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Article:
Mchau, GJ, Makule, E, Machunda, R et al. (2 more authors) (2019) Phycocyanin as a proxy for algal blooms in surface waters: case study of Ukerewe Island, Tanzania. Water Practice and Technology, 14 (1). pp. 229-239. ISSN 1751-231X

https://doi.org/10.2166/wpt.2019.005

Phycocyanin as a proxy for algal blooms in surface waters: case study of Ukerewe Island, Tanzania

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Abstract

Knowledge of the parameters that contribute to water body eutrophication is essential for proper monitoring and management of water quality for human consumption. This study assessed water quality parameters in relation to phycocyanin (PC) as a proxy indicator for harmful algal blooms (HABs). Samples were collected from 23 water sources – lakes, wells, springs and boreholes – in selected villages, for six months. Parameters measured included temperature, pH, redox potential, dissolved oxygen, electrical conductivity, total dissolved solids, nitrate nitrogen, nitrite nitrogen, phosphorus, reactive phosphate and total chlorophyll, which were related to (PC) occurrence. The PC concentration detected in Lake Victoria ranged from 5 to 58.4 μg/l above the WHO alert level and exceeded that in other water sources by almost 30 μg/l ($P < 0.001$). Univariate relationship between water quality parameters and PC indicates association with temperature, redox potential, total chlorophyll, nitrate nitrogen, nitrite nitrogen, phosphate and reactive phosphorus ($P<0.001$). The multivariate model indicates that redox potential, nitrate nitrogen and phosphorus are significant statistically ($P<0.05$). A predictive model indicates that nitrate nitrogen and reactive phosphorus contribute significantly to PC occurrence whereby unit (1 mg/l) increases in these parameters increase PC by 9.55 and 4.38 μg/l ($P<0.05$) respectively. This study demonstrates that water quality parameters can be used to predict increases in PC and hence as a proxy for HABs. It remains important to be able to classify algal blooms, to understand which species are present and their potential cyanotoxin production.

Key words: Cyanobacteria, Phycocyanin, Water quality, Lake Victoria

INTRODUCTION

The presence of cyanobacterial blooms in lakes, reservoirs and rivers poses big challenges in water quality management. Cyanobacteria (blue-green algae), including the harmful algal bloom (HAB) *Microcystis aeruginosa*, are of global concern because they can produce cyanotoxins. Daily human activity around water bodies, including agricultural runoff, inadequate sewage treatment, and runoff from roads can cause excessive fertilization (eutrophication) that might lead to cyanobacterial proliferation (de Figueiredo et al., 2004). Some water quality parameters can enhance cyanobacterial growth, increasing the availability of toxins. They include phosphorus and nitrogen, pH, temperature, electrical conductivity (EC), and dissolved oxygen (DO) (Marion et al., 2012)

Toxins can be classified on the basis of the symptoms produced in humans and other vertebrates – e.g., hepatoxins, neurotoxins and irritant-dermal toxins. The hepatoxins include the microcystin (MC) toxins such as MC-LR, MC-RR and MC-YR, which have high potential for contaminating drinking water (Carmichael et al., 2001). Based on this potential risk, the World Health Organisation (WHO) proposed a provisional acceptable concentration limit of 1.0 µg/L for MC-LR in drinking water (WHO 2006) . MCs can cause substantial health hazards and have been implicated in the deaths of birds, aquatic biota, livestock, and wildlife (Anwar, 1997), as well as being linked to possible primary liver and colorectal cancer (Ueno et al., 1996). Studies in Uganda revealed the presence of MC in Lake Victoria (Miles et al., 2013), and in Tanzania in the Mwanza Gulf on the lake (Sekadende et al., 2005), and that its concentration varies through the seasons. This variation is caused by variations in the availability of nutrients and the water quality (Okello et al, 2010).

MC detection, e.g., by local authorities, brings various challenges including lack of trained personnel, the cost of taxonomic pigment extraction, and expensive equipment involving high-end technology. Hence it is important to develop water quality management mechanisms for predicting parameters related to MC availability (McQuaid, et al, 2011). Phycocyanin (PC) is a green pigment found extensively in cyanobacteria and used as an indicator for HAB in fresh water. A PC concentration of 30 µg/L is reported as equivalent to WHO 'alert level 1' – 20,000 cyanobacteria cells/ml – which requires weekly water monitoring to assess the risk of bloom. 90 µg-PC/L is equivalent to 100,000 cells/ml of cyanobacteria (alert level 2), when water use must be restricted due to the high potential risk of cyanotoxin (Brient et al., 2008). This proxy indicator will help local authorities predict water quality parameter changes that could lead to increases in PC concentrations. Increases in PC and total chlorophyll concentrations correlate strongly with MC toxin increases, and can be used to predict HABs and MC (Brient et al., 2008; McQuaid et al., 2011; Francy et al., 2016).

Knowledge of HAB in Africa is limited. Of 52 countries, only 21 (40%) have well documented scientific information about cyanobacterial bloom occurrence and parameters associated with MC increases in the last decade (Ndlela et al, 2016). Studies by Ndebele-Murisa et al, (2010) and Sekadende et al (2005) identified that cyanobacterial blooms exist in Lake Victoria and that control measures are needed. However, there is limited information about the factors influencing increases in blooms in the lake in Tanzania.

This study focused on water quality parameter assessment in Ukerewe, Tanzania. The water sources investigated were the shores of Lake Victoria, shallow and deep wells, tap water and springs. All samples were assessed on the basis of water quality parameters that influence PC increases, as a proxy for increased HABs. The parameters used were temperature, pH, redox potential, DO, EC, total dissolved solids (TDS), total chlorophyll (total chl), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), phosphate (PO_4^{3-}), and reactive phosphorus (P). The predictive model developed will help alert local authorities to take appropriate measures, ensuring good monitoring and water quality management, using simple resources available locally.

MATERIALS AND METHODS

Site description

Ukerewe District comprises 27 islands in Lake Victoria, in northern Tanzania between latitudes 10^o 45’ and 20^o 15’ S and longitudes 320^o 45’ and 330^o 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

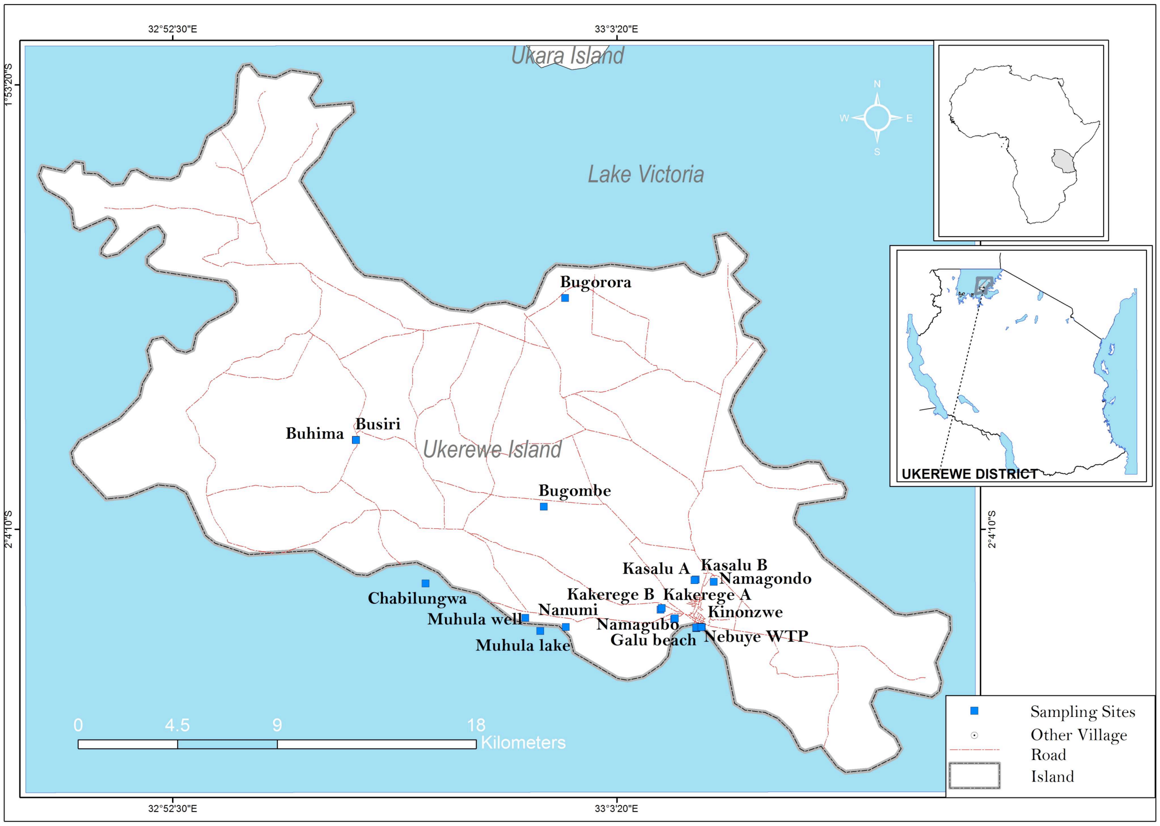


Figure 1: Ukerewe District study and sampling sites

Water and sample analysis

Water samples were collected from sites on Lake Victoria's shores, shallow (<5 m deep) and deep wells (>6 m), a spring, and household water pipes – 23 in all –see Figure 1. One-liter water samples were collected from each site – see Table 1-5 – for six months. The samples were collected into bottles and preserved as per the standard methods for examination of water (APHA, 2012). They were stored in a cool box and transported to Nelson Mandela Africa Institute of Science and Technology in Arusha for analysis.

A multiparameter meter (HI 9829, HANNA Woonsocket, RI, USA) was used on site to determine temperature, pH, redox potential, DO, EC and TDS, and PC and total chl were measured *in situ* with an Aquafluor handheld field fluorometer model 8000-01 (Turner Designs, San Jose, CA, USA). Prior to use, the fluorimeter was calibrated according to the manufacturer's instructions; total chl and PC were both quantified using the intact cells without filtration or extraction. WHO water quality guidelines (Brient et al., 2008) were used to interpret the PC concentration on the basis that a concentration of 30 µg/L is equivalent to WHO alert level 1 (20,000 cyanobacterial cells/mL), and less than 30 µg/L means that the number of cyanobacterial cells/mL is below that level. Nitrate nitrogen, nitrite nitrogen, phosphate and reactive phosphorus were measured by spectrophotometer (HACH, DR2800)

Data Analysis

Data were entered and cleaned using Microsoft Excel (MS), and analyzed using Open Source software, R statistical package version 3.5.0(R. Core Team, 2018). Generalized linear mixed models (GLMMs) with a Gaussian distribution were used to model variations in the amount of PC for different environmental variables. The mixed model was used to account for pseudo-replication during sampling. The amount of PC was included in the model as a response variable, while different variables of interest were included as fixed factors. In the univariate analysis, means and their 95% confidence intervals were reported in tables while in the multivariate analysis adjusted means with their 95% confidence intervals were reported. The results were considered significant when the p-value was less than 0.05. All graphs were generated using R statistical software with a ggplot2 (Gramma for Graphic plot) package (Wickham, 2016)

RESULTS AND DISCUSSION

A total of 138 samples was collected from water sources, which were divided into four main categories – lake shores 54 (39%), deep wells 18 (13%), natural springs 12 (9%), shallow wells 36 (26%) and piped water 18 (13%).

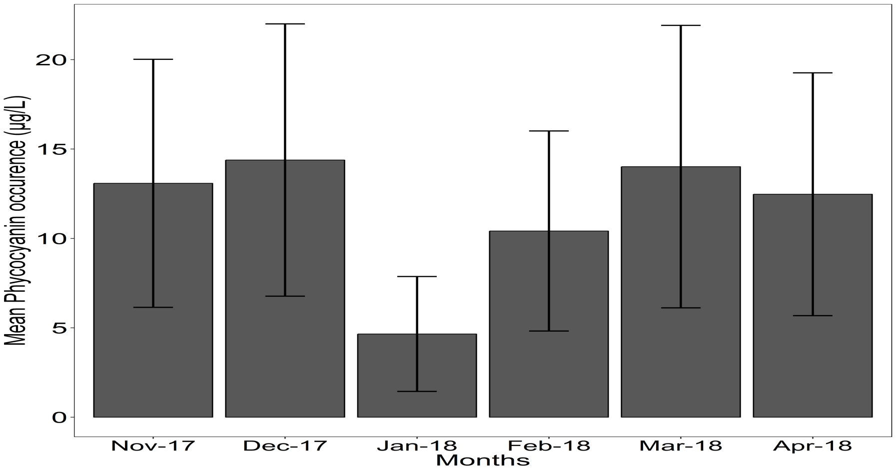


Figure 2: PC concentration means from November 2017 to April 2018 in Ukerewe

The mean PC concentrations found in December 2017 and March 2018 were higher than in other months (Figure 2). The concentration was lowest in January 2018. Other studies conducted in Lake Victoria show that algal blooms vary slightly but can occur throughout the year (Okello et al 2010)

Water quality parameters from selected sampling sites

Table 1. Water quality parameters from selected sites on Lake Victoria's shore

		Water quality parameter											
Sample collection site		**Temp (^{0}C)**	**Redox**	**pH**	**DO (mg/l)**	**EC (µS/cm)**	**TDS (mg/l)**	**PC (µg/L)**	**Total chl (mg/l)**	**NO_3-N (mg/l)**	**NO_2-N (mg/l)**	**PO_4^{3-} mg/l**	**P (mg/l)**
Bugorola	Min	24	55	7	6	248	161	6	26	16	18	0.25	0.01
	Max	29.6	298	9	7	641	416	24	138	30.8	43	0.55	0.26
	SD	2	82.1	0.6	0.4	143.4	92.8	6.1	49.4	6	9.3	0.1	0.1
Namagobo-Male	Min	25	88	7	6	161	155	5	27	11	11.9	0.29	0.09
	Max	29	297	9	8	372	249	40.2	160	30.9	51.8	0,81	0.38
	SD	1.5	76.5	0.8	0.7	74.2	44	13.1	58.1	7.1	14.5	0.2	0.1
Namagobo-Female	Min	25	83	7	5.55	244	158	6	36	21.2	9.7	0.16	0.05
	Max	28	251	8	8	387	285	33	176	33	33.9	0.96	0.55
	SD	1	74	0.5	0.9	49.4	42.6	9.6	63.8	5.4	9.1	0.3	0.2
Galu beach	Min	24.9	97	7	6	198	128	5	33	17	7	0.17	0.05
	Max	29	260	9	8	412	267	44	129	52	37	0.74	0.41
	SD	1.5	66.8	0.8	0.8	76.3	49.5	13.2	39.6	14.2	10.4	0.2	0.1
Water agency-Street	Min	25	95	8	6.37	274	178	11	18	24	24.3	0.24	0.08
	Max	29.5	387	9	8	398	413	48	201.3	60.9	64	2.04	1.06
	SD	2	122.8	0.4	0.6	46.6	97.9	13.5	70.5	12.7	14.9	0.7	0.4
Chabilugwa	Min	25	81	8	6.4	200	97	14	23	24.6	16.6	0.14	0.05
	Max	28	245	9	7	391	286	39	156	65.3	73	16.17	0.79
	SD	1	62.6	0.4	0.2	75.1	77	9.6	52.5	15.9	18.9	6.4	0.3
Muhula- Lake	Min	24.5	80	7.6	5	170	89	25	29	27	17.8	0.14	0.04
	Max	29	286	8	7	298	166	49	195	51	75	18.15	0.65
	SD	1.6	84.9	0.2	1.1	50	28	9.5	65.7	9.7	20	7.1	0.2
Nanumi	Min	25.2	99	7	5	158	48	28	69	29.3	27.3	0.17	0.06
	Max	28	271	8	7	301	183	58.4	213	72.9	84	22.14	0.96
	SD	0.9	66.1	0.4	1.1	59.7	49.9	12	65.3	17.8	20.3	9.1	0.4
Nebuye Intake	Min	25	32.5	7	6	239	108	3	53	15	18	0.94	0.62
	Max	29	191	9	7	440	271	32	159	53.9	59	2.32	1.9
	SD	1.4	66.7	0.8	0.4	90.8	63.2	6	39.6	12.9	15.1	0.6	0.4

Table 2. Water quality parameters from selected deep wells

Water quality parameter

Sample collection site		**Temp (^{0}C)**	**Redox**	**pH**	**DO (mg/l)**	**EC (µS/cm)**	**TDS (mg/l)**	**PC (µg/l)**	**Total chl (mg/l)**	**NO_3-N (mg/l)**	**NO_2-N (mg/l)**	**PO_4^{3-} mg/l**	**P (mg/l)**
Bogombe	Min	25	33	5	6	185	119	0.1	0.36	1.4	11.6	0.19	0.06
	Max	28	232	7	8	440	286	1.21	23	5.7	25	0.59	1
	SD	1	74.3	0.8	0.7	101.6	68	0.4	8.7	1.9	5	0.2	0.5
Mahula well	Min	25	78	5	5	73	52	0	0.06	0.3	1.6	0.19	0.03
	Max	28	251	8	8	284	185	0.7	27	10.4	34.2	1.25	0.44
	SD	1	61.9	1.2	1	85.3	46	0.2	10	4.2	13.4	0.4	0.1
Nakatunguru	Min	25	84	6	5	879	490	0.01	0.02	9	25.8	0.83	0.76
	Max	28	237	7	7	3733	2426	0.5	6.3	35.6	98	4.25	1.5
	SD	1.3	55.1	0.5	0.7	1004.1	670.1	0.2	2.5	9.5	27.2	1.3	0.3

Table 3. Water quality parameters from selected shallow wells

Water quality parameter

Sample collection site		**Temp (^{0}C)**	**Redox**	**pH**	**Do (mg/l)**	**EC (µS/cm)**	**TDS (mg/l)**	**PC (µg/l)**	**Total chl (mg/l)**	**NO_3-N (mg/l)**	**NO_2-N (mg/l)**	**PO_4^{3-} mg/l**	**P (mg/l)**
Namagondo	Min	23	44	5	3	60	78	0.3	8	0.9	24.1	0.21	0.07
	Max	27	257	7	8	226	187	2.9	39	8.4	52	0.42	0.9
	SD	1.4	83.4	0.6	1.7	53.9	37.9	1.2	13	3.1	10.2	0.1	0.3
Kakerege A	Min	25	75	6	6	321	178	0.11	1.84	4.3	6.1	0.17	0.06
	Max	28	256	8	7	1092	710	0.65	15	39	97.2	1.8	0.41
	SD	1.2	62.5	0.8	0.5	312.8	193.7	0.2	5.3	11.7	39.5	0.6	0.1
Kakerege B	Min	25	76	6	5	166	143	0.1	2.5	8.4	22.3	0.31	0.1
	Max	27	324	7	7	1125	732	0.9	13	16.7	56	1.9	0.49
	SD	1	82.2	0.5	0.8	402.2	205.2	0.3	4.6	3	15.2	0.6	0.1
Kinonzwe	Min	25	111	6	6	701	100	0.2	16	2	3.1	0.14	0.04
	Max	27	210	7.2	8	786	510	2	47	5	11	1.3	0.42
	SD	0.8	42.4	0.6	0.8	32.1	171.2	0.7	12.1	1.1	3	0.4	0.1
Kasalu A	Min	25	78	6	6	31	147	0.01	8	1.3	2.8	0.12	0.04
	Max	28	239	7	8	914	594	0.9	41	6.1	24	0.71	0.3
	SD	1.3	78.4	0.5	0.8	342.9	166.5	0.4	11.3	1.8	8.4	0.2	0.1
Kasalu B	Min	25	66	5	5	294	105	0.1	4	0.5	3	0.16	0.05
	Max	27	226	8	8	951	497	0.5	35.6	7	12.3	0.76	0.13
	SD	1	75.6	1	1	325.3	134.3	0.2	10.7	2.3	3.6	0.2	0.08

Table 4. Water quality parameters from springs

Water quality parameter

Sample collection site		**Temp (^{0}C)**	**Redox**	**pH**	**Do (mg/l)**	**EC (µS/cm)**	**TDS (mg/l)**	**PC (µg/l)**	**Total chl (mg/l)**	**NO_3-N (mg/l)**	**NO_2-N (mg/l)**	PO_4^{3-} **mg/l**	**P (mg/l)**
Buhima	Min	25	37	5	5	117	76	0	0.01	1	9.3	0.14	0
	Max	27	256	7	8	269	174	0.5	34	5.2	21	0.48	0.81
	SD	0.8	78.6	1	1.2	59.5	37.3	0.2	14.2	1.5	4	0.1	0.3
Busiri	Min	26	42	5	6	88	57	0	0.03	1.4	12.3	0.12	0.02
	Max	27	277	7	8	288	187	0.6	7	11	38.3	0.82	0.27
	SD	0.5	82.5	0.9	0.7	73.4	44.2	0.3	3.1	3.7	11.9	0.3	0.1

Table 5. Water quality parameters from selected piped water supplies

Water quality parameter

Sample collection site		**Temp (^{0}C)**	**Redox**	**pH**	**Do (mg/l)**	**EC (µS/cm)**	**TDS (mg/l)**	**PC (µg/l)**	**Total chl (mg/l)**	**NO_3-N (mg/l)**	**NO_2-N (mg/l)**	PO_4^{3-} **mg/l**	**P (mg/l)**
Nebuye WTP	Min	26	131	6	6.1	112	163	0.03	6.52	0.3	3.1	0.14	0.04
	Max	27	266	7	8	395	272	0.58	15	11	21.1	0.8	0.5
	SD	0.4	49.5	0.4	0.7	99.4	50.3	0.2	3.4	4.8	6.8	0.3	0.2
Household 1	Min	25	92	6	6	266	167	0.01	1	0.7	3.01	0.12	0.04
	Max	27	665	7	8	483	314	0.33	12	9.4	12.2	0.56	0.18
	SD	0.8	212.5	0.5	0.7	90.8	59.2	0.1	4.2	3.2	3.8	0.2	0.1
Household 2	Min	26	112	6	6	265	168	0.01	0.95	0.7	3	0.13	0.04
	Max	27	171	7.4	8	407	266	0.3	12	8.8	11.2	0.4	0.15
	SD	0.7	21.3	0.6	0.6	69.3	44.4	0.1	4.3	3	3.9	0.1	0

Temperature and pH

The temperature ranged from 25 to 29.6 ^{0}C in the lake water and from 24 to 28 ^{0}C in the shallow wells, the temperature recorded from the lake exceeding that in 2004 (Kishe, 2004). Temperature has been reported to have a direct relationship with algal blooms and toxin production (Davis et al., 2009). Temperature increase is thought to be a factor contributing to the global increase in algal bloom globally – continental Africa is heating up faster than the rest of the world (Liu et al., 2011). The pH recorded was between 7 and 9 in the lake water samples, and 5 and 8 from the deep wells (Table 1). Spring water had the lowest pH range (5 to 7) and piped the narrowest (6 to 7) (Table 4 and 5). The pH range of the lake water is that most favoured for PC and cyanobacterial production. Other studies have also reported that this pH range contributes to increased cyanobacterial bloom (Ndlela et al, 2016; Dalu & Wasserman, 2018).

EC, TDS and DO

EC varied greatly between the sampling sites, the highest range was in the deep wells, from 73 to 3,733 µS/cm , followed by shallow well water ranging from 31 to 1,125 µS/cm (Table 3). The narrowest range recorded was in spring water, ranging from 88 to 288 µS/cm.

The TDS concentration varied substantially in all sources, from 52 to 2,426 mg/l, 78 to 732 mg/l, and 48 to 416 mg/l in water from deep and shallow wells, and lake water, respectively.

The DO concentration in the lake water ranged from 5.5 to 8 mg/l and from the shallow wells from 3 to 8 mg/l. DO is an important water quality parameter reflecting the physical and biological processes prevailing in the water (Trivedy & Goel, 1984). Waters with low DO concentrations can be aesthetically displeasing in colour, taste and/or odour, as well as resulting in microbial reduction of nitrate to nitrite (WHO 2006)

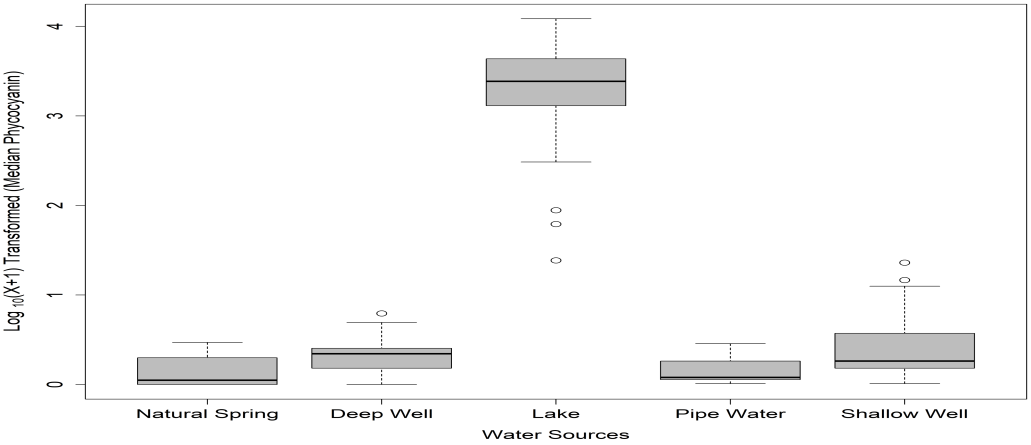


Figure 3: PC distribution by water source

Total chlorophyll and Phycocyanin pigment

Total chlorophyll reported high concentrations in the lake and shallow well samples, with ranges of 18 to 213 mg/l and 4 to 47 mg/l, respectively. Other water sources generally reported much lower concentrations. PC reported the highest concentrations in lake water samples with a range of 5 to 58.4 µg/L (Figure 3) as compared to shallow well waters with a range of 0.01 to 2.9 µg/L. PC concentrations in other sources were very low, ranging from 0 to 1.21 µg/L, 0 to 0.6 µg/L and 0.01 to 0.58 µg/L in deep well, spring and piped waters respectively. The maximum PC concentration in a lake water source was 58.4 µg/L (Table 1), which exceeds WHO's "alert level 1" (Brient et al, 2008). Univariate analysis for the different water source types associated with PC indicated that lake water can contain concentrations of almost 30 µg/L ($P < 0.001$) – see Table 6. The lake environment favours cyanobacterial growth leading to PC and chlorophyll production due to the inflow of effluents from human habitats. Because of the high PC concentrations in the lake it is important to institute control measures to help lake water users.

Table 6: Univariate analysis for different water sources associated with the presence of PC

	UNIVARIATE		
Water Sources	**Comparison Factors (µg/L)**	**95% CI**	**P**
Spring	Ref	-	-
Deep Well	0.24	-9.67, 10.17	0.962
Lake	28.61	20.11, 37.11	**<0.001**
Piped supply	-0.02	-9.94, 9.91	0.998
Shallow Well	0.4	-8.47, 9.28	0.93

Nitrate, Nitrite and Phosphate

The nitrate (NO_3-N) concentration varied from different water sources with a range of 11 to 72.9 mg/l in the lake, 0.3 to 35.6 mg/l in deep wells and 0.9 to 39 mg/l in shallow wells. The nitrite concentration also varied – ranges of 1.6 to 97.2 mg/l in deep wells, 2.8 to 97.2 mg/l in shallow wells, and 7 to 84 mg/l in lake waters.

Phosphate (PO_4^{3-}) was found at high concentrations in lake water, ranging from 0.14 to 22.14 mg/l. Spring waters reported lower concentrations ranging from 0.12 to 0.82 mg/l. It is thought that the higher phosphate concentrations in the lake might be related to the elevated pH, which could promote desorption of sedimentary inorganic phosphorus (Gao et al 2012)

PC association with water quality parameters

Table 7: Univariate and multivariate analyses for different water quality parameters and their association with the presence of PC

	UNIVARIATE			**MULTIVARIATE**		
Variable	**Comparison factor** (µg/L)	**95% CI**	**P**	**Comparison factor** (µg/L)	**95% CI**	**P**
Temperature	-3.04	-3.95, -2.13	**<0.001***	-1.26	-2.21, -0.32	**<0.05***
Redox	1.6	0.43, 2.77	**<0.01***	1.33	0.42, 2.23	**<0.05***
pH	-0.62	-2.44, 1.19	0.507			
DO	-0.19	-1.45, 1.08	0.773			
EC	-0.16	-2.07, 1.74	0.867			
TDS	-0.17	-2.01, 1.66	0.856			
Total Chl	5.67	4.12, 7.23	**<0.001***	4.6	2.98, 6.23	**<0.001***
Nitrate (NO_3-N)	9.55	7.62, 11.48	**<0.001***	5.06	3.12, 6.96	**<0.001***

Nitrite (NO_2-N)	4.74	3.21, 6.26	**<0.001***	0.89	-0.51, 2.29	0.217
Phosphate (PO_4^{3-})	2.57	1.28, 3.87	**<0.001***	0.07	-1.01, 1.15	0.898
Phosphorus (P)	4.38	2.76, 5.99	**<0.001***	0.31	-0.97, 1.60	0.633

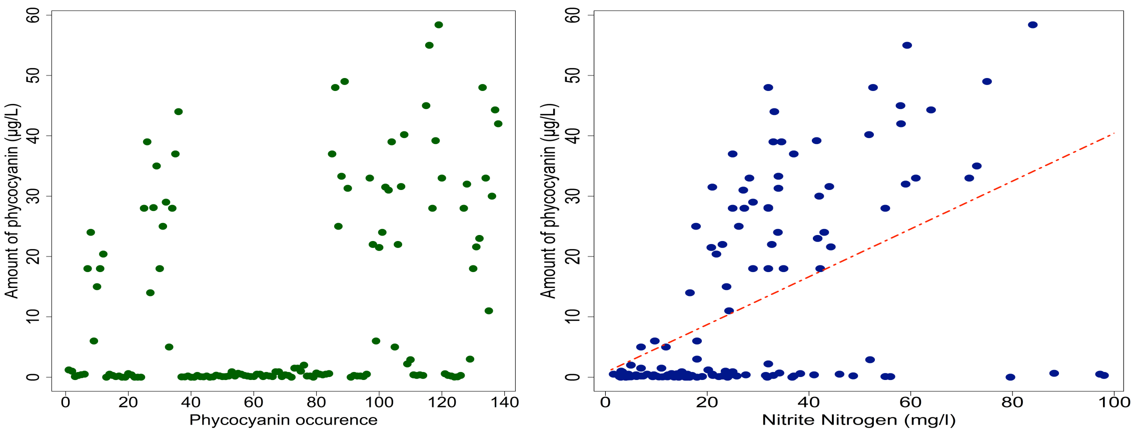
*Refers to statistically significance variable where $P<0.05$

The univariate relationship between water quality parameters and PC indicates statistically significant associations with temperature, redox potential, total chlorophyll, nitrate nitrogen, nitrite nitrogen, phosphate and reactive phosphorus, for all of which $P<0.001$ (Table 7)

All water quality parameters reported as statistically significant on the univariate analysis where subjected to the multivariate model. Temperature, redox potential, total chl and nitrite nitrogen all correlated with PC with $P<0.05$ (Table 7)

Nitrogen and Phosphorus

The nitrate (NO_3-N) and nitrite (NO_2-N) species, reported at high concentrations in lake water samples with maxima of 72.9 and 84 mg-N/l, respectively. The maximum phosphate (PO_4^{3-}) concentration was 22.14 mg-P/l, while that of reactive phosphorus (P) was 1.06 mg/l. Nitrate, nitrite, phosphate and phosphorus show positive associations with increased PC concentrations; $P<0.001$ (Table 7). Natural increases in nitrogen and phosphorus concentrations lead to eutrophication, causing algal proliferation and HABs, with cyanotoxin production (Yang et al., 2008). About 70% of the reports reviewed in African publications indicate that nitrogen and phosphorus have major impacts on cyanobacterial growth and increased PC concentrations, as well as MC (Ndlela et al, 2016). Previous studies have also confirmed that nitrogen is a strong contributing factor to MC toxin abundance (Lee et al, 2000; Harke et al., 2016)



A

B

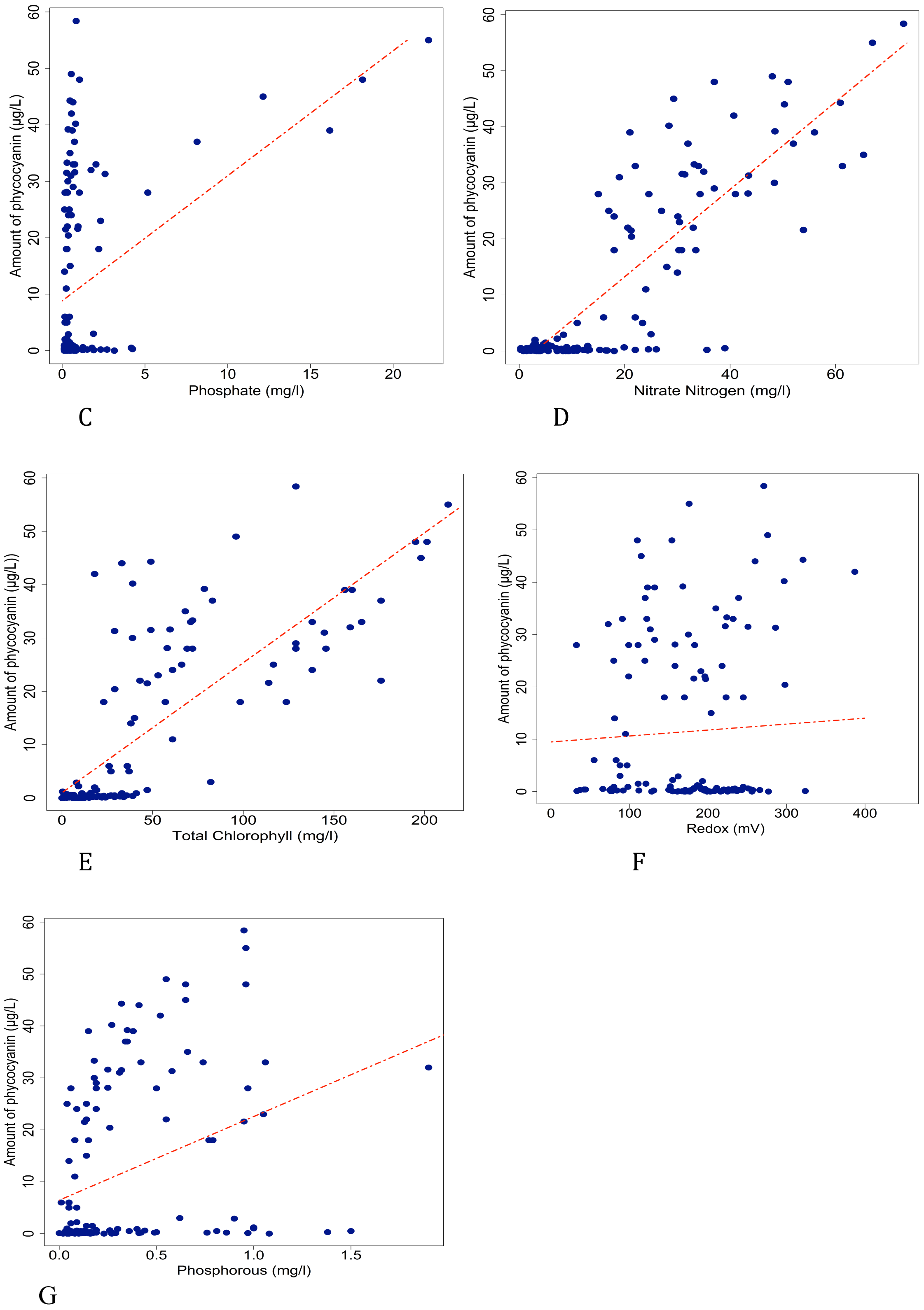


Figure 4: Predictions of PC (A) increases because of its positive association with other water quality parameters (B, C, D, E, F & G)

Predictive model of association between PC and water quality parameters

The statistical model developed in this study shows that some water quality parameters are associated with the presence of PC. Those with univariate association include: temperature, redox potential, total chl, NO_3-N, NO_2-N, PO_4^{3-} and P, with $p<0.001$. The same finding was reported for the same parameters in a study conducted by Marion et al., (2012). The multivariate model indicates that temperature, redox potential, total chl and NO_3-N are all statistically significant, with $p<0.001$ (Table 7). The associations were further quantified with respect to the extent that the parameters contribute to increases in PC.

Nitrate contributes highly to PC occurrence, with unit increase (1 mg-N/l) causing an increase in PC concentration of 9.55 µg/L ($P<0.001$), while unit increase of P (1 mg/l) can increase PC concentration by 4.38 µg/L ($P<0.001$). Other parameters such as total chl, nitrite, $PO_4^{3-}$and redox potential all also have positive correlations with PC concentration ($P<0.001$) – see Figure 4. It was shown that, in essence, the nitrate and phosphorus loads determine the rate and magnitude of cyanobacterial growth (PC concentration). The higher the loads the greater the potential for algal growth (Wetzel, 2001). The associations observed can be used as water quality surveillance indicators that can be invoked easily and cheaply using simple detection methods.

Conclusion

This study has provided the baseline information on water quality parameters in Ukerewe district in relation to PC as a proxy indicator of cyanobacterial bloom. The PC proxy indicator is a surveillance tool that enables anticipation of water body contamination by cyanobacteria. The PC concentration range of 5 to 58.4 µg/L observed in this study goes beyond the WHO recommended maximum level, above which measures must be taken to control cyanobacterial bloom. In accordance with WHO recommendations on quantifying the PC concentration equivalence to cyanobacterial cell numbers that 30 µg-PC/L is equivalent to 20,000 cyanobacterial cells/ml and 90 µg/L to 100,000 cells/ml, this reference will be used as a guide until proper water monitoring can be instated in the district.

The concentrations of parameters like redox potential, total chlorophyll, nitrate, nitrite, phosphate and reactive phosphorus all have positive correlations with PC concentration, and can be measured and monitored easily, to enable prediction of increasing PC. This will address the challenges of lack of advanced technological equipment in district level government bodies in most developing countries for identifying, monitoring and managing cyanobacterial blooms

The predictive model developed in this study has quantified the water parameters that affect PC concentrations on the basis of a case study in Ukerewe district. To validate this approach, more long-term studies are needed on several water bodies, which will also enable it to be used more efficiently. Algal blooms in Lake Victoria need to be classified to provide understandings of which species are present and their potential in cyanotoxin production

ACKNOWLEDGEMENT

This research was funded by Microcystin project through Nelson Mandela African Institution of Science and Technology (NM-AIST). The authors are grateful for the technical support of laboratory staff for sample analysis and instrumentation.

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