wetland reclamation to filter runoff before reaching the Lake should be prioritized;
5. enforcement of the regulatory frameworks in place should be improved to reduce industrial and domestic pollution sources; and
6. continuous monitoring should be done by the scientists to inform the relevant agencies for mitigation.
7.

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