



**Article title:** Health risk of cyanotoxins in Lake Victoria and household drinking water for riparian communities along Nyanza Gulf

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**Health risk of cyanotoxins in Lake Victoria and household drinking water for riparian communities along Nyanza Gulf**

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**Abstract**

Cyanotoxins are produced by cyanobacteria which are single-celled algae that thrive in warm and nutrient rich water bodies including lakes. There are different kinds of cyanotoxins and microcystin is the most common. Microcystin mostly affects the liver. Epidemiological studies in China and Serbia have shown an association between cyanotoxins and occurrence of Primary Liver Cancer. Cyanobacteria have been reported in Lake Victoria, which is an important source of drinking water for the riparian communities, thus posing a danger to human health. However, the health risk from exposure to toxic cyanobacteria in the Nyanza Gulf water remains unknown. The purpose of this study was to assess the health risk of toxic cyanobacteria to the riparian communities in the Nyanza Gulf. In a longitudinal study adopting survey and experimental design, 127 samples were collected monthly from both households and six beaches over six months. Cyanobacterial levels were determined using an enzyme assay method (PP2A). Different

methods of household water treatment were compared. Two-way ANOVA was done to determine statistical significance of microcystins levels. 84% of water samples contained microcystins. Concentration of microcystins was 3.44 $\mu$ g/L which is over the WHO limit of 1 $\mu$ g/L. There was no variation between beaches and water treatment (ANOVA: F=0.97, p=0.47). Filtration proved to be the most efficient method of water treatment. The health risk factor of cyanotoxins in drinking water is 3.86. There is a health risk posed by cyanotoxins to the residents of the Nyanza Gulf who use the lake water for drinking since is over the WHO limit. This information provides an insight into the quality of Lake Victoria water for drinking. The study recommends development of cyanobacteria removal methods as well as sensitizing the riparian communities on the health risk of cyanotoxins in drinking water.

**Keywords:** Cyanotoxins, Microcystin, Health risk, TDI, PP2A, Water treatment

## **Introduction**

Cyanotoxins from cyanobacteria can cause serious threats to drinking water supplies using surface water as source (Li *et al.*, 2017). Lake Victoria has experienced major deterioration in its water quality mainly due to pollution and Nyanza Gulf is one of the bays of Lake Victoria that is most affected by nutrient enrichment (Gikuma-Njuru *et al.* 2013). It is estimated that only about 20% of the Kenyan rural population has access to safe water but for both Nyanza and Western provinces, it is only 8% (LBDA, 2004). Drinking water sources are unique and need to be investigated to determine the risk and the best management strategy for cyanotoxins risk reduction. Different drinking water treatment technologies are applied in different countries and contexts. Studies investigating cyanotoxins in drinking water and their removal during the water treatment have been even scarcer on the entire African continent (Addico *et al.*, 2017). Cyanotoxins are

highly stable in water and are resistant to boiling thus presenting a risk to consumers in less developed regions who collect water from surface sources to drink (Dietrich & Hoeger, 2005).

Based on their toxin production, to which human can be exposed via different routes, the World Health Organization (WHO) has listed cyanobacteria among the emerging health issues (Manganelli *et al.*, 2012). WHO has set the Tolerable Daily Intake (TDI) of microcystin-LR (MC-LR) to be 0.04µg/kg-bw/day. For drinking water, the levels of MC-LR should not exceed 1µg/L.

The most well characterized case on the effects of cyanotoxins in water was the poisoning of renal dialysis patients in a clinic in Caruaru, Brazil, in 1996, where the patients treated in a dialysis clinic during one week suffered severe illness following perfusion, with hepatic failure and death in more than 50 cases. Investigation of the water treatment unit at the clinic found contamination of the filters by two types of cyanobacterial toxin, cylindrospermopsin and microcystins (Jochimsen *et al.*, 1998; Carmichael, 2001).

Ueno *et al.* (1996) hypothesized that the high incidence of Primary Liver Cancer (PLC) in south east China is likely related to microcystin contamination in drinking water. Another study carried out in Brazil identified microcystin in the serum of highly exposed fishermen in addition to indication of liver damage (Chen *et al.*, 2009). The symptoms of poisoning by the main toxic cyanobacteria in drinking water reservoirs overlap with a range of other gastrointestinal illnesses, largely caused by infectious disease organisms. As a result, during an outbreak of enteric disease, the pathogens are investigated first, as the most probable cause, and only after exhaustive exploration are toxins of any type evaluated.

Agricultural chemicals and industrial pollutants such as heavy metals are likely to be next suspected, with cyanobacterial toxins ignored until well after the event (Teixeira *et.al.*,1993). Microcystins require additional attention not only for their ability to cause acute poisoning but also for their ability to initiate cancer through acute doses and potentially promote it through chronic exposure to low microcystin concentrations in drinking water (Lun *et al.*, 2002; Svirčev *et al.*, 2009).

Despite the presence of cyanobacteria blooms in the Lake Victoria water, the health risk this could pose from cyanotoxins has not been assessed. As such, the current study evaluated the health risk of cyanotoxins in both Lake Victoria water and household drinking water for Nyanza Gulf residents. This study established the concentration of cyanotoxins in both Lake Victoria water and household drinking water for Nyanza Gulf. It also assessed the effectiveness of different treatment methods in removal of cyanotoxins. The risk cyanotoxins may be potentially posing to users of the Lake Victoria water was determined. This was done against the TDI and the provisional guideline value set by the WHO.

## **Materials and Method**

### ***Study Area***

Nyanza Gulf is in Western Kenya whose watershed lies between 0.25N - 1.00S latitudes and 34.0E - 36.0E longitudes. It covers an approximate total drainage area of 12,300 km<sup>2</sup>. It has an area of 1400 km<sup>2</sup>, mean depth 7 m, maximum depth 30 m and a 550 km shoreline that is located entirely in Kenya on the northeast of Lake Victoria (Misigo & Suzuki, 2018).

Samples were collected from six beaches along the Nyanza Gulf of Lake Victoria: Ogal Beach (0°9'S, 34°35'E), Mawembe (0°9'S, 34°37'E), Rang'ombe (0°25'S, 34°28'E), Alum

(0°26'S, 34°28'E), Olambwe (0°26'S, 34°15'E) and Kolunga (0°25'S, 34°8'E). Water was also collected from households along these beaches.

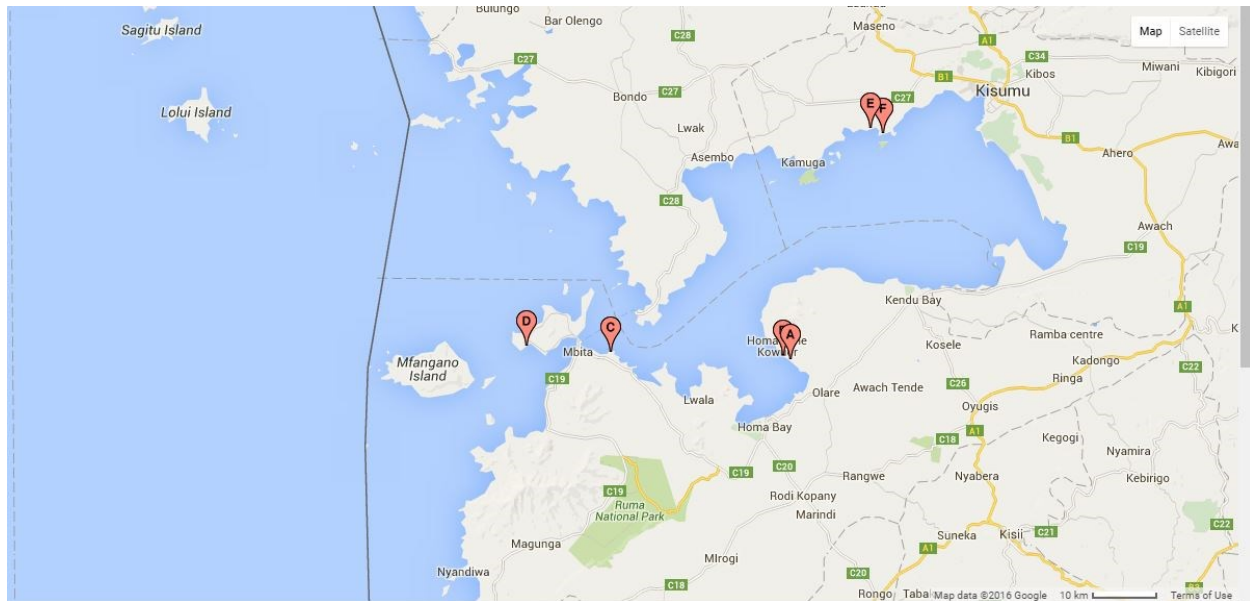


Figure 1: Map of the Nyanza Gulf, Lake Victoria with sampling points

### ***Sample collection and Analysis***

This study adopted both survey research and experimental methods. Survey research approach was used to collect water source, treatment and consumption data at the household level using a structured questionnaire. Experimental methods were used for determination of levels of Microcystins in both lake and household drinking waters. The sample size was calculated using the formula by Fisher's *et al.* (1998) arriving at 422 subjects. The primary caregiver from each household was selected for participation in the study from the systematically sampled households. Water samples for analysis of microcystins in the Lake Victoria water were collected once a month for a period of 6 months beginning May to October 2015 from the exact point where the riparian communities draw water from Lake Victoria. Standard water abstraction techniques were used to

obtain water in a manner that minimized contamination during sampling. A similar amount of water was also collected from 30% (approx. 127) of all the households sampled.

### ***PP2A***

The water samples were analyzed for presence of microcystin using Protein Phosphatase 2A (PP2A) enzyme assay method according to Heresztyn and Nicholson (2001). 2ml of water samples was boiled for an hour then centrifuged for 15 minutes at 3000rpm. 10 $\mu$ l of the supernatant was transferred to a 96-well microplate. 10 $\mu$ l of enzyme dilution (PP2A enzyme in Bovine Serum Albumin {BSA}, 0.1 M Tris, 40mM Dithiothreitol {DTT}, 10mM MnCl<sub>2</sub>, 0.3M MgCl<sub>2</sub> and MilliQ water) was added to the samples, shaken and incubated for 5 minutes at 37°C. 100 $\mu$ l of reaction mixture (containing 4-nitrophenyl phosphate disodium salt {Sigma Aldrich}, BSA, 0.4M Tris, 10mM MnCl<sub>2</sub>, 0.3 MgCl<sub>2</sub> and MilliQ water) was added to the wells containing samples. The microplate was then incubated for 60 minutes at 37°C. Absorbance was measured at 405nm by a microplate reader and the results analysed in a Microsoft Excel sheet. Standards of 10 $\mu$ l, 5 $\mu$ l, 2.5 $\mu$ l, 1.25 $\mu$ l, 0.625 $\mu$ l, 0.3125 $\mu$ l and 0.15625 $\mu$ l of MC-LR (from Sigma Aldrich) were used. For higher concentrations, serial dilutions of the sample were carried out, analyzed and the results extrapolated by the dilution factor.

### **Data Analysis**

#### ***Estimation of risk for human health from data on microcystin in water***

Assessment of health risk of microcystin was evaluated based on the formula (Falconer & Humpage, 2005),

$$\text{Daily Intake of Microcystin} = \frac{\text{Average Concentration of MC} \times \text{Water Ingested}}{\text{Body Weight}}$$

$$\text{Risk Factor of MC} = \frac{\text{Daily Intake of Microcystin}}{\text{Tolerable Daily Intake of Microcystin}}$$

Where:

Tolerable Daily Intake of 0.044 $\mu\text{g/kg-bw/day}$  (WHO, 1999)

Standard Body Weight taken to be 60kg (Falconer & Humpage, 2005)

Water Ingested is the average daily water intake in litres by an individual.

## **Results**

### ***Concentration of microcystin in beach and household water***

Out of the 127 samples collected from households, 103 (80%) samples were positive for presence of microcystin. For a similar number of samples from the beaches on the lake, 112 (88%) samples had microcystin. On average, 215 (84%) of samples contained microcystin. The highest microcystin concentration was 13.813 $\mu\text{g/L}$  and 12.302  $\mu\text{g/L}$  for lake and household respectively while lowest value was 0.151  $\mu\text{g/L}$  for lake and 0.009  $\mu\text{g/L}$  for household. There was a general trend in the level of microcystin in households being lower those of the respective beaches as the Figure 2 shows. Ogal and Mawembe beaches had higher values of microcystin than the rest in both beach and household.

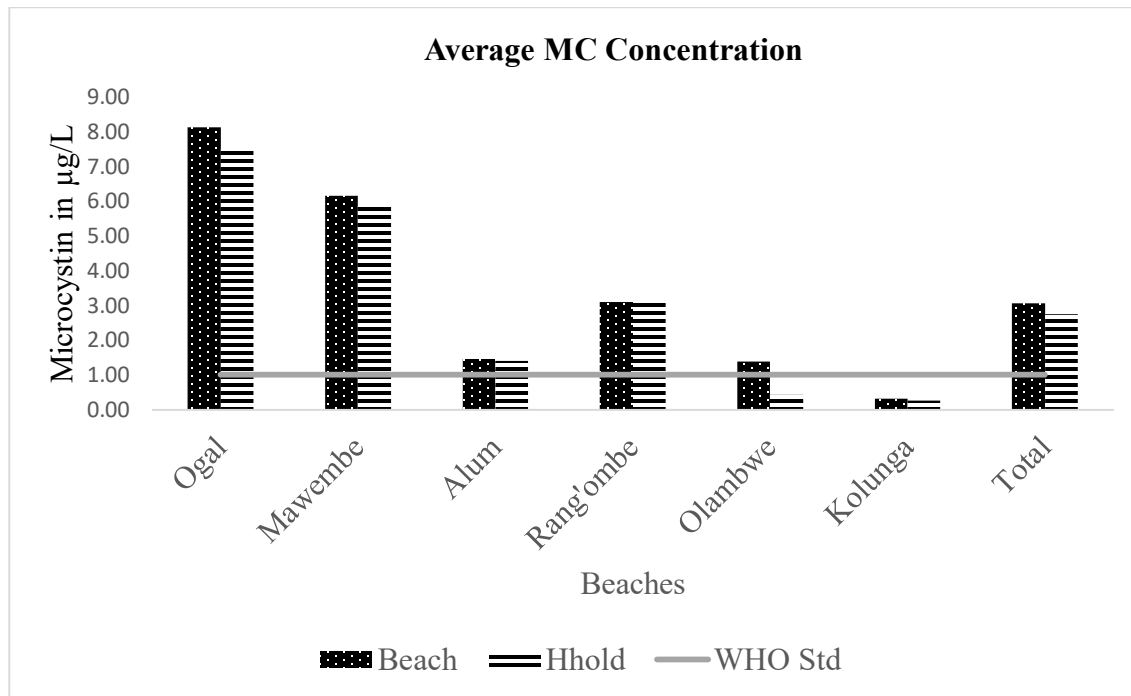


Figure 2: Average microcystin Concentration per beach between May-October 2015

***Effectiveness of the various water treatment methods on the level of MC in the households***

Water treatment was undertaken in 324 (77%) of the homes not done in the remaining 97 (23%) homes. Out of those that treat their water, 265 (82%) did chlorination which was the most commonly used method of water treatment followed by filtration 20 (6%), boiling 20 (6%), combination of boiling and filtration with 18 (5.6%) and others was 1 (0.5%) as shown in the Figure 3. In general, the results showed that chlorination is the most commonly used method.

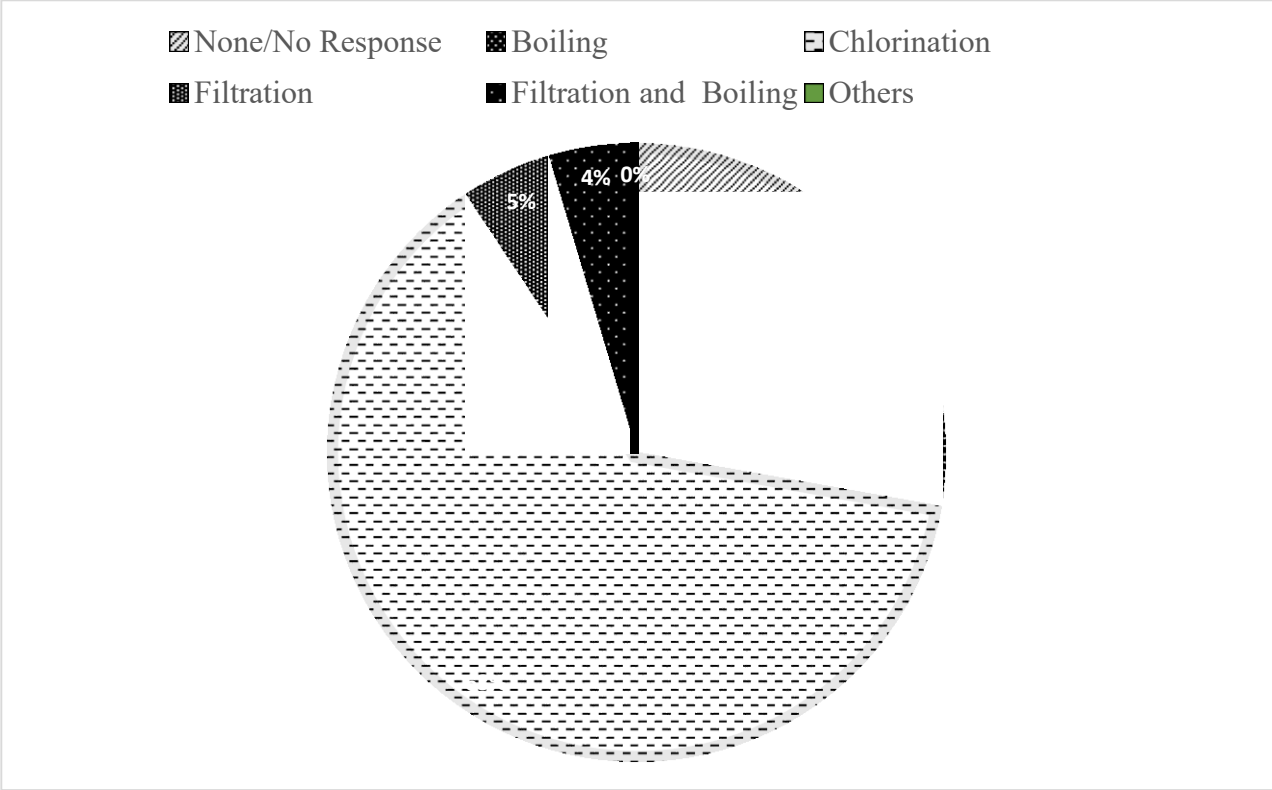


Figure 3: Frequency of Treatment Methods

All 421 (100%) use the lake water for cooking. A higher portion of them, 408 (97%) respondents said use the beach water for drinking including preparation of tea/coffee/porridge while 13 (3%) replied that they don't consume water from the lake in beverages. From the questionnaire responses, it was established that the respondents consumed 6 cups of beach water daily on average either directly through drinking the water or indirectly in tea and food. For this study, the cup of reference had a capacity of 500 milliliters (ml).

In trying to find out the efficacy of the water treatment methods conducted in households, levels of microcystin were recorded at both the beaches and the households. Difference was calculated between the level of microcystins in the beach and the corresponding household water samples. The average concentration of microcystins in beach water samples was

3.06  $\mu\text{g/L}$ , the average concentration for household water samples was 2.75 $\mu\text{g/L}$  and the mean difference was 0.31 $\mu\text{g/L}$ . ANOVA was then conducted to determine if there were significant differences with regards to the change in the level of microcystin between the household and the various methods of water treatment. The result was that there was no significant difference given the p value of 0.456 against a significance level of 0.05.

An analysis of the mean change in the level of microcystin in water between beaches and households with regards to water treatment method gave the following results: Boiling and non-use of any treatment method resulted into an increase in the level of microcystin concentration while chlorination and filtration led to the decrease in the level of microcystin concentration. This is shown in Figure 4.

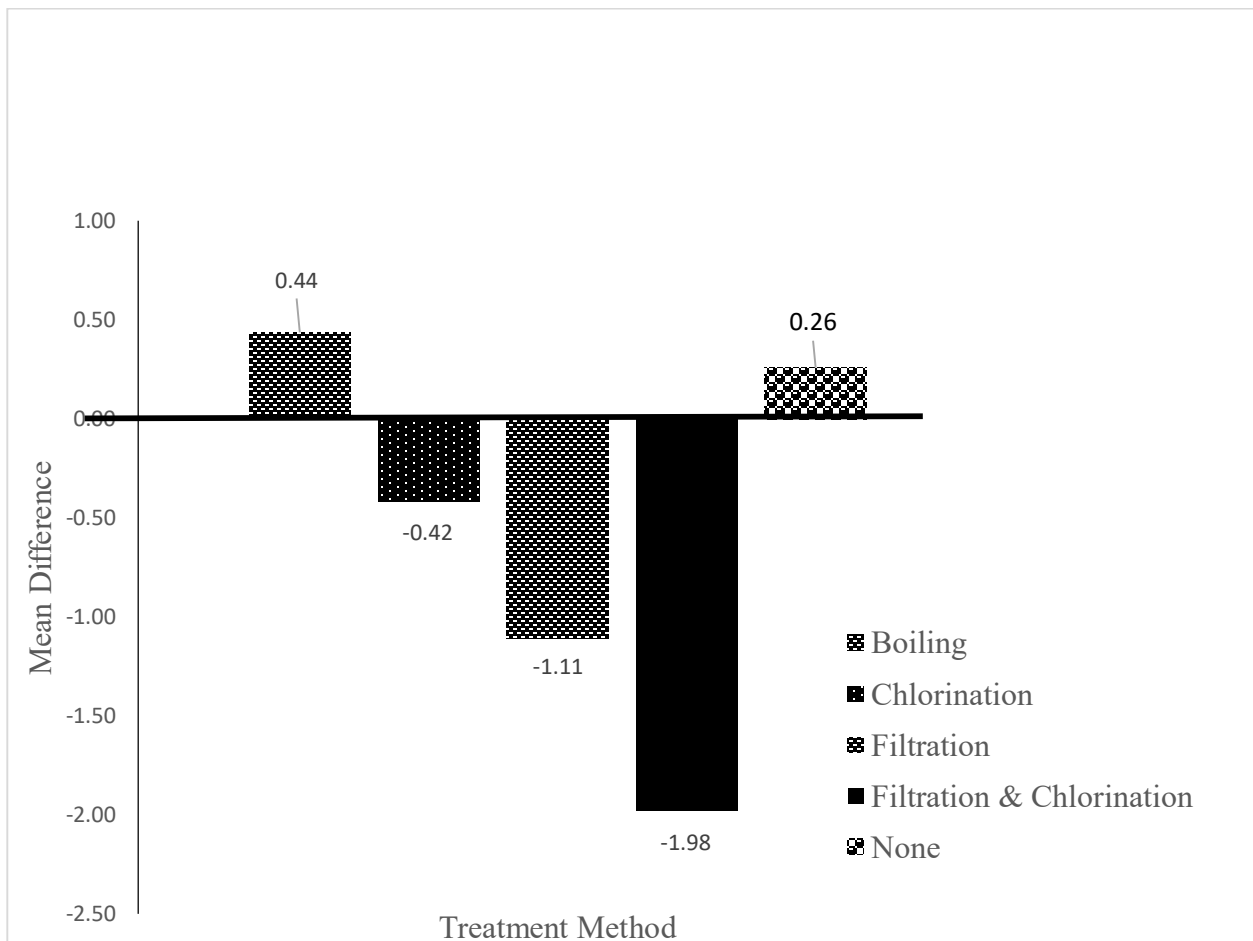


Figure 4: Mean change in microcystin levels between Beaches and Households based on Water Treatment Method

A correlation test was conducted to find out whether there was a relationship between the levels of microcystin concentration in the beaches and the households. The results as shown in Figure 5 found out that there was a strong positive relationship between the two ( $r = 0.822$ ,  $n=128$ ,  $P<0.0000$ ,  $\alpha=0.01$ ). Regression analysis was thereafter done and a model fit with the R squared being 0.672 implying that 67.2 % of the levels of microcystin in households can be explained by levels of microcystin in beaches. The resulting linear equation is  $Y = 0.158+0.846X$ . This therefore means that an increase in the level of microcystin in beaches by a value of 1 increases the levels of microcystin in household by 0.846.

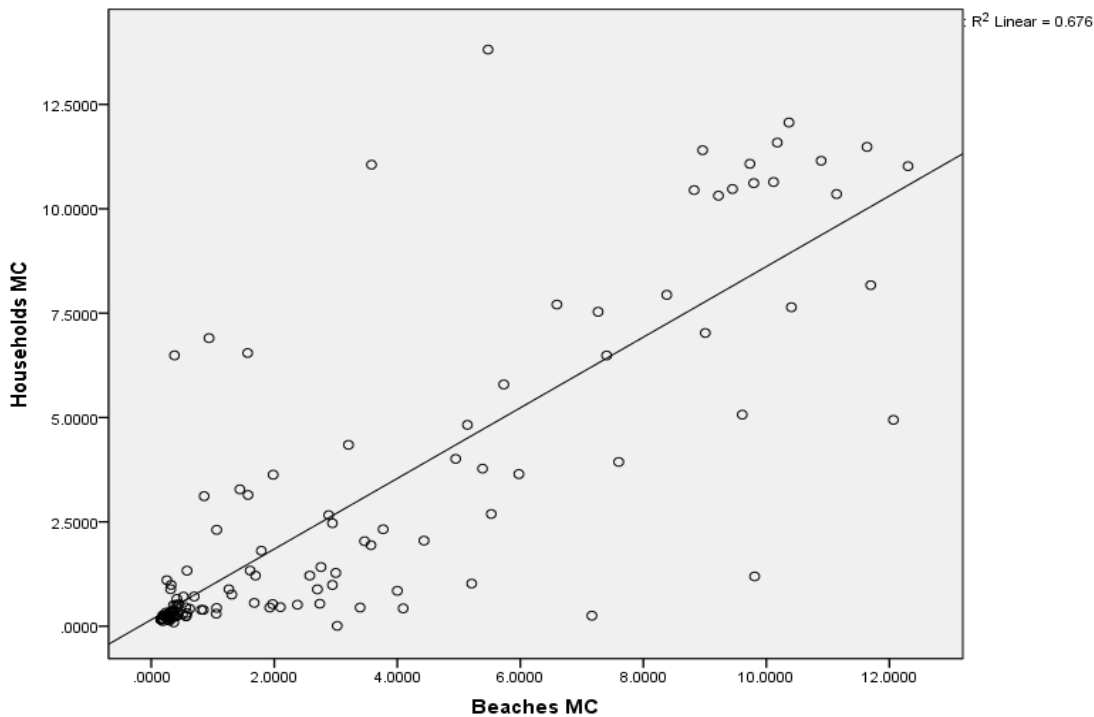


Figure 5: Correlation test showing relationship between the levels of microcystin concentration in the beaches and the households

To find out whether the source of the water (beaches) and the method of water treatment had an effect on the levels of microcystin in the samples drawn from the households, a two-way ANOVA was done. It was found that there was no interaction between the effect of beaches and effect of water treatment method used on the level of microcystin in 127 samples drawn from the households,  $F(9, 110) = 0.97, P > 0.05 (P = 0.4708)$ . Therefore there was no significant variation in the level of cyanotoxins from samples drawn from household drinking water with regards to treatment method used and the beach from which the water in the household was drawn.

### Health Risk based on TDI

The health risk was calculated based on the formula stated earlier. Daily intake of microcystin was calculated and compared with the Tolerable Daily Intake by WHO set at  $0.044 \mu\text{g}/\text{kg}$ . The risk factor for Ogal beach was the highest at 9.32, followed by Mawembe beach at 7.05. Alum beach had a relatively low risk factor of 1.36 but Rang'ombe was much higher at 3.18. Olambwe beach had a risk factor of 1.59 whereas Kolunga beach had the lowest value at 0.45. On average, the waters of Nyanza Gulf were 3.86 times higher than the recommended TDI.

Characteristic	Ogal (n=61)	Mawembe (n <sub>1</sub> =59)	Alum (n <sub>2</sub> =80)	Rang'ombe (n <sub>3</sub> =64)	Olambwe (n <sub>4</sub> =78)	Kolunga (n <sub>5</sub> =79)	Total %(N=421)
<b>Cups (500 ml) of Drinking Water Consumed</b>							
1-3	28	34	47	4	41	24	42.3(178)
4-6	27	22	32	57	31	42	50.1(211)
7-9	5	3	0	3	4	13	6.7(28)
10 or more	1	0	1	0	2	0	1(4)
<b>Cups (500 ml) of Tea/Porridge/Coffee Consumed</b>							
None	2	0	0	41	0	0	10.2(43)

1	21	14	33	22	7	12	25.9(109)
2-3	34	35	47	1	59	41	51.5(217)
4-5	3	7	0	0	12	23	10.7(45)
≤6	1	3	0	0	0	3	1.7(7)
<b>Average of Total Cups Consumed</b>							
Average	6.0	6.0	5.2	5.3	6.4	7.6	100(6.1)

Table 1: Water consumption

<b>Beach</b>	<b>Average Concentration of Microcystins (µg/L)</b>	<b>Average Water Ingested (L)</b>	<b>Body Weight (kg)</b>	<b>Daily Intake of Microcystins (µg/kg-bw/day)</b>
Ogal	8.14	3.00	60	<b>0.41</b>
Mawembe	6.17	3.00	60	<b>0.31</b>
Alum	1.46	2.60	60	<b>0.06</b>
Rang'ombe	3.17	2.65	60	<b>0.14</b>
Olambwe	1.39	3.20	60	<b>0.07</b>
Kolunga	0.31	3.80	60	<b>0.02</b>
<b>Average</b>	3.44	3.04	60	<b>0.17</b>

Table 2: Daily intake of Microcystin per beach

<b>Beach</b>	<b>Daily Intake of Microcystins (µg/kg-bw/day)</b>	<b>Tolerable Daily Intake (µg/kg-bw/day)</b>	<b>Risk Factor for MC</b>
Ogal	0.41	0.04	<b>9.32</b>
Mawembe	0.31	0.04	<b>7.05</b>
Alum	0.06	0.04	<b>1.36</b>
Rang'ombe	0.14	0.04	<b>3.18</b>
Olambwe	0.07	0.04	<b>1.59</b>

Kolunga	0.02	0.04	<b>0.45</b>
Average	0.17	0.04	<b>3.86</b>

Table 3: Risk Factor for MC per beach

## Discussion

The Tolerable Daily Intake (TDI) is the amount of a potentially harmful substance that can be consumed daily over a lifetime with negligible risk of adverse health effects. This study found that the daily intake of microcystins in the Nyanza Gulf is way above the recommended for drinking water by WHO. The average TDI was four times higher and the average risk factor was four. High levels of risk to human health are linked to the ingestion of large cyanotoxin quantities from water or the intake of small doses during extended chronic exposure (Svirčev *et al.*, 2010). Therefore, observing that this study found the levels of cyanotoxins in household drinking water way above what is recommended (2.75µg/L), this is posing a health risk to the consumers. Given that this study only focused on drinking water, the daily intake of microcystins could be higher if other sources of microcystin exposure are factored in. For example, in a study conducted by Soares *et al.* (2004), microcystins accumulate in the liver, muscle and tissues of tilapia and can be subsequently passed to consumers. If these two sources of ingestion of water are combined, especially given that tilapia is a common delicacy in the Nyanza Gulf, it is very likely that microcystins are consumed way more than the TDI recommended in the Nyanza Gulf.

Chronic exposures to cyanobacteria and their toxins have been associated with increased occurrence of liver and colorectal cancer (Yu, 1995; Zhou *et al.*, 2002; Svircev *et al.*, 2009). This is a potential health risk the consumers of the lake water are exposed to due to the levels of cyanotoxins recorded from the samples. According to a survey conducted on the microcystin

exposure risk from lakes in Uganda by Poste *et al.* in 2011, it was shown that more than 50% of the WHO lifetime tolerable daily intake results from consuming untreated drinking water. They recommended strategies of dealing with microcystins from the lake water used for drinking to involve regular monitoring of cell numbers of toxic cyanobacteria in the raw water. Such methods include removal of particles by flocculation and ozonation followed by activated carbon filtration or sand filtration to remove dissolved microcystins (Chorus & Bartam, 1999). None of these methods is currently in the households sampled during the study, for treatment of drinking water. Chlorination which is the most commonly used method for treating drinking water in the households sampled is not very effective in destroying cyanobacteria and cyanotoxins. Although there was a decrease in cyanobacteria concentrations in households where chlorination was used to treat water, the difference is not significant. The efficiency of chlorination depends mainly on the chloride compounds used as well as the concentration used. Filtration is comparatively more effective in removing cyanobacterial cells but dissolved toxins remain in the drinking water.

Cyanotoxins occur in two modifications: cell bound and dissolved in water. This study therefore identified a need for water treatment methods for removal of cyanotoxins. Given that a population of 94 000 inhabitants of the Nyanza Gulf depend on the lake water for drinking, development of methods that will remove cyanobacterial cells as well as get rid of cyanotoxins in the water is paramount. Although adverse health effects have not been documented from the region, we cannot rule out any effects of drinking water contaminated by cyanotoxins. In other countries such as China and Serbia (Svirčev *et al.*, 2010; Svirčev *et al.*, 2009; Svirčev *et al.*, 2007; Ueno *et al.*, 1996) where cyanobacteria and cyanotoxins occurrence in water is much studied and

effects documented, chronic exposure to cyanotoxins has led to liver and neurological diseases.

### **Conclusion and Recommendation**

There is a health risk posed by cyanotoxins to the residents of the Nyanza gulf who use the lake water for drinking since the microcystin levels for drinking water is four times the TDI that is recommended by WHO and the risk factor is four. Ways of getting rid of the cyanotoxins identified need to be developed. This should include the removal of both intracellular and extracellular toxins. There should be sensitization of the riparian communities about the health risk that comes with consuming water contaminated with cyanobacteria and cyanotoxins. The county governments should carry out advocacy sessions in the riparian communities regarding the health risk of cyanotoxins from drinking water directly from the lake.

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