THE IMPACTS OF HARMFUL ALGAL BLOOMS IN LAKE VICTORIA, KENYA

Kiran Ganga
Cornell University, Ithaca

Harmful Algal Blooms and Human Health

It is known that harmful algal blooms are increasing noticeably in occurrence and concentration around the world (Van Dolah, 2000). In analyzing the impacts of harmful algal blooms on human health, we focus on microcystins, a class of toxins produced by freshwater cyanobacteria *Microcystis*. This is a genus that is commonly found on algal blooms and its presence is nearly always toxic. It is suggested that nutrient deprivation can significantly upregulate the production of microcystins by bacteria (Pimentel & Giani, 2014). Microcystins are soluble peptides that may be lethal to many aquatic organisms and higher-order animals (Oh et al., 2000). The attention to microcystins is largely due to their increased abundance and detection across multiple seasons and their broad prevalence in water and fish from temperate and tropical lakes that support important commercial, sport, and subsistence fisheries (Poste et al., 2011; Roegner et al., 2020). Cyanotoxins have been reported in all continents but are more commonly seen in tropical and subtropical regions. Microcystin-LR is mentioned as the most commonly occurring toxin in current literature from nearly all reported regions. However, the variant profile (which is dependent on amino acid composition) differs based on location-from calcareous rivers to freshwater lakes to smaller-scale lakes and springs and more (Rastogi et al., 2014). Moreover, the causes of microcystin abundance vary across location. For example, while microcystins were reported in sewage treatment plants in Kenya, occurrence was more common in water reservoirs and lakes in the U.S, Saudi Arabia, and parts of Asia (Rastogi et al., 2014).

There are a few reasons for the high concentration of microcystins within Lake Victoria. Many of these impacts can be attributed to climate change, which has accelerated eutrophication in Lake Victoria by increasing water temperature (Poste et al., 2011). Generally, increases in greenhouse gases have led to increased temperatures and acidity of oceans, while decreasing oxygen concentrations. These factors ultimately alter vertical mixing, permitting blooms to grow more easily (Moore et al., 2008). There are areas, such as the Nyanza Gulf and Kisumu Bay, labeled as hypereutrophic (Miruka et al., 2021; Sitoki et al., 2012). Increase of phosphorus concentrations and nitrogen limitation are considered principal factors that have led to a shift in the dominance of diatoms to cyanobacteria (B. Simiyu et al., 2018; Sitoki et al., 2012). This leads to low oxygen levels, increasing mortality of aquatic organisms and reducing water quality for human consumption (Mchau et al., 2019). Cyanobacteria are now far more diverse and are seen to dominate primarily bays and gulfs, as opposed to open lakes, irrespective of the season (Olokotum et al., 2020). This increase in eutrophication can be attributed to an increase in population density in Lake Victoria. The population growth may be due to economic benefits or from forced migrations within the area, including from Rwanda, Burundi, and the Democratic Republic of Congo. This has led to increased demands for fishing, industrial and other commercial activities and additional wetland destruction, overgrazing, deforestation, amongst other effects. Soil erosion is seen to increase eutrophication. The shift in urbanization has led to increased pollution of the lake, alongside increased deposition of phosphorus and nitrogen, and lack of methods of natural purification due to wetland degradation (Olokotum et al., 2020; Onyango et al., 2020).

Harmful algal blooms in Lake Victoria

In some studied areas of Lake Victoria- including the shores of Ukerewe District, Murchison Bay, and parts of the Nyanza Gulf- the concentration of cyanobacteria blooms are significantly elevated (Mchau et al., 2019; Semyalo et al., 2010; B. M. Simiyu et al., 2022). Specifically, along Kisumu Bay in the Kenyan portion of Lake Victoria, *Microcystis* was the most dominant algal species (B. M. Simiyu et al., 2022). Microcystin toxin concentrations were significantly correlated and exceeded WHO standards, even in comparison to other temperate areas globally (Miruka et al., 2021; Roegner et al., 2020). However, there are other studies that found no significant or decreasing cyanobacteria abundance in other areas, like the Mwanza Gulf and Mbita Channel of the Nyanza Gulf (Sekadende et al., 2005; B. M. Simiyu et al., 2022). Regardless, it is imperative to note that there are few to no alternative options for water and food use for local residents (Poste et al., 2011; Roegner et al., 2020).

While microcystin exposure is a concern regardless of a season, there is an increased risk between November and March in the basin. This coincides with the wet season and when nutrient enrichment from the catch has increased (Sitoki et al., 2012). It is worthwhile to note that colonies high in toxin concentration typically accumulate in patches by currents formed by Langmuir circulations (B. Simiyu et al., 2018).

Exposure pathways

There are a few main exposure pathways to which humans can be exposed to microcystins: drinking water, body contact, inhalation, consumption of contaminated food, consumption of algal dietary supplements, or hemodialysis (Massey et al., 2018). However, there are some reports of possible transmission through breastfeeding, placental transfer, and sexual contact (Young et al., 2020). A dose-dependent increase in human chorionic gonadotropin produced by the placenta was found as a result of elevated microcystin-LR levels, though the implications of the findings are unknown (Douglas et al., 2016). Further, paternal exposure to microcystin before mating may be transmitted to the placenta, inhibiting cell and fetal growth (Gao et al., 2021). These routes are understudied yet imperative to investigate, as they pose unique risks specific to women's health.

The World Health Organization's guidelines state that cyanobacteria cell concentrations at 20,000 cells/mL is associated with risk for short-term adverse health outcomes and concentrations at 100,000 cells/mL for long-term illness (World Health Organization, 2003). The WHO has set a standard value of microcystins in drinking water of 1 μg/L, on the basis that 80 percent of exposure is attributable to water consumption. However, this clearly assumes that majority of ingestion comes from drinking water, as opposed to other food sources that may also be contaminated (Roegner et al., 2020; World Health Organization, 2017). Further, applying WHO's guidelines on recreational water use to Lake Victoria poses challenges in a study, as cell counts in the region are consistently elevated and it is difficult to follow recommendations to avoid consumption of contaminated water altogether (Roegner et al., 2020).

Within fisheries, drinking water and food vectors, namely fish consumption, are dominant routes that can lead to excess microcystin intake (Meneely & Elliott, 2013; Poste et al., 2011; Young et al., 2020). Past global studies have also pointed to the accumulation of microcystins in fish. Microcystins are seen to accumulate in the muscle tissue of fish harvested regularly above the WHO acceptable limit for human consumption in Brazil (Magalhães et al., 2003). Studies conducted in Egypt and China find that the distribution of cyanotoxins within fish differ drastically; the highest level of microcystin accumulation was found in fish gut, liver, and kidneys respectively, with muscle buildup being the least significant (Mohamed et al., 2003; Xie et al., 2005). This trend was also indicated in a case study conducted in Murchison Bay of Lake Victoria, which found the gut to have the highest microcystin content, followed by liver and muscle (Nyakairu et al., 2010). It has been posited that fish at the top of the aquatic food chain likely have been the most exposed to cyanotoxins and, therefore, have the greatest risk potential for humans near the end of the food chain (Freitas de Magalhães et al., 2001; Nyakairu et al., 2010; Xie et al., 2005). This risk is further amplified by the heat stability of microcystins (Nyakairu et al., 2010). Small fish, mainly dagaa, were examined for microcystin content in Kisumu Bay (B. Simiyu et al., 2018). As expected, microcystin content in the fish was related to the location in water they were found in. Like other studies, accumulation was found primarily in the gut. However, findings in fish were significantly lower than cyanotoxin content found in water. In this study, fish found in open water showed even lower concentrations than those in Kisumu Bay. Further, highest microcystin concentrations, which exceeded total daily intake guidelines established by the WHO, were found in *Haplochromis* spp. and the dagaa, potentially due to inclusion of cyanobacteria the gut. This is a key concern, as these small fish are eaten whole, making a transfer of microcystins to humans more likely when compared to solely eating fish muscle tissue. Moreover, there is a high consumption of dagaa within local residents in Lake Victoria due its status as an affordable source of animal protein, it is imperative to address this health risk (Fiorella et al., 2016; B. Simiyu et al., 2018). The marketing of smaller fish done primarily by local women offers a gender dimension that requires further research.

There is a unique risk present to nearshore communities within the basin, who experience increased contact with the water. Further, women and children are found to utilize the Lake for daily activities, perhaps indicating an increased susceptibility to negative health effects (Roegner et al., 2020). Moreover, while there are alternate sources of rainwater collection and boreholes, these methods rely on season and access may be correlated with socioeconomic status (Roegner et al., 2020)

While there are limited studies on microcystin content within human populations of the basin, other research indicates a clear risk. A clear presence of microcystins was found in serum samples of fishermen in China that were chronically exposed to cyanotoxins via the oral route, leading to indications of liver damage (Chen et al., 2009; Zhao et al., 2020). This is consistent with long-term studies in China indicate microcystin content from drinking water. Moreover, an episode of deaths in Brazil was attributed to exposure to microcystin-related hepatotoxins (Codd, 2000).

Health effects of microcystin exposure

Microcystins may enter the intestine and be transported via the bloodstream to impact multiple systems (Massey et al., 2018). Reported symptoms of poisoning include stomach pains, fever, anorexia, nausea, pallor, fatigue, muscle tremors, trouble breathing, vomiting, diarrhea, numbness, burning, incoherent speech, and skin, throat, and eye irritation (Massey et al., 2018; Mchau et al., 2019; Roegner et al., 2020). Most existing studies focus on acute, as opposed to chronic outcomes (Young et al., 2020).

Broadly, the main concern associated with microcystin exposure lies in liver function, which can lead to metabolic disorder (Chen et al., 2009; Massey et al., 2018; Meneely & Elliott, 2013; Moreno et al., 2005; Shi et al., 2021). This includes impacts on iron homeostasis through inducing hepcidin down-regulation and even water metabolism dysfunction (Shi et al., 2021). At a global scale, there have been observed alterations in lactate dehydrogenase (indicative of tissue damage) and aspartate transferase (indicative of hepatitis, cirrhosis, or other liver diseases). These activities were coupled with an increase in direct bilirubin and uric acid concentrations and an increase in alanine aminotransferase and alkaline phosphatase activities-both are suggestive of liver damage (Meneely & Elliott, 2013). Additionally, microcystins can induce hepatocyte death by affecting glucose metabolism through insulin-related pathways, thereby affecting the pancreas as well. Exposure may also increase liver fat weight. Acute exposure to microcystin leads to significant oxidative stress and, ultimately, a decrease in the endogenous antioxidant defense system (Shi et al., 2021). These findings may manifest as liver cancer, hepatocyte necrosis, and hepatocellular cancer (Massey et al., 2018; Shi et al., 2021). Other systems influenced include the heart, leading to cardiac arrest, hypovolemic shock, and hypotension, as well as the brain, leading to neurodegenerative disease (Massey et al., 2018). While reproductive toxicity or congenital defects may be linked to exposure, this has only been reported in case reports and more research is necessary (Backer, 2002; Massey et al., 2018). Chronic exposure has been associated with several cancers by affecting the expression of proto-oncogenes and tumor suppressor genes (Shi et al., 2021). Observed cancers are primarily concerned with the digestive tract, including renal cell carcinoma and colorectal cancer (Massey et al., 2018; Mchau et al., 2019; Young et al., 2020).

Measures to mitigate health impacts

Most individuals in Lake Victoria understand that the blooms pose a significant risk to human health, with a reported decrease in interaction with water via activities like swimming. This is likely due to their high dependence on Lake Victoria. However, there was diversity amongst individuals in identifying the causes for blooms. Fishers also perceived that little action was being taken at a managerial level. On the other hand, others cite the Lake Victoria Environmental Management Project initiated by the World Bank in 1994 as a significant step to reduce eutrophication and restore the aquatic ecosystem (Secaira, 2022).

Existing health impacts demonstrate the necessity for appropriate public health measures. This is amplified by the fact that routine clinical diagnostic tests are not available for any syndromes. As a result, reported numbers demonstrate a level of uncertainty and underreporting (Grattan et al., 2016; Young et al., 2020). Furthermore, there is no antidote for exposure to microcystin. Thus, it is critical that measures are taken to make symptom management and supportive care more available post-diagnosis. Any public health interventions taken requires active communication between researchers and appropriate health resource entities and providers (Grattan et al., 2016). Currently, the most widespread treatments used in communities are household chlorination and boiling of water and extensive drying of fish. However, it is possible that such treatment leads to increased concentrations of microcystins in household water after such treatment via oxidation, cellular lysing, and evaporation of water. Moreover, the efficacy of chlorination has not been properly assessed at a wider scale (Roegner et al., 2020). On the other hand, reliance on a plant or identification of alternative water sources may offer a high burden for many low-income individuals near Lake Victoria.

There is a clear need for the development of a technique that would remove microcystins from large quantities of water, as opposed to relying on individual or household-level interventions. Bloom remediation and treatment technologies that limit growth of organisms and removal of toxins in water by other mechanisms, including flocculation, ozonation, and charcoal filtration, are other potentially effective measures that need better understanding (Backer, 2002). Protection and restoration of wetlands can prevent soil erosion that is linked with eutrophication-a primary cause of increased microcystin levels in Lake Victoria (Olokotum et al., 2020). The main challenge present is combatting rapid urbanization, which makes waste removal and water purification difficult. Education plays a key role; it is crucial to create more active water safety policies and increase awareness about the issue (Massey et al., 2018). This includes creating accurate exposure guidelines regarding water use, especially considering that current guidelines for quantifying risk may not truly reflect the potential for fish to significantly contribute to exposure (Backer, 2002; Poste et al., 2011). It is posited that drugs that inhibit the binding of microcystins to protein phosphates may help combat illness (Massey et al., 2018). However, many of these developments require more research, including a more elaborate understanding of the mechanisms through which microcystins impact humans.

Future research focus

We need better epidemiological studies that can conclusively assess human responses to newly identified toxins, better identify vulnerable populations, and deduce appropriate biomarkers for diagnosis (Backer, 2002; Young et al., 2020). Populating the database with efficient research is vital, as much of the literature is centered on case reports where it is difficult to make generalizable conclusions (Young et al., 2020). These changes must be accompanied by a larger form of effective safety and climate change policy implementation. Existing guidelines must be better adapted to consider the livelihoods of Lake Victoria residents. Additional studies should be done to understand the means to meet international safety guidelines.

We need a better understanding of the mechanisms through which microcystins impact people, as it is plausible that each exposure route affects individuals uniquely. This is considering the high reliance of individuals on the lake for their livelihood, from obtaining necessities to crafting social networks to recreation to occupying employment. Thus, the socioeconomic variables, including income, occupation, educational level, gender, predisposition to other health risks and illnesses, amongst other factors, that impact risk to microcystin exposure must be better elucidated. These variables may create experiences where people are required to increase contact with cyanobacteria, perhaps as a financial or household requirement, to promote familial or community well-being. These are aspects that will affect knowledge of microcystin presence and its effects. It is still unclear what kind of handling leads to more exposure-whether the hazards lie mainly in fishing, processing, or marketing. Moreover, existing literature has not conclusively determined the patterns of bioaccumulation, which makes it difficult to determine what kind of fish or seafood consumption is the most toxic. Finding a wide-scale treatment option better than the status quo to eliminate toxins before consumption is imperative, as it is still unclear what public health measures are affordable, implementable, and truly effective. Better understanding the barriers that affect access to good water will help shape superior, more equitable public health initiatives.

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