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Harmful algal bloom and associated health risks among users of Lake Victoria freshwater: Ukerewe Island, Tanzania

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ABSTRACT

There is a global concern regarding the occurrences of harmful algal blooms (HABs) and their effects on human health. Lake Victoria (LV) has been reported to face eutrophication challenges, resulting in an increase of bloom-forming cyanobacteria. This study is aimed at understanding the association of HABs and health risks at Ukerewe Island. A cross-sectional study conducted on 432 study subjects and water samples for cyanobacteria species identification were collected at LV shores. The results reveal that concentrations of cyanobacteria cells are beyond (WHO) acceptable limits; species of *Microcystis aeruginosa* range from 90,361.63 to 3,032.031.65 cells/mL and *Anabaena* spp. range from 13,310.00 to 4,814,702 cells/mL. Water usage indicates that 31% use lake water, 53% well water and 16% treated supplied pipe water. Vomiting and throat irritation was highly reported by lake water users as compared to wells and pipe water ($P < 0.001$). Gastrointestinal illness (GI) was significantly elevated among lake water users as compared to pipe and well water users ($P < 0.001$). Visible blooms in lake water were associated with GI, skin irritation and vomiting as compared to water without visible blooms ($P < 0.001$). The concentration of cyanobacteria blooms poses greater risks when water is used without treatment.

Key words | cyanobacteria, harmful algae blooms, health effects, Lake Victoria

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INTRODUCTION

Cyanobacteria blooms have some toxin producing species which pose a potential health hazard to humans and other living organisms, and the risk is high when eutrophication occurs in fresh waters. Lake Victoria (LV), being a fresh water lake, has faced eutrophication challenges, resulting in an increase of bloom forming cyanobacteria throughout the year with the ability to produce hazardous cyanotoxins (Mbonde *et al.* 2004). Harmful algal blooms (HABs) can be visible as excessive scum of algal biomass on top of fresh water, which may be attributed to an increase in the levels of nitrogen and phosphorus in fresh water bodies, and this has been observed in Lake Victoria (Mchau *et al.* 2019). This increase in algal biomass causes low oxygen levels in the water which leads to the mortality of aquatic organisms, as well as reducing the quality of water for human consumption.

The toxins produced by cyanobacteria are classified on the basis of the symptoms observed in humans and other vertebrates, namely hepatotoxins, neurotoxins and irritant-dermal toxin. Microcystin (MC) produces hepatotoxins

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such as MC-LR, MC-RR and MC-YR, which often contaminate drinking water (Carmichael *et al.* 2001). The World Health Organization (WHO) has therefore proposed a provisional guideline for an acceptable limit of MC-LR concentration in drinking water of 1.0 μg/L (WHO 2003). In addition, cyanobacteria blooms create a threat to recreational water by producing harmful toxins and malodorous compounds as well as causing hypoxia and disruption of food webs in the ecosystem (Cheung *et al.* 2013). The occurrence of toxigenic cyanobacteria *Anabaena* and *Microcystis*, which produce cyanotoxins such as MC-LR, MC-RR and MC-YR, has been documented in all the countries that share the lake Victoria shores, namely Kenyan, Ugandan and Tanzania (Okello *et al.* 2010; Sitoki *et al.* 2012).

Human diseases due to cyanobacteria vary based on related exposure such as swimming, skin contact, bathing, and drinking. Several acute symptoms have been reported in humans such as stomach upset, vomiting, skin irritation, nausea, diarrhea, fever, throat irritation, headache, mouth blisters, muscle and joint aches, eye irritation, and allergic reactions (Kibria 2016). Chronic health effects include the possible human carcinogen for liver and colorectal malignancies. The International Agency for Research in Cancer (IARC) has categorized MC-LR as a causative factor for chronic illness (IARC 2010). Water ingestion has been identified as the major route of exposure to harmful cyanobacteria toxins in human and animals, which causes human health effects and animal deaths (Codd *et al.* 1994; Hilborn *et al.* 2014). However, few epidemiological studies have been conducted to document acute and chronic human health effects caused by cyanobacteria and cyanotoxin with regards to the route and modes of exposure (Chorus & Bartram 1999).

Globally, few countries have set up surveillance systems that monitor occurrences of HAB related illnesses as well as establishing country specific acceptable limits for the concentration of cyanobacteria cell density in waters used for different human activities. Instead they use the WHO set general guidelines which are not country specific. The World Health Organization (WHO) has proposed guidelines for different cell densities of cyanobacteria bloom levels and related illnesses, such as: for recreational waters cell densities of 20,000 cells/mL are associated with risk of short-term adverse health outcomes; and at a higher cell density of 100,000 cells/mL an additional risk for long-term illness exists. Cyanobacteria scum formation in bathing areas is associated with the risk of potential severe health outcomes such as throat irritation, stomach upset, skin irritation, vomiting, nausea, diarrhea, fever, and headache (WHO 2003). Due to the non-specific nature of the symptoms of HAB related illnesses and lack of specific guidelines for surveillance and diagnosis, it has proven to be difficult for health-care providers to identify and document HAB associated illnesses. This poses a serious public health omission in the identification of HAB related effects in human. Therefore, health-care providers should be aware of the HAB related symptoms as illness may present differently from other recreational water-associated illnesses and onset may occur soon after exposure such as headache, throat irritation, stomach upset, diarrhea, vomiting, skin and eye irritation to name but a few.

This study aims to identify the different species of cyanobacteria and their potential health effects that may be attributed to the existing dominant HAB species in Lake Victoria in the Ukerewe districts. Most of the HAB associated water illnesses are underestimated and go unrecognized due to lack of water quality assessment and disease surveillance systems that can record the water quality parameters as recommended by WHO and monitor illness related to cyanobacteria blooms. This study will document health related effects of HABs on the population of Ukerewe Island which mostly depend on the lake water for their daily human consumption. The documented information can be used to develop evidence-based HAB related illness prevention strategies.

METHODS

A cross-sectional study was conducted at Ukerewe district (Island), Mwanza region in Tanzania. A total of 432 subjects were recruited in December 2018. The study subjects were individuals who have been residing in the district for more than five years and were above the age of 18 years. The study protocol was adopted and modified from a water quality and associated illness study carried out in the USA by Wade *et al.* (2008) and Collier *et al.* (2015).

Water samples for cyanobacteria species identification were collected from selected sites at the lake Victoria shore in Ukerewe district, where water is fetched for different domestic purposes and recreation activities take place. Semi-structured questionnaires were used to collect information from all study subjects on demographic information, practices on water utilization and observed illness after exposure. The National Institute for Medical Research (NIMR) ethical committee reviewed the protocol for this study and granted ethical clearance number NIMR/HQ/R.8a/Vol. IX/2426.

Study site

Ukerewe District comprises 27 islands within Lake Victoria, in Mwanza region, northern Tanzania between latitudes 10°45′ and 20°15′ S and longitudes 320°45′ and 330°45′ E. Lake Victoria is the world's second largest freshwater body, measured by surface area, and the largest in the developing world, with a surface area of 68,800 km^2 and a catchment covering 284,000 km^2. Water samples were collected at eight different sites along the Lake Victoria shore, namely Lugenzi, Water Agency Street, Namagondo, Barazani, Bugolora, Nebuye, Kahama and Galu beach.

Water sample collection and Phytoplankton identification

At each sampling site 20 L of water was concentrated using a 13 μm phytoplankton net to obtain the desirable sampling volume of 20 mL of water. The concentrated water samples were preserved in 20 mL vials and stained with Lugols solution at a final concentration of 0.7%. Identification and counting of phytoplankton species was carried out using an inverted microscope at 400× magnification using morphological criteria according to freshwater phytoplankton keys by Whitton *et al.* (2002). At least 10 fields were randomly selected during the observation and counting of the species from the sedimentation chambers. Different species were counted by numbers of filaments and cells depending on the nature of the species. Phytoplankton abundance was calculated using the formula (Greenberg 1992):

$$Abundance = \frac{C \times At \times v}{Af \times F \times V \times Vi}$$

where C = number of organisms counted, At = total area of bottom of settling chamber (mm^2), v = volume of concentrated sample (20 mL), Af = area of field (mm^2), F = number of fields counted, V = volume of sample observed (2 mL) and Vi = volume of the sedimented sample.

Health effect assessment

Health effects were self-reported by the study subjects, based on the following definition: Having diarrhea was considered when an individual reported having three or more loose stools in a 24-hour period; vomiting; ejection of stomach contents through the mouth, stomach upset; disorder of digestive system functions characterized by discomfort or nausea. All the three symptoms together (diarrhea, vomiting and stomach upset) were regarded as gastrointestinal illness (GI) that interferes with regular activities. Skin irritation was defined as a state of inflammation, itching or painful reaction of the skin; eye irritation was either eye itching, eye infection or watery eyes and throat irritation was defined as pain, itchiness of the throat that can lead to cough, runny nose, or cold as general upper respiratory illness (URI) (Wade *et al.* 2008; Collier *et al.* 2015).

Statistical methods

Data were collected through an open data kit (ODK) which was then exported to Microsoft Excel (MS). Analysis was carried out using Epi Info Version 7.2.1.0. The outcome of interest was the observed health effects such as skin irritation, vomiting, diarrhea, stomach upset, and throat and eye irritation. Each outcome of interest was independently tested in Univariate analysis using a 2 × 2 and Chi-square–Mantel-Haenszel (2-tailed *P*-value) was used to determine the level of significance for the outcome of interest response with less than five in the 2 × 2 table. The Fisher exact test was used to determine the level of significance. All statistically significant outcome variables in the univariate analysis were further put together in the multivariate analysis.

Multivariate analysis was carried out by a backward method where the outcome with the weakest association was removed in the model sequentially until the best-fit model was realized. In the univariate analysis crude odds ratio and their 95% confidence intervals were reported, while in the multivariate analysis adjusted odds ratio with their 95% confidence intervals were reported. The results were considered significant when the *P*-value was less than 0.05.

RESULTS

During this study, while collecting the samples the water colour was observed to be greenish with bloom on the surface, which was a clear indication that cyanobacteria member dominated the areas, four main groups (classes) of phytoplankton were found, namely Chlorophyceae, Cyanophyceae, Bacillariophyceae and Dinophyceae (Table 1). The results indicate that cyanobacteria (Cyanophyceae) were blooming in all eight sites and they formed more than 97% of all phytoplankton in the lake. The most common members were *Microcystis, Anabaena, Merismopedia*, the concentration of *Microcystis aeruginosa* ranged from 90,361.63 to 3,032,031.65 cells/mL and among the eight sample collection sites five (62.5%) had above 100,000 cells/mL and three (37.5%) had less than 50,000 cells/mL. *Anabaena* spp. cells concentration ranged from 13,310 to 4,814,702 cells/mL, of which seven (87.5%) sites had above 100,000 cells/mL and one (12.5%) had less than 100,000 cells/mL. *Merismopedia* spp. cells concentration ranged from 2,843.69 to 201,113.04 cells/mL where only two (25%) sites had cells above 100,000 cells/mL and six (75%) sites had less than 100,000 cells/mL (Table 1). Well and treated pipe water were not tested for availability of cyanobacteria.

Reported health effects from the study area

The study was conducted in December 2018, and a total of 432 subjects participated. The mean age was 42 years old with a range of 18–86 years old, 234 (54%) were male and 198 (46%) female. One hundred and thirty-four subjects (31%) reported using lake water as their main source of water, while 229 (53%) used well water and 69 (16%) used treated supplied pipe water as their main source of water for drinking and other domestic uses.

Reported health effects among the subjects were as follows: 78 (18.06%) did not report any health effects while 71 (16.44%) reported one health effect, 81 (18.75%) reported two health effects, 124 (28.70%) reported three health effects, 62 (14.35%) reported four health effects, 12 (2.78%) reported five health effects and four (0.98%) reported all six health effects. The study observed that there is a mixture of water uses and different exposure whereby a person can use pipe water for drinking purposes but use lake water for bathing and other water activities and vice versa. More than 50% of the subjects reported skin irritation, stomach upset and eye irritation followed by diarrhea (32%) while vomiting (9%) and throat irritation (10%) were least reported.

In univariate analysis, individuals who used the lake as their source of drinking water were six times more likely (OR 6.1, 95% CI 2.8–13.58) to have vomiting compared to those individuals who used wells as their source of drinking water and this was statistically significant ($P < 0.001$). The odds of getting throat irritation when using the lake as a source of drinking water were six times higher than when using wells as a source of drinking water OR = 6.57 (95% CI = 2.74–15.79, $P < 0.001$).

Those who had used the lake as their source of drinking water were observed to be associated with more stomach upsets (OR = 8.4, 95% CI = 4.49–14.78, $P < 0.001$) compared to those using wells as their source of drinking water. The risk of vomiting when an individual consumed lake water was observed to be 17-fold higher compared to when an individual consumed treated supplied piped water (95% CI = 2.28–127.2) and this was statistically significant ($P < 0.001$). Bathing using treated supplied pipe water was protective against eye irritation as compared with the contaminated lake water source with cyanobacteria (OR = 0.46, 95% CI = 0.24–0.85) and this was statistically significant ($P = 0.01$). Getting a stomach upset when an individual used lake water for drinking was 45.2-fold higher than when they used treated supplied pipe water for drinking and this was statistically significant (95% CI = 19.78–111.81, $P < 0.001$).

The odds of vomiting when consuming water with visible bloom was almost four times higher compared to drinking water without visible bloom, which was statistically significant (95% CI = 1.49–10.44, $P = 0.003$). The odds of getting diarrhea when drinking water with visible bloom is two-fold higher as compared with consuming water source with no visible bloom (95% CI = 1.39–3.6 and $P < 0.001$).

Table 1 | List of Phytoplankton species found at Ukerewe area in Lake Victoria

List of Phytoplankton species found at seven selected Lake Victoria lake shores

Taxa		**Selected sites along Lake Victoria shores**							
Chlorophyceae (Green algae)	**Unit**	**Lugenzi**	**Water Agency St.**	**Namagobo**	**Barazani**	**Bugolora**	**Nebuye**	**Kahama**	**Galu Beach**
Ankistrodesmus sp.	cells/mL	90.25	150.9	75	33.85	22	10	21	80
Coelastrum microporum	cells/mL	0	12.10	33.85	0	33.85	4	2	13
Pediastrum sp.	cells/mL	0	0	0	33.85	0	0	0	0
Scenedesmus spp.	cells/mL	0	0	0	135.41	270.83	1,218.72	1,624.96	3,656.16
Staurastrum spp.	cells/mL	0	0	0	0	33.85	0	0	0
Cyanophyceae cyanobacteria									
Anabaena spp.	cells/mL	677,068.00	4,814,702.00	142,316.75	174,054.31	112,310.00	67,321.00	73,292.00	13,310.00
Chroococcus dispersus	cells/mL	32	42.00	812.48	12	812.48	31	11	54
Merismopedia spp.	cells/mL	2,843.69	201,113.04	2,843.69	1,421.84	2,447.60	4,361.00	32,562.00	189,815.90
Microcystis aeruginosa	cells/mL	90,361.63	3,032,031.65	148,139.02	111,239.53	136,104.03	92,302.00	104,032.00	154,212.00
Microcystis flos aquae	cells/mL	14,387.70	443,507.30	10,156.02	5,078.01	8,463.34	100,950.78	100,239.86	203.12
Microcystis spp.	cells/mL	110	21,202.20	302	13,541.36	6,770.68	321	2,761.00	5,211.00
Planktolyngbya circumcreta	filament/mL	118.49	0.00	67.71	50.78	78.98	0	0	0
Planktolyngbya spp.	filament/mL	50.78	0	169.27	50.78	0	0	0	0
Bacillariophyceae diatoms									
Aulacoseira spp.	cells/mL	1,692.50	1,4026.70	1,777.30	4,824.11	761.7	0	0	3,046.80
Cyclotella spp.	cells/mL	84.63	308.13	67.71	50.78	67.71	101.56	203.12	541.62
Fragilria spp.	cells/mL	33.85	0	50.78	67.71	33.85	0	101.56	372.32
Navicula spp.	cells/mL	0	0	67.71	0	67.71	101.56	101.56	101.56
Nitzschia acicularis	cells/mL	1,263.85	0.00	1,218.72	220.05	327.23	0	0	203.12
Synedra cunningtonii	cells/mL	440.09	210	293.37	84.63	67.71	0	0	0
Dinophyceae									
Glenodinium spp.	cells/mL	0	0	0	203.12	33.85	0	0	0

The odds of getting skin irritation among those individuals using water with visible bloom was almost two times higher compared to those who used water for bathing without visible bloom (95% CI = 1.0–2.3, $P = 0.04$). Study subjects who reported drinking water with visible bloom were four times more associated with throat irritation than those who consumed water without visible bloom (OR = 4, 95% CI = 1.37–11.8, $P = 0.006$). The study showed that the likelihood of getting stomach upset when consuming water with visible bloom was three-fold higher than those who consumed water with no visible bloom and this was statistically significant (OR = 3.4, CI = 2.28–5.28, $P < 0.001$).

The study subjects' occupation was compared between fishermen and those employed with non-fishing activities. Individuals who were in the fishing activities were more likely to have reported symptoms of vomiting as compared with their counterparts who were involved in non-fishing activities (OR = 2, 95% CI = 1–4.5, $P = 0.02$). This study indicated that fishermen were twice as likely to report symptoms of diarrhea as compared to those in other non-fishing occupations (95% CI = 1.2–3.3, $P = 0.003$). The odds of getting skin irritation among fishermen were almost two-fold higher (95% CI = 1–2.9, $P = 0.02$) as compared with individuals in other non-fishing occupations.

Study subjects with fishing occupations were more than twice as likely to have throat irritation as compared to those with non-fishing occupations (OR = 2.4, 95% 1.1–5.1, $P = 0.02$).

Diarrhea and throat irritation were reported to be mainly associated with the consumption of more than 1 L of lake water (OR = 2, 95% CI = 1–2.4, $P = 0.02$ and OR = 4, 95%CI = 2.11–8.9, $P < 0.001$ respectively).

DISCUSSION

Based on WHO guidelines, cyanobacteria cell concentration at 20,000 cells/mL is associated with a risk for short-term adverse health outcomes and at 100,000 cells/mL the risk for long-term illness exists; potentially severe health outcomes (WHO 2003). The observed levels of cyanobacteria's scum concentration in this study are very high and utilization of water from the lake without treatment may lead to acute and chronic health problems. The predominance of cyanobacteria in the plankton of Lake Victoria has been linked with eutrophication of the lake that may be caused by excessive nutrients such as nitrogen and phosphorus nutrient (Hecky 1993; Mchau 2019). Other studies have indicated that the occurrence of *Anabaena* and *Microcystis* species in higher abundances in Lake Victoria has threatened the water quality due to the ability of these species to produce toxins (Sekadende *et al.* 2005; Mbonde *et al.* 2015). The dominant species of cyanobacteria observed in this study, such as *Anabaena* and *Microcystis*, may be a threat to aquatic organisms and pose a potential health risk to humans when water from the lake is consumed without treatment (Chorus & Bartram 1999; Semyalo *et al.* 2010).

Toxin produced by *Microcystis*, *Anabaena* and *Merismopedia* and their health effects

The observed dominant cyanobacteria of genera *Anabaena, Merismopedia* and *Microcystis* can produce variants of Microcystin toxin that can lead to hepatotoxicity, which inhibits eukaryotic protein phosphatases in human. These toxins have potential health effects such as gastrointestinal illness, liver inflammation, and hemorrhage and liver failure leading to death, pneumonia, and dermatitis (Chorus *et al.* 2000; Boopathi & Ki 2014). *Anabaena* spp. can also produce Cylindrospermopsin toxins that are hepatotoxic, cytotoxic, and neurotoxic, which will inhibit glutathione synthesis, protein synthesis and cytochrome P450 in humans. Cylindrospermopsin toxin has the following health effects: pneumonia, liver inflammation, and hemorrhage, gastrointestinal and dermatitis (Carmichael 2001). Anatoxin-a toxins are one of the cyanobacteria toxins which are produced by *Anabaena* spp. and lead to neurotoxicity and imitation of the neurotransmitter acetylcholine. Anatoxin-a toxins can cause a number of health effects including: tingling, burning, numbness, drowsiness, incoherent speech, and respiratory paralysis leading to death. The observed dominant *Anabaena* spp. in the lake can potentially produce Saxitoxin, which causes neurotoxicity and blockage of voltage-gated Na^{+} channels in humans and other vertebrates. The toxin can cause numbness, burning, tingling, drowsiness, incoherent speech and respiratory paralysis leading to death (Funari & Testai 2008; Boopathi & Ki 2014). Apart from the chronic health effects, the dominant species can potentially

Table 2 | Reported health effects from various water sources

		Response		Univariate		Multivariate	
Health effect	**Water source**	**Yes**	**No**	**cOR (95% CI)**	***P* value**	**AOR (95% CI)**	***P* value**
Vomiting	Lake	27	107	6.1 (2.8–13.58)	<0.001	2.8 (1.18–6.4)	0.01
	Wells	9	220				
Diarrhea	Lake	48	86	1.5 (0.95–2.38)	0.08		
	Wells	62	167				
Skin irritation	Lake	80	54	1.21 (0.78–1.86)	0.3		
	Wells	126	103				
Eye irritation	Lake	69	65	0.86 (0.56–1.33)	0.5		
	Wells	126	103				
Throat irritation	Lake	23	111	6.57 (2.74–15.79)	<0.001	4.3 (1.5–11.76)	0.004
	Wells	7	222				
Stomach upset	Lake	119	15	8.14 (4.49–14.78)	<0.001	7.7 (4.2–14.4)	<0.001
	Wells	113	116				
Vomiting	Lake	27	107	17 (2.28–127.2)	<0.001		
	Pipe	1	68				
Diarrhea	Lake	48	86	1.19 (0.64–2.2)	0.5		
	Pipe	22	47				
Skin irritation	Lake	80	54	0.65 (0.35–1.2)	0.16		
	Pipe	48	21				
Eye irritation	Lake	69	65	0.46 (0.24–0.85)	0.01	0.2 (0.07–0.57)	0.002
	Pipe	48	21				
Throat irritation	Lake	23	111	Undefined	0.005		
	Pipe	0	69				
Stomach upset	Lake	119	15	45.2 (19.72–111.81)	<0.001	58.96 (21–162.73)	<0.001
	Pipe	10	59				

cause acute symptoms such as stomach upset, vomiting, skin irritation, nausea, diarrhea, fever, throat irritation, headache, mouth blisters, muscle and joint aches, eye irritation, and allergic reactions (Kibria 2016).

Health effects reported from different water sources utilization

The assessment of water consumption among study subjects shows that 31% use lake water as the main source of water, 53% use well water and 16% used treated supplied pipe water as the main water source for drinking and domestic purposes. The subjects reported vomiting as one of the health effects occurring after drinking water from the lake source, which is infested with cyanobacteria. The risk of vomiting is 6.1-fold higher compared to those accessing drinking water from wells ($P < 0.001$). The risk of vomiting when consuming bloom contaminated water is 17-fold compared to treated supplied pipe water ($P < 0.001$; see Table 2). The same finding that cyanobacteria infested water can cause vomiting was reported in the UK (Turner *et al.* 1990) and in Australia (Pilotto *et al.* 1997). Vomiting was still statistically significant in multivariate analysis ($P < 0.05$; Table 2). The odds of getting throat irritation when drinking cyanobacteria contaminated water from the lake source is 6.57 higher than when drinking from the wells ($P < 0.001$), and this association was also strong in multivariate analysis ($P < 0.05$; Table 2). Throat irritation is one of the documented health effects after ingestion of algal bloom contaminated water in most recreational activities or water related exposure (Kibria 2016).

Gastrointestinal illness (GI) was significantly elevated among study subjects using water from the lake as compared to pipe and well water users. Getting stomach upsets when drinking cyanobacteria contaminated water from the lake source is 45.2 and 8.4-fold higher than drinking treated supplied pipe and well water respectively ($P < 0.001$). This finding was also reported by Hilborn *et al.* (2014) and Collier *et al.* (2015). The association between stomach upset and contaminated water was observed to be strong in multivariate analysis ($P < 0.001$). Bathing using treated supplied pipe water is protective against eye irritation as compared to contaminated lake water source with cyanobacteria (OR = 0.46, $P < 0.05$) and the observation was the same on multivariate analysis ($P < 0.05$). Acute and short-term health effects can be preventable with adequate treatment which significantly reduces cyanobacteria cell numbers by up to 99%, hence making the water safe for human use (Dietrich & Hoeger 2005; Funari & Testai 2008). WHO reported that swimmers in water containing cyanobacteria may suffer from allergic reactions such as eye irritation (WHO 2014).

Bloom availability

The evidence that bloom was present during reporting of HAB related illness is important for proper linkage of disease related to HABs in the water. The scum of cyanobacteria may be visible at some time during the day and then disappears and therefore it was important to associate the health risk with the visible algal scum in the water. The study reveals the odds of vomiting when consuming water with visible bloom is almost four-fold compared to drinking water without visible bloom ($P = 0.003$). The likelihood of GI was higher when consuming water with visible bloom, and for diarrhea and stomach upset the chances were 2 and 3.4 respectively ($P < 0.001$) as compared with water sources with no visible bloom. The same finding was observed on multivariate analysis where diarrhea and stomach upset still had a statistically significant link with bloom availability ($P < 0.001$); previous research has reported the same (Stone & Bress 2007; Collier *et al.* 2015). The odds of reported skin and throat irritation among water users with visible bloom is almost two and four times higher than those using water without visible bloom respectively ($P < 0.05$; see Table 3). The Harmful Algal Bloom-related Illness Surveillance System (HABISS) of the USA reported an association of bloom availability in water with related illness for the year 2009–2010 (Hilborn *et al.* 2014).

Occupation risk and amount of water consumption

Occupation of the study subjects was compared between fisherman and other non-fishing activities, which includes employed, non-employed and farmers. Fishing is reported to be one of the risk activities of contracting health effects related to cyanobacteria bloom and cyanotoxin due to the frequency of water contact and usage during fishing activities. GI was strongly linked with the fishing occupation whereby vomiting and diarrhea were reported among

Table 3 | Reported health effect based on bloom availability

		Response		Univariate		Multivariate	
Health effect	**Variable**	**Yes**	**No**	**cOR (95% CI)**	***P* value**	**AOR (95%CI)**	***P* value**
Vomiting	Bloom	29	220	3.95 (1.49–10.44)	0.003		
	No bloom	5	150				
Diarrhea	Bloom	85	164	2.25 (1.39–3.6)	<0.001	2.4 (1.5–4)	<0.001
	No bloom	29	126				
Skin irritation	Bloom	159	90	1.5 (1–2.3)	0.04		
	No bloom	81	74				
Eye irritation	Bloom	140	109	1.2 (0.8–1.8)	0.36		
	No bloom	80	75				
Throat irritation	Bloom	24	225	4 (1.37–11.8)	0.006		
	No bloom	4	151				
Stomach upset	Bloom	171	78	3.4 (2.28–5.28)	<0.001	3.39 (2.2–5.2)	<0.001
	No bloom	60	95				

fishermen as compared to non-fishermen (OR = 2, $P < 0.05$), vomiting and diarrhea shows a strong association in multivariate also ($P < 0.05$). Throat irritation was reported more by fishermen as compared to other occupations ($P < 0.05$; see Table 4). Studies conducted in China report the same higher risk for fishermen (Chen *et al.* 2009). The amount of water consumption was reported to be one of the factors that may contribute to reported health risk, whereby drinking more than 1 L is more of a risk than less than 1 L. Diarrhea and throat irritation were reported to be associated with the amount of water consumption where the likelihoods were two and four times more than these reported to consume less than 1 L respectively ($P < 0.05$); throat irritation had a strong link with the amount of water intake in multivariate analysis ($P < 0.05$; Table 5). The association of the amount of water ingested and the degree of illness was also reported in England, where soldiers become ill after ingesting bloom water with *Microcystis* spp. (Turner *et al.* 1990), and in the USA (Wade *et al.* 2008; Collier *et al.* 2015).

CONCLUSIONS

The concentration of cyanobacteria blooms found in this study goes beyond the WHO acceptable limit whereby dangerous dominant cyanobacteria species of *Microcystis aeruginosa* range from 90,361.63 to 3,032.031.65 cells/mL

Table 4 | Reported health effect based on occupation

		Response		Univariate		Multivariate	
Health effect	**Exposure**	**Yes**	**No**	**cOR (95%CI)**	***P* value**	**AOR (95%CI)**	***P* value**
Vomiting	Fisherman	13	77	2 (1–4.5)	0.02	2.2 (1.05–4.4)	0.03
	Non-fisherman	24	318				
Diarrhea	Fisherman	40	50	2 (1.2–3.3)	0.003	2 (1.2–3.2)	0.004
	Non-fisherman	97	245				
Skin irritation	Fisherman	63	27	1.8 (1–2.9)	0.02		
	Non-fisherman	194	148				
Eye irritation	Fisherman	53	37	1.1 (0.7–1.8)	0.5		
	Non-fisherman	190	152				
Throat irritation	Fisherman	11	69	2.4 (1.1–5.1)	0.02		
	Non-fisherman	19	323				
Stomach upset	Fisherman	53	37	1.1 (0.7–1.9)	0.53		
	Non-fisherman	189	153				

Table 5 | Reported health effect based on amount of water consumption

		Response		Univariate		Multivariate	
Health effect	**Variable**	**Yes**	**No**	**cOR (95%CI)**	***P* value**	**AOR (95% CI)**	***P* value**
Vomiting	Less than 1lt	19	204	1 (0.5–2)	0.88		
	>1lt	17	192				
Diarrhea	Less than 1lt	79	144	1.6 (1.06–2.44)	0.023		
	>1lt	53	156				
Throat irritation	Less than 1lt	35	188	4 (2–7.7)	<0.001	3.3 (1.6–7)	0.001
	>1lt	10	199				
Stomach upset	Less than 1lt	121	102	0.86 (0.58–1.26)	0.44		
	>1lt	121	88				

and *Anabaena* spp. cells concentration range from 13,310.00 to 4,814,702 cells/mL. At this level water use from the lake source was found to be associated with acute health outcomes. The result indicates the potential health risk of using lake water without any treatment for human consumption. It is therefore advised to continue to monitor the water quality at Ukerewe area in order to understand its spatial and temporal dynamism of phytoplankton. The long-term study of Phytoplankton helps to understand the nature of nutrients or pollution entering the water body because phytoplanktons are a good and cheaper indicator of environmental change as compared to chemical indicators. The documented illness associated with cyanobacteria infested water can be used as a baseline to improve case detection in the district and contribute to the development of evidence-based prevention strategies to mitigate adverse health outcomes that may result in long-term exposure to HABs. It remains important to be able to identify and quantify the different types of cyanotoxin produced which exist in lake water. This will help to establish a long-term study that determines the chronic effect of persistence exposure of cyanotoxin.

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