ARTICLE IN PRESS

Journal of Great Lakes Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

Socioeconomic consequences of cyanobacterial harmful algal blooms in small-scale fishing communities of Winam Gulf, Lake Victoria

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A R T I C L E I N F O

Communicated by Richard Ogutu

Keywords:
Human health
Microcystis
Cyanotoxins
Risk assessment
African Great Lakes

A B S T R A C T

Lake Victoria has experienced progressive eutrophication which has exacerbated the proliferation of cyanobacterial harmful algal blooms (cHABs). Fueled by anthropogenic nutrient loadings and climate change, these cHABs are increasing in distribution, duration, and frequency, particularly in areas such as the Winam Gulf. With limited resources and infrastructure, local communities have been left vulnerable as they rely on the lake for water for domestic use. Our study presents the results of a localized survey on how small-scale fishing communities perceive and respond to the threat of cHABs in the Winam Gulf of Lake Victoria, Kenya. We used a mixed-methods approach of quantitative and qualitative data-gathering techniques to elucidate the perceptions and consequences of cHABs in local communities. Our results demonstrate most (93.67%) respondents were aware of cHABs in the lake, but were not knowledgeable of cHAB threats to human and animal health. Respondents noted that fish catches decreased during cHABs, with this economic consequence serving as a primary concern of communities. Notably, respondents altered their use of lake water during perceived cHAB events and relied on other means of water treatment or alternative water sources. Overall, cHAB information was self-sourced or passed on from community elders, with no public mechanism for adequate cHAB risk communication. Lake Victoria serves as a critical resource to the Eastern African region and requires a concerted cHAB response effort. Therefore, we recommend the development of a public awareness program to reduce cHAB exposure in these at-risk communities.

1. Introduction

Anthropogenic pollution remains an emerging threat to the African Great Lakes, especially Lake Victoria (Mugidde et al., 2005; Raburu and Okeyo-Owuor, 2006; Poste et al., 2013; Yunana et al., 2017). Lake Victoria is the second largest freshwater lake in the world by area (Hecky, 1993), and is a critical resource to the 45 million residents in the region and the broader Eastern African continent (Olokotum et al., 2020), Yet, increased nutrient loading in lake region such as the Winam Gulf (Fig. 1) has induced prolific algal blooms and macrophytes (i.e., water hyacinth) (Sellner et al., 2003; Gikuma-Njuru et al., 2013b; Olokotum et al., 2020) (Fig. 2) which occurred along the shoreline of Homa Bay (Winam Gulf) in June of 2022. These blooms invoke ecological damage when they accumlate on the water's surface and decompose (Heisler et al., 2008). Further, certain species of cHABs produce harmful secondary metabolites (*e.g.,* toxins) that disrupt the cellular processes of mammals (Landsberg, 2002; Sitoki et al., 2012; Grattan et al., 2016). In Lake Victoria, a great diversity of cyanobacterial species has been documented (Hecky et al., 2010; Poste et al., 2013), with the dominant species being *Microcystis* spp. in Winam Gulf (Sitoki et al., 2012; Olokotum et al., 2020). Species of this genus produce microcystins which induce hepatotoxicity (Rastogi et al., 2014; Sitoki et al., 2012; Oberholster et al., 2004) and have been identified as a significant threat to human health (Abd Rashid et al., 2022). Beyond microcystins, other

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https://doi.org/10.1016/j.jglr.2023.09.007
Received 22 April 2023; Accepted 17 August 2023
Available online 30 September 2023

toxins of prevalence within Lake Victoria include neurotoxins such as anatoxins and saxitoxins.

The threat cyanotoxins pose to humans is exacerbated by their resistance to environmental degradation and classical removal techniques. For example, microcystins are known to be stable even under high temperatures thus they are not destroyed/denatured by boiling (Bullerman and Bianchini, 2007). Further, these toxins are resistant to pH changes and dissolve easily in water, ethanol, methanol, and acetone (Codd et al., 1999; Kabak, 2009). The solubility of microcystins facilitates their distribution throughout the water column, which increases the risk of contamination in drinking water sources (Xu et al., 2020). Cumulatively, these characteristics determine how microcystins are detected, analyzed, and treated in water sources, which ultimately affects the risk of human exposure. Therefore, the presence of cyanobacterial toxins within Lake Victoria represents a critical (and potentially lethal) threat to local communities which rely on this system for water for domestic use and recreational activities (Nyamweya et al., 2023).

The increasing occurrence of cHABs in freshwater systems such as Lake Victoria endangers human health (Juma et al., 2014; Brooks et al., 2016; Wells et al., 2020). To date, there are several human health effects linked to cHAB exposure *via* avenues such as skin contact, ingestion, and inhalation (Schmale et al, 2019). The severity of these impacts can vary depending on the type of toxin, the level of exposure, and the individual's health status (Carmichael and Boyer, 2016). As a result, studies regarding the impacts of cyanotoxins on human health have been conducted in a variety of Eastern African Lakes (Kotut et al., 2006; Poste et al., 2013; Mchau et al., 2019; Yan et al., 2022). For example, Mchau et al. (2019) assessed health risks among Lake Victoria shoreline communities in Ukerewe Island (Tanzania). This study revealed that vomiting, throat irritation, and gastrointestinal illness (GI) were significantly elevated among consumers of the lake water compared to those who relied on wells and tap water. Children and individuals with weakened immune systems are particularly susceptible to the negative health effects of these toxins (Weirich and Miller, 2014; Kubickova et al., 2019).

Beyond lake water consumption, microcystin concentrations of various fish within Lake Victoria have been previously reported to range from 1.3 to 88.9 μg/kg wet weight (Poste et al., 2011): suggesting individuals who regularly consume fish from Lake Victoria are routinely exposed. In addition to human health risks, cHABs also impact other aspects of human well-being, including economic losses, ecosystem value losses, and social impacts (Berdalet et al., 2016; Ritzman et al., 2018). For example, Kotut et al. (2006) suggested that cyanotoxins played a role in the mass mortality events of flamingos in East African Lakes Bogoria and Nakuru.

The riparian communities in Lake Victoria (such as Homa Bay, population ~1.2 million) use the lake water for domestic activities including drinking, cooking, bathing and cleaning (Fig. 3) (Onyango and Opiyo, 2021). These individuals are routinely exposed to cyanotoxins through ingestion of contaminated water and food. In Kenya, riparian counties which border the Lake Victoria basin (Kisumu, Homa Bay, Migori, Siaya, and Busia) have implemented a framework for water treatment to improve access to safe and clean drinking water. One such framework is the establishment of county water treatment plants. These water treatment plants use a combination of physical, chemical, and biological processes to reduce contaminants (Agwanda and Iqbal, 2019) and contain laboratory facilities to ensure compliance with international standards. However, incomplete removal of persistent cyanotoxins, such as anatoxin and saxitoxin, has proven to be a significant challenge. In addition, the inconsistency of water delivery from treatment plants to household taps often leads individuals to resort to the direct collection of untreated lake water (Fig. 3). Hence, there remains a critical need to determine how residents respond to cHAB events and educate these communities of the risks associated with consuming the lake water.

There has been a growing interest in Lake Victoria (Simiyu et al., 2022; Nyamweya et al., 2023; Ogega, et al., 2023), as this tropical freshwater lake serves as a sentinel concerning how climate change and population pressure effect cHABs in global freshwater systems (Mugidde et al., 2005). Yet, despite growing international attention, the effects of cHABs on local Lake Victoria communities remain widely unassessed.

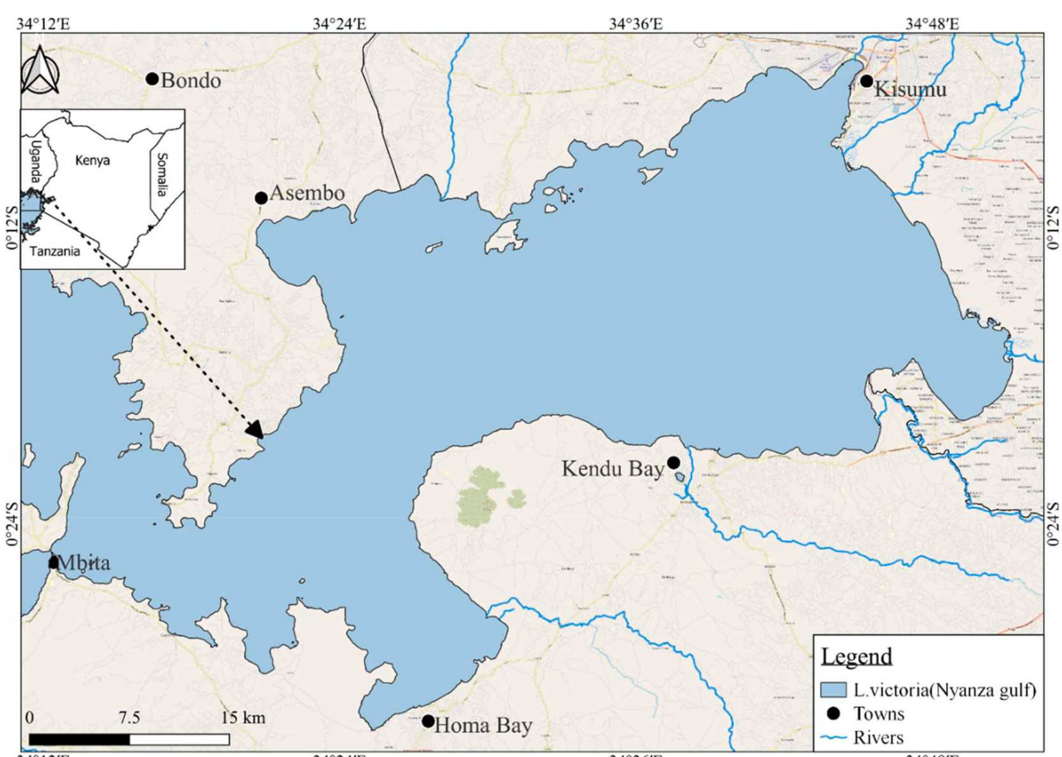

Fig. 1. Map of the Winam Gulf, Lake Victoria (Kenya). Surveys were conducted in Kisumu (western side of Winam Gulf) and Homa Bay (southern side of Winam Gulf).

Recent studies have begun to address this critical knowledge gap. Notably, Roegner et al., (2023) conducted fisher and household interviews across the Kisumu Bay region of Lake Victoria (July 2016–March 2017) to assess how cHABs affect small-scale fishers. While this work provided valuable insights concerning how cHABs alter fishing strategies, behavior, and revenue, it did not assess how the presence of cHABs altered the direct use (i.e., consumption) of water by individuals within these small-scale fishing communities. Further, Ziegler et al. (2023) paired cultural models with interviews (July 2019) to investigate stakeholder conceptions of Lake Victoria cHABS and compare resource user vs. resource expert perceptions. Though this study lays a framework as to how cHABs are perceived on cultural, regional, and governmental levels, it falls short of addressing how individuals respond to cHABs at the household level. Cumulatively, the aforementioned studies assess the economic, cultural, and regulatory implications of cHABs in at-risk communities, yet they do not identify how individuals in these communities alter their direct use of the water.

Considering these communities rely on the untreated lake water for drinking, cooking, cleaning, fishing etc. (Nyamweya et al., 2023), this is a critical gap that must be addressed before meaningful mitigation policies can be put into place on regional and economic scales. Efforts to mitigate cHABs in Lake Victoria such as reducing nutrient inputs to the lake, monitoring for the presence of cyanobacteria, and developing strategies for managing the blooms once they occur have been implemented (Lung'Ayia et al., 2001; Nwankwegu et al., 2019; Miruka et al., 2021). However, such efforts have been difficult to achieve due to the complexity of the blooms, inadequate monitoring, and limited community engagement in the mitigation process (Ndlela et al., 2016; Mchau et al., 2019; Kazmi et al., 2022). Local communities that rely on the lake for drinking water and socioeconomic livelihood are impacted by the devastating effects of cHABs. Thus, it is important to include these communities in cHAB dialogues. Notably, cHABs can have a significant impact on local communities by jeopardizing their economic livelihoods. Dense cHABs reduce small-scale fishing revenue by decreasing the efficacy of traditional fishing practices, biofouling nets, and decreasing fish populations. Yet, fishing remains a primary economic mainstay within the Lake Victoria region. The total annual fishing revenue from Lake Victoria was recently estimated to be ~$300 million (USD), with small-scale fishermen estimated to earn an annual income of ~$4,000 (USD) (Onyango et al., 2021). Thus, cyanoHAB effects on fisheries must also be considered and implemented into risk assessments.

This study assessed the algal bloom perceptions and responses of small-scale fishing communities residing along the Winam Gulf of Lake Victoria (Kenya). The overarching goal of this study was to assess the sociocultural knowledge, response, and adaptation strategies of individuals residing in at-risk communities frequently exposed to algal blooms.

2. Methods

2.1. Study region

This study was based on Lake Victoria, the second-largest freshwater lake in the world and the largest in Africa with a surface area of 68,800 km^2 (Njiru et al., 2008). The lake holds cultural, ecological, and economic importance to bordering countries (Njiru et al., 2018; Aura et al, 2018). The Lake Victoria basin is characterized by a hot and humid climate with a bi-modal rainfall pattern; short rains from October-December and long rains from March-May, and annual precipitation ranging from 2400 mm in Uganda to 1350 mm in Kenya (Awange and Ong'ang'a, 2006). This study was conducted in Winam Gulf, which is a semi-enclosed embayment of Lake Victoria, Kenya (Fig. 1). The Gulf is a large, wide, shallow body of water (surface area of 1300 km^2 and a mean depth of 10 m) and is connected to the main lake by the Rusinga Channel and Mbita Causeway (Gikuma-Njuru et al., 2010). These waters are a valuable resource for Kenya and serve as the main source of drinking water, but they also receive pollutants, nutrients, and sediment from the country's urban and agricultural areas (Lung'ayia et al. 2001). In turn, these pollutants have been found to remain largely contained within the Gulf (Gikuma-Njuru et al., 2013a). Several water-quality issues, such as cHABs and fish kills, have emerged putting riparian livelihoods at risk (Ochumba 1990; Lung'ayia et al. 2000). Fish kills in cages were recently reported in the Kenyan part of Lake Victoria (Mwainge et al, 2021; KMFRI Unpublished reports, 2022), with the Kenya Marine and Fisheries Research Institute (KMFRI, 2022) estimating losses of 950 million Kenyan Shillings (USD6.5 million). The majority of those affected were located within the Winam Gulf.

3. Household surveys

The data collection target for this survey was the household. It

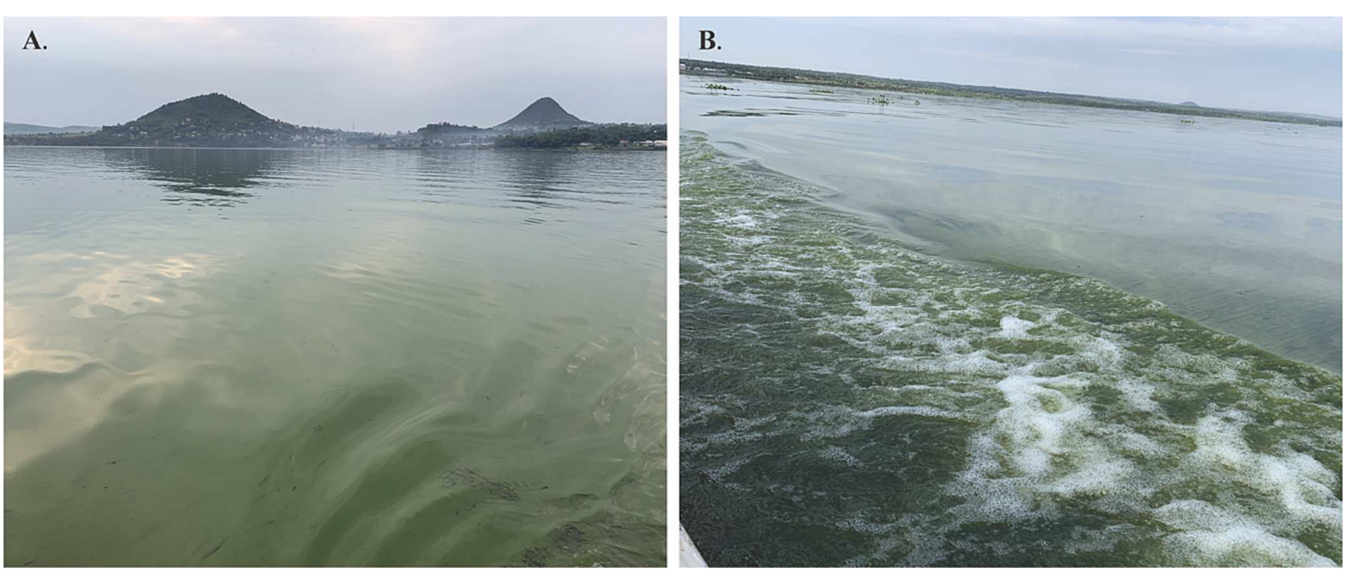

Fig. 2. Algal blooms along the shoreline of Homa Bay in June of 2022. (A) Thick green surface scum against the silhouette of Homa Bay, a city home to approximately 1.2 million residents. (B) Algal scum observed in the wake as we traveled back to the research vessel after conducting interviews in Homa Bay. Photo credit: Brittany N. Zepernick.

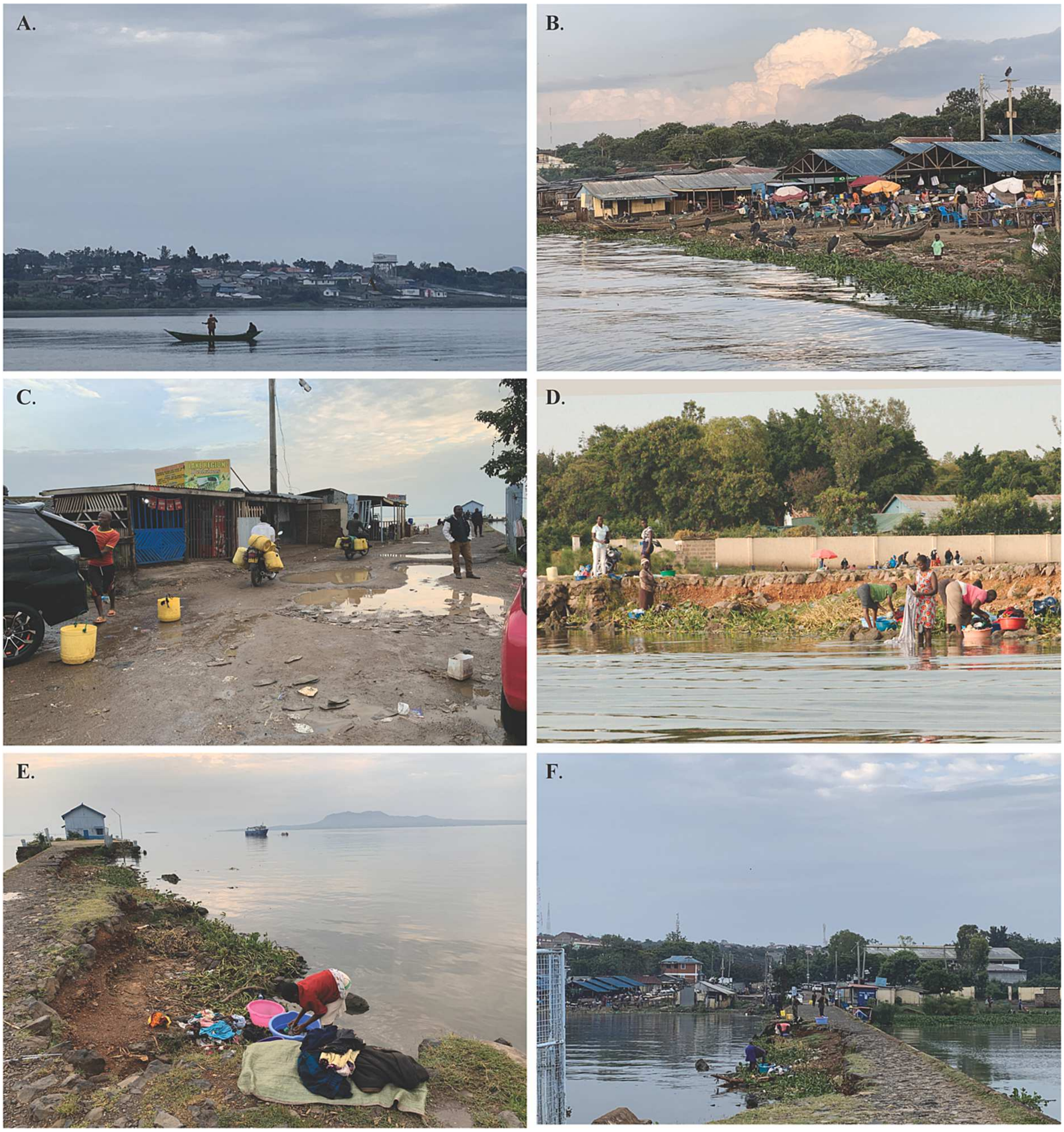

Fig. 3. Residents of Homa Bay performing daily tasks along the shore of Lake Victoria in June of 2022. (A) A fisherman fishing along the coast of Homa Bay, with the water intake plant visible in the background. (B) Fish traders selling the days fresh catch (caught by the fisherfolk) at the outdoor market in Homa Bay. (C) Locals travel with their yellow water jugs to the Homa Bay Pier where they will collect lake water for drinking, cooking, cleaning, and domestic tasks. (D) Women washing laundry and performing domestic tasks along the shore of Lake Victoria in Homa Bay. (E) A woman washes her family's laundry at the Homa Bay pier. (F) Local residents of Homa Bay performing domestic tasks (laundry, water collection for drinking, cooking, cleaning etc.) at the Homa Bay pier. Photo credit: Brittany N. Zepernick and Ken Droulliard.

provided the vital context for understanding the socio-cultural norms and socio-economic activities that relate the fishing communities to their lake habitat and resources. Using secondary information from past surveys which have shown the Winam Gulf to be one of the most polluted parts of the lake (Gikuma-Njuru and Hecky, 2005; Misigo and Suzuki, 2018; Mwamburi et al., 2020; Simiyu et al., 2022). Information was collected from Homa Bay and Kisumu County regions on the Winam Gulf which are highly polluted parts of the lake due to urbanization. The specific landing sites from which data was collected were Koguta and Dunga villages in Kisumu and Lela and Homa Bay Pier in Homa Bay. These sites were chosen purposely based on the visual characteristics of the water which indicated the presence of algal blooms (Fig. 2). Visual criteria such as green surface scum were used to confirm the presence of algae blooms. However, these observations alone cannot determine the presence of toxigenic species or quantify toxicity. Images of algal blooms taken from Lake Victoria were presented to the respondents to illustrate the visual differences between bloom seasons/severity. Prior to conducting surveys, participants were verbally asked for their consent in their native language (English, Swahili, or Luo) and informed of the identity/affiliation of the researchers, the purpose of the surveys, and the end uses/goals of the data as performed in previous interviews in this region (Ziegler et al., 2023).

A structured questionnaire was developed to collect data at the household level. It included questions on the socio-demographic features of the household, their water utilization dynamics (source, treatment, and use), the prevalence of water-borne diseases, awareness of algal blooms, and mitigation strategies employed in relation to the risk of cHABs. Key Informant Interviews (KII) were also administered to the community leaders (Beach Management officials and Village elders) to provide insights on the community's response to algal blooms, including their awareness and understanding of the issue, their efforts to prevent and mitigate algal blooms, and their overall level of preparedness. A pre-tested semi-structured questionnaire coded in English was uploaded on the KOBO Collect Android-assisted application to collect information. This module enhanced accuracy in data capture, including real-time data transmission. Whereas the data tools were drafted in English, during their administration, conversations were adapted to the most appropriate local dialects: Luo and Swahili. A total of 76 questionnaires; Homa Bay Pier (21), Lela (20), Koguta (18) and Dunga (17) and five KII were administered to households and community leaders, respectively, throughout June-July 2022. To increase the sample size and statistical power, the data from the four landing sites were pooled in the overall analysis.

Survey data stored within the KOBO database (i.e., online submissions) were retrieved for descriptive analyses using Microsoft Excel. Further analyses were performed using R statistical software version 4.2.1. Graphical visualization packages included plyr (Wickham, 2011) for data manipulation, ggplot2 and ggpubr (Wickham et al, 2016) for illustrating the variations in the community's water treatment methods, graphics (Murrell, 2018), vcd (Meyer et al., 2020), and ggstatsplot (Patil, 2021) for exploring the relationship between the methods of water treatment during bloom and non-bloom season. Figures generated from these analyses were subject to further editing in Adobe Illustrator. Descriptive analyses were conducted to establish associations within the variables of the study. Qualitative data generated from the interviews were coded against themes arising from the research questions which included 'experience', 'health impacts', and 'causes.' This identified common themes in the research findings. Qualitative data was used to provide detailed explanations of results, general attitudes, and tones of survey participants.

4. Results and discussion

4.1. Sociodemographic of small-scale fishing communities

Socio-demographic characteristics of the respondents (n = 76) are summarized in Table 1. There were relatively more female respondents (n = 44; 57.89%) compared to males (n = 32; 42.11%). This was likely due to the survey being conducted at the household level where women are more likely to be at home and willing to participate. Additionally, women use water more for domestic purposes than men and are often seen as primary caretakers and decision-makers for household matters, such as food and health. Hence, they provide a comprehensive picture of the household's economic and social characteristics (Doss and Quisumbing, 2020). The majority of the respondents were 36–45 years of age (n = 34; 44.74%) which is the most productive age in the Kenyan workforce. Education, as one of the most important indicators of poverty, demonstrates literacy among the households is moderate, with 36.84% (n = 28) having completed O'Level, 32.89% (n = 25) obtaining A'Level and 11.84% (n = 9) completing tertiary education. The household's educational background was also important in determining their ability to understand dangers associated with cHABs and their potential engagement in monitoring/management programs. Community involvement is critical in ensuring cHAB management decisions are informed by local priorities and satisfy the needs of local populations (Hudnell, 2008; Armstrong et al., 2022).

Table 1
Sociodemographic characteristics of the riparian communities in Lake Victoria, Kenya (July 2022).

Variable	Category	Proportion
Gender	Female	57.89% (n = 44)
	Male	42.11% (n = 32)
Age	18–25	15.79% (n = 12)
	26–35	18.42% (n = 14)
	36–45	44.74% (n = 34)
	46–55	18.42% (n = 14)
	>56	2.63% (n = 2)
Marital status	Married	68.42% (n = 52)
	Separated/Divorced	7.89% (n = 6)
	Single	3.95% (n = 3)
	Widowed	19.74% (n = 15)
Marital status	Monogamous	76.32% (n = 58)
	Polygamous	23.68% (n = 18)
Education Level	None	18.42% (n = 14)
	Primary	36.84% (n = 28)
	Secondary	32.89% (n = 25)
	Tertiary	11.84% (n = 9)
Household size	1–3	34.21% (n = 26)
	4–6	63.16% (n = 48)
	7–10	2.63% (n = 2)

4.2. Socio-economic consequences of cHABs on small-scale fishing communities

4.2.1. Awareness of cHABs

The households in our study are closely associated with or directly involved with the fishing industry of Lake Victoria. The majority of respondents were fish traders (n = 33; 43.42%), with the remaining identified as fishermen (n = 25; 32.89%) and fish farmers (n = 18; 23.68%). Fishing is the mainstay of the lake region (Nyamweya et al., 2020). A great proportion (n = 71; 93.67%) is aware of the presence of algal blooms in Lake Victoria, with no significant variation in awareness across several sociodemographic variables (Table 2). The respondents were able to identify the algal bloom images presented to them and agreed they had seen the blooms in the lake during dry seasons (June-September and December-March). Indeed, increases in water temperature (especially during the warmest months of December-March) coincide with reductions in water flow, which presents favorable conditions for cHAB proliferation (Ochumba and Kibaara, 1989).

The majority of respondents (90.8%) believed that careless disposal of waste including discharge of untreated sewage from industries and households, could be a factor in proliferation of blooms in the lake. A few individuals (9.2%) asserted that blooms were a natural occurrence, but they did not understand the cause. Regardless, research indicates industrial and domestic nutrient loadings remain a primary cause of water quality degradation in the lake (Halder and Islam, 2015; Bashir et al., 2020; Njagi et al., 2022, Nyamweya et al., 2023). Overall, while respondents were aware of algal blooms and often referred to them as "The Green", there was little awareness of the primary cause.

Respondents agreed that the cHABs posed a serious threat to their health (n = 62; 81.6%). Health impacts experienced by respondents which were thought to be associated with cHAB exposure include itchiness and cracked skin (51.61%), occasional gastrointestinal disorders (33.87%), and vomiting (14.52%). Management of these illnesses occurred at home due to inadequate financial means to visit the health

Table 2
Awareness of cyanobacterial Harmful Algal Blooms in Lake Victoria tested against various socio-demographic variables (Awareness = percentage of individuals who have heard of cHABs in Lake Victoria).

Categories	X2	p
Awareness/Gender	X2 = 2.8243, df = 1, p = 0.09285	> 0.05
Awareness/Occupation	X2 = 4.1903, df = 3, p = 0.2416	> 0.05
Awareness/Education	X2 = 4.1903, df = 3, p = 0.2416	> 0.05
Awareness/Income	X2 = 2.9817, df = 3, p = 0.3945	> 0.05

*General (93.67% of respondents are aware).

centers (85.4%), but a number of severe cases were referred to the hospitals (14.6%). Nonetheless, respondents expressed dissatisfaction (71.4%) with the treatment due to recurrent symptoms which could have been due to multiple exposures. They expressed dissatisfaction with the limited tests conducted by medical professionals and were uncertain if such tests could reveal the presence of cHABs toxins in their bloodstream. Local health practitioners seem to be unaware of cHAB symptoms, due to a lack of publicly available information on symptoms of human cHAB exposure in the region. As a result, these communities continue to suffer the effects of the blooms in the absence of proper medical attention. According to Roegner et al. (2020), the communities in Lake Victoria face an increased risk of exposure to cyanotoxins through multiple routes. They found out that the microcystin levels tested in drinking and cooking water exceeded the recommended levels of (1 μg/L) by the World Health Organization (WHO), and over 60% of source water samples exceeded US EPA guidelines for children and immunocompromised individuals (EPA, 2019). Further, Kotut et al. (2006) also reported that two freshwater sites, Nyanza Gulf (Lake Victoria) and Lake Baringo, recorded cyanotoxin concentrations exceeding the WHO upper limit of 1.0 mg/L for drinking water. These high concentrations of toxins within Lake Victoria place shoreline communities in great danger. Hence, there is critical need for cHAB public awareness programs, monitoring, and regular updates by public and private sectors.

4.2.2. Access to information on cHABs

While most individuals are aware of cHABs, communities lack critical information on the causes, health risks, and mitigation of cHABs. Indeed, ~45% of respondents indicated they were not informed on the risks of cHABs, with only 10% indicating they felt well informed. (Fig. 4A). Our results indicate the available sources of cHAB information are fisherfolk (n = 60; 78.95%), friends/relatives (n = 10; 13.16%), and to a small extent research institutes (n = 6; 7.89%). This is problematic, for though fisherfolk and relatives are aware of the presence of cHABs, they lack information on extent, risks, and management. Indeed, the lack of information on this emerging threat serves to increase the vulnerability of these communities to cHAB exposure. As a result, the cHAB literature has explicitly called for increased recognition of cHABs in the context of human impacts (Willis et al., 2018), with some previous studies providing examples of sociocultural consequences (Rongo and Woesik, 2012). There is need to curate informative resources regarding cHABs that can be readily accessible to small-scale fishing communities across vulnerable villages along the Lake Victoria basin.

Surprisingly, knowledge of existence of cHABs did not influence how the majority of individuals interacted with the lake water (Fig. 4B). The majority (n = 63; 82.9%) of respondents reported a lack of adequate information on cHABs to inform their response when they occur. Some also mentioned a lack of the resources and infrastructure to monitor and respond to cHABs as a hindrance to effective preparations for the blooms. Yet, significant improvements in the local economy, health, and environment are possible if proper communication on cHABs is provided. According to Bauer et al. (2010), effective communication is essential not only in responding to cHABs, but also in implementing novel methods of mitigating these algal blooms. Therefore, the community needs proper education on cHABs to effectively respond when they occur.

4.2.3. Impacts of cHABs on small-scale fishing communities

When individuals were asked how cHABs have affected them, the most popular consequence reported was the biofouling of fishing gears and boats which reduces their efficiency. These incidents cause economic losses for fishers and households that directly depend on fishing for their livelihoods and protein. Broadly, approximately 200 million Africans derive high-quality and low-cost proteins from fish, such as Lake Victoria's booming Nile Perch population (Obiero et al., 2019) (Fig. 5). Hence, cHAB-induced declines in fishery catch not only invokes economic losses but jeopardizes the food security of millions. In this study. Fishermen reported fish catches were relatively lower during the bloom seasons, hence reducing economic income from fishing activities. However, the majority of respondents (n = 61; 80.1%) continued fishing activities despite bloom interference, while few (17%) diverted to alternative sources of livelihood such as sand harvesting. Prior studies indicate blooms reduce light penetration which affects food sources and migration patterns of fish, further reducing their populations (Lucas and Baras, 2000; Griffith and Gobler, 2020). This could in part explain the reduced catches during the periods of cHABs, but further research is

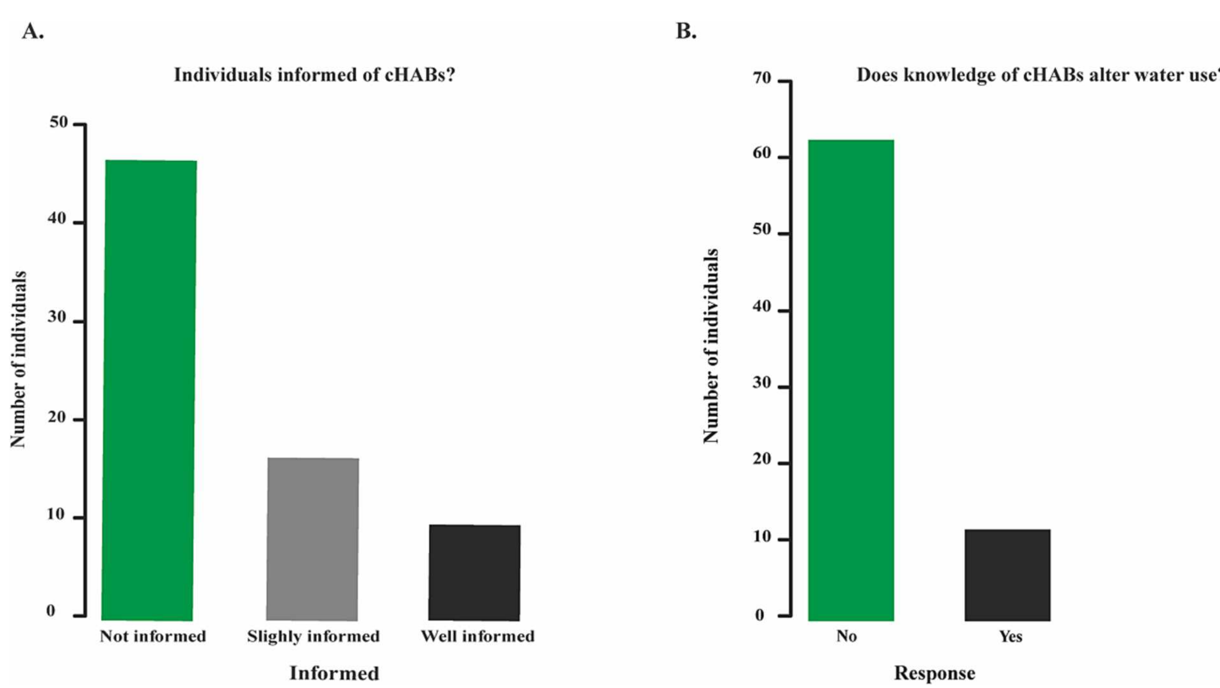

Fig. 4. Response of small-scale fishing community residents to cHAB surveys. (A) Extent to which individuals are informed of cHABs and their risks. (B) Reports of whether knowledge of cHABs alters individual use of lake water.

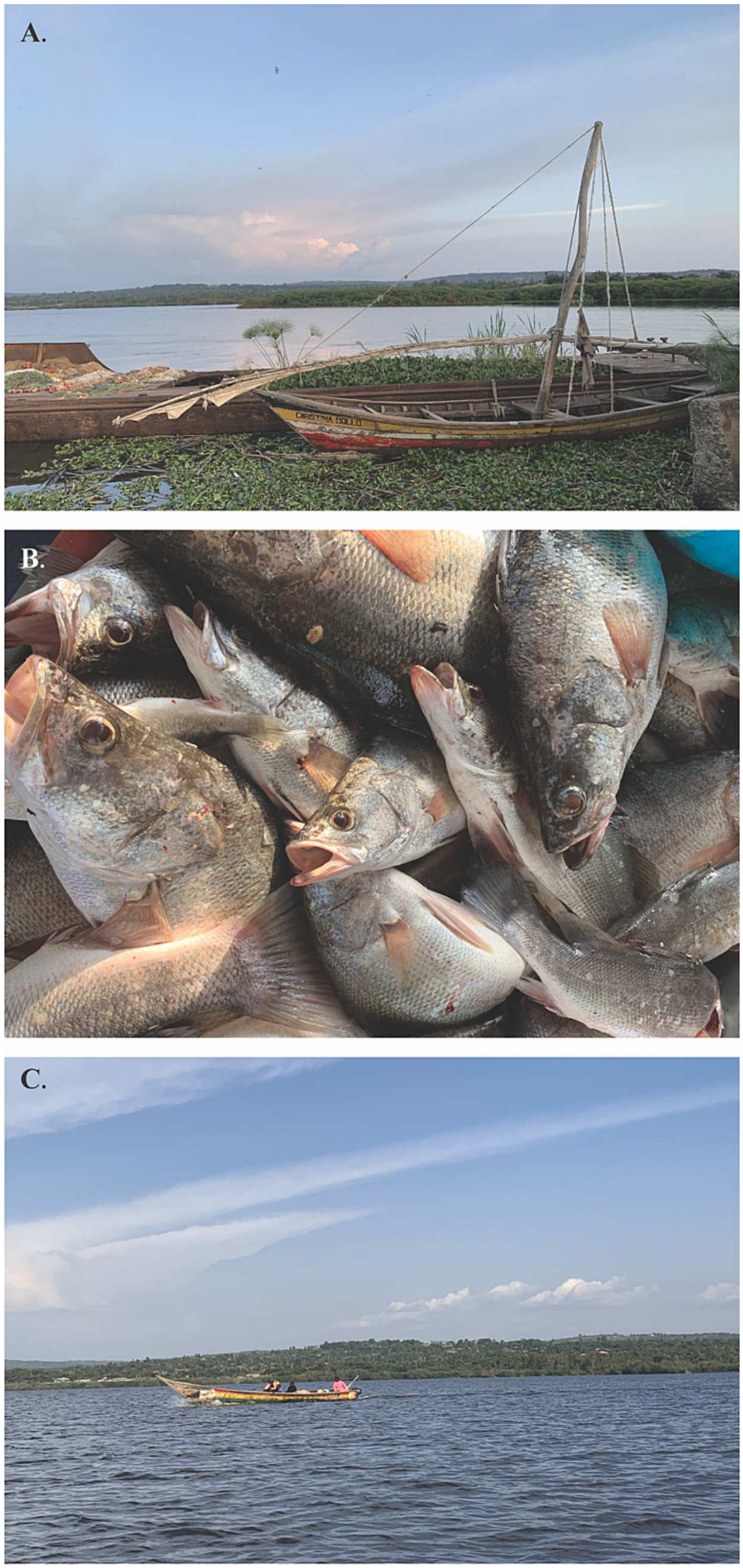

Fig. 5. Images of the small-scale fishing communities. (A) Image of fishing boats moored along the pier in the Winam Gulf. (B) Freshly caught Nile Perch, the main species fished and consumed across the Lake Victoria basin. (C) Image of fisherfolk returning to work after dropping off their morning catch. Photo credit: Brittany N. Zepernick.

required to investigate the dynamics of blooms in relation to fish production in Lake Victoria. Indeed, the fishing industry in the Winam Gulf supports more than 15 million people and is estimated to be worth 5.8 billion Kenya shillings ($40.4 million USD) per annum (Opande et al., 2004). This fishery is one of Kenya's highest sources of revenue, with the Lake Victoria fisheries previously identified as the world's largest freshwater small-scale fishery (Kimani et al., 2018). Given that cHABs are projected to increase in frequency globally, these events serve to jeopardize this lucrative means of livelihood which will result in long-term economic losses for the Lake Victoria fishing industry.

4.3. Community approaches for decreasing cHAB exposure

4.3.1. Sources of water for drinking and cooking in different bloom seasons

Though the community depends on the lake for water during both the bloom and non-bloom seasons, this dependency is highest during the non-bloom season (Fig. 6). This supports our prior finding that individuals are aware of cHABs and suspect they are detrimental to their health, despite being uninformed on cHAB causes and health effects. Significant differences exist in sources of drinking water by bloom season ($X2 = 24.161$, $df = 3$, $p = 2.312e\text{-}05$), with increased use of water from boreholes, taps, and rain reported during the bloom seasons. Bloom seasons are categorized as periods in which phytoplankton can be easily observed at the water's surface (which usually coincides with dry seasons). In turn, the community believes during such seasons, the toxin concentration in the water is high. As a result, they resort to using other sources of water for drinking and cooking. In contrast, the community's dependence on the lake water is heightened during non-bloom periods which coincide with the rainy season. However, it is unclear why respondents would continue to use lake water as a primary water source when rainwater could be collected and thus serve as a preferable option. Factors such as inadequate rain harvesting systems and ease of access (Chumo, 2012; Ondigo et al., 2018) likely influence the observed dependence on lake water. This high dependency on lake water coupled with the unawareness of individuals regarding toxin accumulation renders these communities vulnerable to cHAB exposure. Thus, it is important to monitor the quality of water sources and inform individuals of cHAB risks to ensure their access to safe drinking water, regardless of the season.

4.3.2. Water treatment methods applied by local communities

The majority of small-scale fishing communities apply simple treatment techniques to the lake water before use to decrease cHAB exposure (Fig. 7). Yet, these methods only remove visible phytoplankton aggregates in the water and do little in regard to dissolved toxin removal. There were statically significant differences in bloom season and the method of water treatment, with increased chlorination and boiling

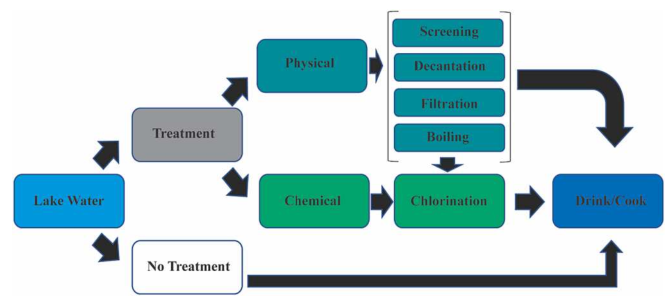

Fig. 7. Simple water treatment methods employed by the community to treat the lake water and decrease cHAB toxin exposure. Screening is the visual inspection of water for the presence of algal blooms, and it is usually the first step in the treatment process. Decantation is the process whereby the households leave the water to settle and carefully transfer the surface water to another container. Filtration involves the use of a clean cloth covered on the barrel for storing water to remove visible blooms. For chlorination, they use sodium hypochlorite, while boiling involves heating the water to its boiling point.

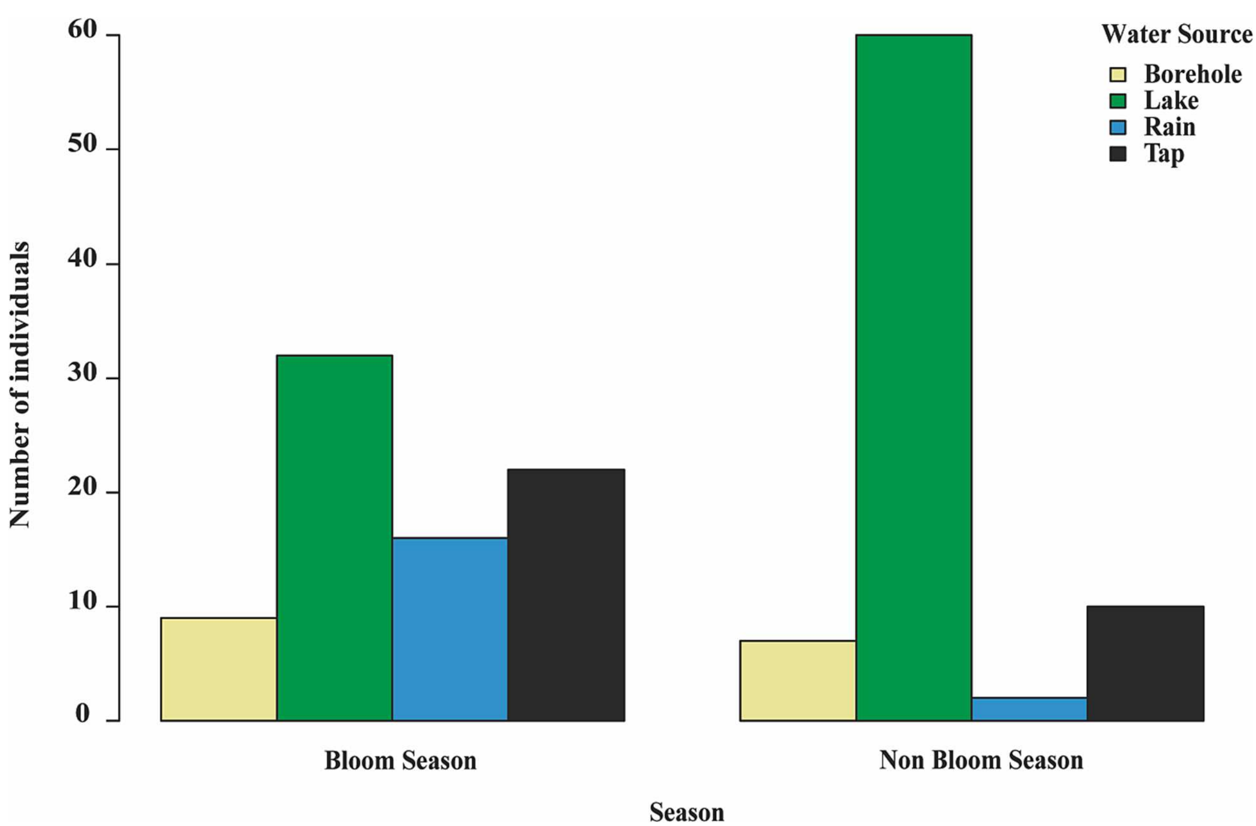

Fig. 6. Sources of water individuals use during the algal bloom season vs. non-bloom season.

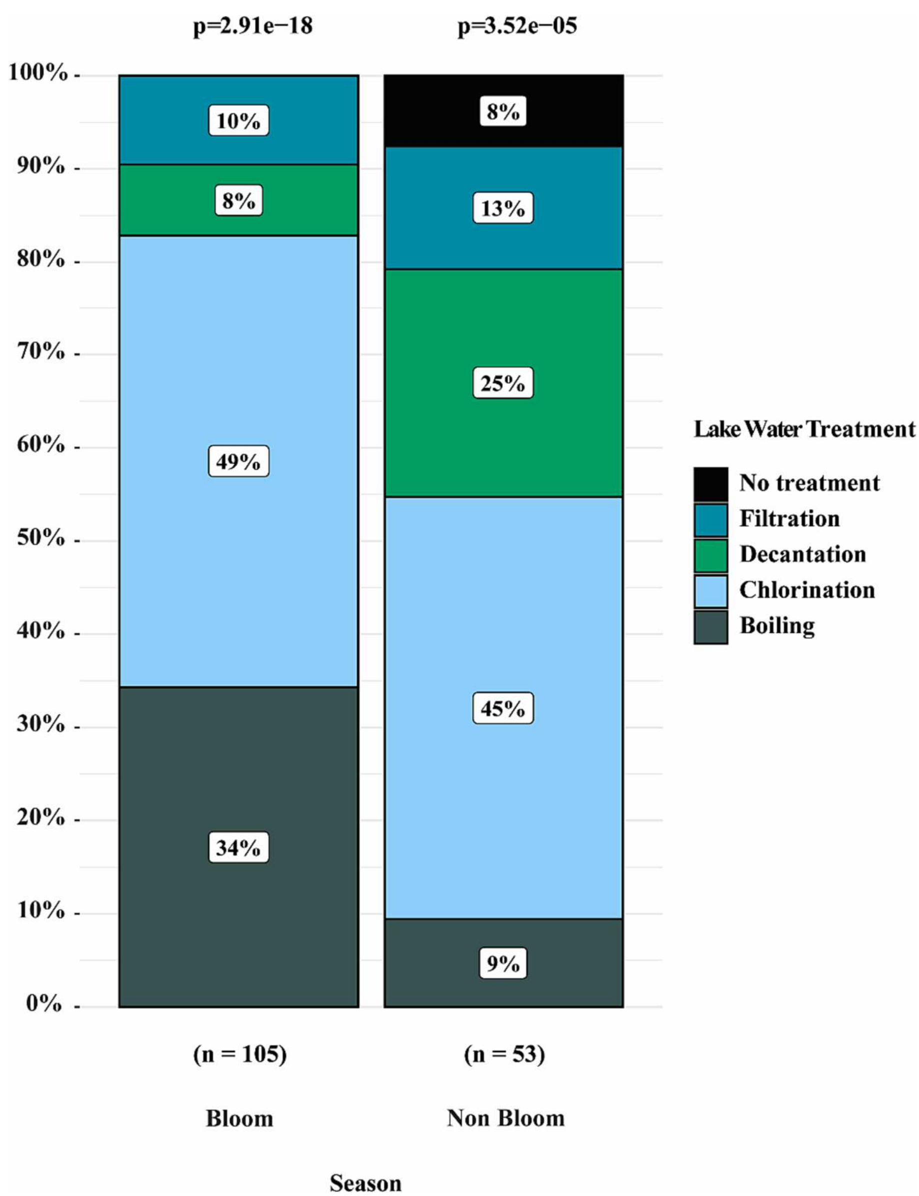

Fig. 8. A Pearson Chi-Square test yielded significant results ($p = 6.61e\text{-}05$), indicating a substantial difference in the method of water treatment and the season of bloom in Lake Victoria. Bloom season = the time of year when blooms of cyanobacteria or blue-green algae occur. Method of water treatment = the process used to treat and purify water for consumption such as chlorination, boiling, and filtration.

observed during cHAB bloom periods (Fig. 8). Chlorination-based disinfection is widely used in drinking water treatment and has been shown to reduce the concentration of cyanotoxins (Pan et al., 2011). However, studies have shown that chlorine doses, contact time, and pH all have a strong influence on microcystin degradation, and simply adding chlorine may not be an effective treatment for removing microcystins (Jasim and Saththasivam, 2017). Experimental studies also reveal that boiling may reduce some toxins produced by cHABs, but it may not be effective against all toxins as many are resistant to heat (Bell and Krail, 2016). For example, most microcystins are heat-resistant within the range of conventional food-processing temperatures (80–121°C), so little or no reduction in overall toxin levels occurs as a result of normal cooking conditions or pasteurization (Codd et al., 1999; Kabak, 2009). The effectiveness of boiling as a treatment method depends on several factors, including the type of toxin, the temperature/duration of boiling, and the concentration of the toxin in the water (Bullerman and Bianchini, 2007). Hence, further research is warranted to better understand the behavior of different toxins in various methods of treatment. Locally directed management policies on cHABs can be developed at scales more appropriate to riparian communities to better respond to their specific needs (Mchau et al., 2019).

5. Conclusions and recommendations

This study builds upon prior findings by investigating how small-scale fishing communities perceive and respond to algal blooms which include high proportions of cHABs, with a focus on how they alter their consumption of lake water during cHAB events. Overall, our results suggest an increased awareness of cHABs in Lake Victoria's small-scale fishing communities and indicate individuals are attempting to avoid cHAB exposure by altering water sources, treatment strategies, or consumption during blooms. Yet, the lack of comprehensive resources and publicly available information greatly hinders these attempts. Most community members recognize the dangers of cHABs on an economic scale but lack sufficient information regarding the threat to human and animal health. Individuals employ simple water treatment methods such as filtration, boiling, and chlorination to reduce the concentrations of toxins in the lake water before use, yet the efficacy of these strategies is low. In addition, we demonstrate local communities are increasingly reliant on internal village resources to respond to cHABs rather than external government support for the management of HABs. In turn, the major sources of cHAB information within these communities are fisherfolk and village elders, who themselves are not properly informed of cHAB risks. In summary, this study serves as a critical call-to-action: there is a need to inform individuals of the risks and avoidance strategies of cHABs in at-risk communities. We recommend more research on cHABs, a comprehensive public education and outreach program to improve local community knowledge and response to cHABs. By increasing awareness, promoting safe practices, and fostering a culture of preparedness and responsiveness, these programs can help curb the impacts of cHABs and protect human and ecosystem health.

Funding

This study was funded by the National Science Foundation NSF IRES award 1953468 to George Bullerjahn and facilitated by BGSU, Kisii University, Technical University of Kenya, Kenya Marine Fisheries Research Institute, and the African Center for Aquatic Research and Education. This work is a product of the collaborative NSF IRES program "Advanced Studies Institute on Water Quality and Harmful Algal Blooms in Lake Victoria, Kenya".

We also acknowledge NSF CNH2 (NSF BCS# 2009658) funding for HOO, Cornell Atkinson Center Atkinson Venture Fund award and Cornell University's Einaudi Center Faculty Seed Grants (to KJF). These funds supported by man-hours for HOO while he participated in the study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank George Bullerjahn, R. Michael. M. McKay, Kenneth Droulliard, and Kefa Otiso for their collaboration, mentorship, and support during this study, which was funded by IRES grant 1953468 by the National Science Foundation. The authors would also wish to thank Christopher Aura and Chrisphine Nyamweya for their invaluable contributions to the implementation of the program in Kenya. Lastly, the authors would like to extend their sincere gratitude to the Lake Victoria community for their support and participation in this program. Their insights, knowledge, and perspectives were critical to our understanding of the challenges facing the lake and its ecosystem.

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