# An overview of cyanobacterial bloom occurrences and research in Africa over the last decade

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## Abstract

Cyanobacterial blooms are a current cause for concern globally, with vital water sources experiencing frequent and increasingly toxic blooms in the past decade. These increases are resultant of both anthropogenic and natural factors, with climate change being the central concern. Of the more affected parts of the world, Africa has been considered particularly vulnerable due to its historical predisposition and lag in social economic development. This review collectively assesses the available information on cyanobacterial blooms in Africa as well as any visible trends associated with reported occurrences over the last decade. Of the 54 countries in Africa, only 21 have notable research information in the area of cyanobacterial blooms within the last decade, although there is substantial reason to attribute these blooms as some of the major water quality threats in Africa collectively. The collected information suggests that civil wars, disease outbreaks and inadequate infrastructure are at the core of Africa's delayed advancement. This is even more so in the area of cyanobacteria related research, with 11 out of 20 countries having recorded toxicity and physicochemical parameters related to cyanobacterial blooms. Compared to the rest of the continent, peripheral countries are at the forefront of research related to cyanobacteria, with countries such as

Angola having sufficient rainfall, but poor water quality with limited information on bloom occurrences. An assessment of the reported blooms found nitrogen concentrations to be higher in the water column of more toxic blooms, validating recent global studies and indicating that phosphorous is not the only factor to be monitored in bloom mitigation. Blooms occurred at low TN: TP ratios and at temperatures above 12°C. Nitrogen was linked to toxicity and temperature also had a positive effect on bloom occurrence and toxicity. *Microcystis* was the most ubiquitous of the cyanobacterial strains reported in Africa and the one most frequently toxic. *Cylindrospermopsis* was reported more in the dry, north and western parts of the continent countries as opposed to the rest of the continent, whilst Anabaena was more frequent on the south eastern regions. In light of the entire continent, the inadequacy in reported blooms and advances in this area of research require critical intervention and action. .

**Keywords:** Cyanobacteria, Africa, *Microcystis*, *Anabaena*, *Cylindrospermospis*, Climate change

## 1. Introduction

Water depletion in developing countries has been a crisis for decades (Falkenmark, 1989). Over the past decade, substantial evidence has been presented on the looming water crisis in Africa. Although social factors and energy generation systems contribute to the strain on water availability, environmental factors are also significant contributors. Some of the factors attributed to this depletion are anthropogenic activity, pollution, phosphorous and nitrogen loading (Vörösmarty et al., 2010). In African countries, the supply of potable water is an eminent issue, with water quality affected by the inadequacy of water purification plants and lack of knowledge in chlorine dosing being some of the reasons (Momba et al., 2006). These issues are further compounded by contamination during storage of purified water from plants to point-of-use stages (Massoud et al., 2010). The contamination of water results from a variety of factors, and a more imminent source of contamination in both reservoirs and water bodies is algal blooms (WHO, 2011).

In nature, excessive phosphorous and nitrogen loading have consequently been found to result in eutrophication, which then cause the proliferation of algae, leading to algal blooms (Carpenter, 2005, Yang et al., 2008). Algal blooms are a natural phenomenon that occasionally occurs with nutrient loading from anthropogenic and natural activity in water bodies. Historically, these blooms were not always considered harmful and were more prevalent in summer months (Mowe et al., 2015). However, with the rise in global temperatures through climate change, there has been a rise in algal blooms, particularly in coastal countries (Oberholster et al., 2009a). Of particular significance are harmful algal blooms (HABs). The phenomenon of harmful algal blooms came to the fore over fifteen years ago, when the simultaneous increase in anthropogenic activity and climate change resulted in an increase in eutrophication and subsequently, algal blooms. These are defined by having a negative environmental impact and are primarily caused by microalgae (Zingone and Enevoldsen, 2000). Although various micro-algal species can be present under bloom conditions, the algae of concern are cyanobacteria, also known as blue-green algae. Cyanobacteria are a group of microorganisms that exist as filaments or single cell. They may also present as colonies under different environmental conditions (Ma et al., 2014). They are larger than bacterial cells but are able to photosynthesize. Their production of the phycobilin pigment results in a bluish tint at high concentrations, which has led to them being coined as blue-green algae (Stocks, 2013). These algae are of major concern during algal blooms due to their potential production of cyanotoxins when in large numbers. Cyanotoxins are released by cyanobacteria and have potentially fatal effects on human and animals exposed to contaminated water (Paerl et al., 2001).

Though Africa has been known to lag behind in research and information sharing, quite a few countries have reported algal blooms and toxicity, especially in the recent years. Consolidation of information in this review has been through the assessment of available journals, theses and reports from various internet sources and contact with relevant authors in the field of cyanobacterial blooms. This review aims to provide the context of cyanobacterial blooms in Africa and assess the current state of cyanobacterial blooms in Africa over the last decade, although in some cases, the information may date as far back as the year 2000.

## 2. Overview of global reports of cyanobacteria

Increased temperatures, salinity and anthropogenic activities have resulted in cyanobacteria gaining greater advantage over other phytoplankton in freshwaters (Paerl and Huisman, 2009). Europe, Asia and America have documented just under half of their lakes as eutrophic, with reports that at least 25% of reported blooms being toxic (Bláha et al., 2009).

Over the past decades, blooms have been further classified as harmful algal blooms or cyanobacterial harmful blooms. The defining factor in the classification of these blooms is firstly the causative species and the toxin release associated with the bloom (Anderson et al., 2002; Paerl and Huisman, 2009). Generally, algal toxins are either not produced or produced in high concentrations in surface waters, remaining at 1 $\mu g.L^{-1}$ or less. Harmful algal blooms are classified as blooms in which the amount of toxin exceeds and reaches or exceeds 10 $\mu g.L^{-1}$ concentrations in surface waters, which has a direct negative impact on aquatic and human life when exposed to the toxic water (Schaedel, 2011).

Toxic blooms have serious human health impacts; of particular significance is an incidence in Brazil where over a hundred dialysis patients died from cyanotoxin exposure (Azevedo et al., 2002). Initially, they were mapped as occurring in tropical countries due to suitable temperature and seasonal conditions. However, with climate change and global warming prevalence, the increase in blooms has resulted in occurrences all over the world in the past decade (O'Neil, et al, 2012; Lefebvre et al., 2016).

Among the literature on toxic blooms, a lot of research has focused on understanding the onset of toxic blooms as well as monitoring guidelines. Although it is not exactly clear what triggers the production of toxins in certain strains, climate change has seen an increase in bloom occurrence and toxicity globally (Paerl and Huisman, 2008). Some of the greatest lakes around the world from Lake Taihu in China to Lake Eerie in America have experienced toxic blooms beyond the past decade (International Joint Commision, 2014; Paerl et al., 2014)

In water scarce countries, increased toxic blooms introduce greater strain in the security of water for both humans and the environment. Africa is one of the continents comprising the most developing countries. Amongst the social issues surrounding the countries, water quality is at the core. The challenge is not only in underdeveloped infrastructure but also in the political issues affecting service delivery. These issues prevail against a back drop of poverty and high population growth (Clay, 1994). Four of the southern countries contributing to the economic development within the continent are described as water scarce in comparison to the rest of the continent (Turton, 2008). Figure 1 shows an overview of the affected water bodies within the African continent over the last decade.

## 3. Cyanobacterial blooms in Africa

### *3.1 The African context of cyanobacterial blooms*

The issues surrounding Africa as a continent are somewhat unique to the rest of the world; wars, poverty, water pollution and disease outbreaks are common in most African countries with rapid population increases, as most countries are developing. Numbers of slum populations in most of the countries are nearing the 50% mark. This of course ties in with nutrient loading into waters from wastes and emerging contaminants of concern, as well as added pressures on the efficiency of current wastewater treatment facilities. Cyanobacterial blooms arise as an area of concern within this context. Based on the Africa water atlas (UNEP, 2010) and data collected in this review, Table 1 offers brief information relevant to cyanobacterial blooms and the current water state in Africa. The average values were derived from 2008 reports of each country in Africa. Northern Africa is the most water scarce region, followed by southern Africa. Central and Western Africa have the most rainfall, followed by the Island regions. The Islands have limited information, with one toxic isolate report, whilst approximately two bloom reports were from central Africa, in Cameroon specifically. The more water scarce regions have numerous reports on cyanobacterial blooms compared to regions with higher rainfall. The urban water access figures indicate that improved drinking water access in urban areas is over 50% overall in the continent, this excludes water access in rural areas. Allocation to agriculture in the continent showed that apart from Central Africa (34%), over 70% of the continent's water allocation in each region is for agriculture. Heavy agricultural dependence is also a contributor to nutrient loading into water sources. Combining the effects of climate change as well as the known erratic rainfall and droughts occurring in the continent Africa is particularly vulnerable to eutrophication, specifically cyanobacterial blooms.

### *3.2 Occurrence and diversity of cyanobacteria*

Presented in Table 2 is a summary of cyanobacterial occurrences over the years in Africa, specifically the source, species and description of the occurrences in different water sources For the purposes of this review, 21 countries have information on bloom occurrences relating to the past decade and a few in the early 2000s. Based on Table 2, the dominant genus in the blooms overall was *Microcystis*, with occurrences in various sources, from saline lakes to hot springs. The description of occurrences indicates nearly all the blooms were toxic or caused by toxin producing strains.

## *4. Southern Africa*

Comprising the more water scarce countries, Southern Africa has lower rainfall, and higher evaporation (Heyns, 2008). This means that in comparison to the rest of the world, water supply is generally lower (Ashton, 2002). Southern Africa comprises 7 countries with some of the most frequent reports of cyanobacterial blooms being from South Africa.

### *4.1 Angola*

Although hardly water scarce (90000-1000 mm per year rainfall) (Turton, 2008), Angola has water quality issues. A 2009 publication by Vale et al. (2009) investigating paralytic shellfish poisoning (PSP) in Luanda and Mussulo bays, briefly referred to cyanobacterial or dinoflagellate blooms as the causative agents. When the screening for the common toxins associated with PSP produced atypical results, the authors alluded to the possibility of cyanobacterial toxins being the possible cause. This study is one of the few available relating to cyanobacteria, although no mention of monitoring programs for PSPs or cyanotoxins was made in this report.

### *4.2 Botswana*

Reports on cyanobacterial blooms in the available water bodies are limited to a 2010 publication assessing the presence of algae in stabilization ponds of the Gaborone wastewater treatment works. The study found cyanobacteria to be more abundant compared to other algal species, with *Microcystis* and *M. flos-aquae* being the most dominant species. This finding was a key concern as the water from these ponds fed into one of the most important river sources in south eastern Botswana. The authors postulate that potential illnesses observed downstream of the ponds may be linked to microcystin toxins, particularly the consumption of fresh produce exposed to this toxin through irrigation (Lusweti et al*.,* 2010) A more recent study by Kirumba et al.(2014) found biotoxic *Microcystis* and *Merismopaedia* isolates among the cyanophyta in the river however, these toxin producers were not the dominant phytoplankton in the river and overall, the river was considered to be in a fairly good state.

### *4.3 Lesotho*

A study in 2009 of 3 Dams in Lesotho reported the highest cyanotoxicity to be around 1 $\mu g.L^{-1}$, which coincided with the highest chlorophyll measurement (Mohale, 2011). Although toxic *Microcystis* and *Oscillatoria* species were found, the water treatment facility did not have measures to eliminate toxins and applied pre-chlorination, which seemed to be effective (Mohale, 2011).

### *4.4. Mozambique*

In Mozambique, recent work on toxic cyanobacteria entails the study of microcystin producing isolates through the use of PCR (polymerase chain reaction) methods. The study used RFLP (restriction fragment length polymorphism) to differentiate microcystin and non-microcystin producing strains in various water sources. The study found *Microcystis* to be the most dominant strain present in three different lake areas, with MC-L-R, R-R and Y-R being the dominant variants (Pedro et al, 2011).

### *4.5 Namibia*

There is limited information available on toxic cyanobacterial blooms in Namibia. Among the available literature is a 2001 paper by Gunnarson and Sanseovic, indicating links between microcystins and incidences of diarrhoea in Namibia. The recorded concentrations of microcystins were never beyond the WHO 1 $\mu g.L^{-1}$ guideline (WHO, 1998), however there was a direct relationship between the amount of chlorophyll, rainfall and incidences of diarrhoea or complaints to the municipality about water quality. A more recent publication of interest describes a novel species of cyanobacteria from the family of Oscillatoriales, *Phormidium etoshii*, in the Etosha pan of Namibia, with no toxicity reported (Dadheech et al. (2013).

### *4.6 South Africa*

South Africa has some of the most documented information on cyanobacterial blooms over the past decade.

The outbreak of cyanobacterial blooms has been recorded across the country, with most reports initiated by an outbreak of illness or animal death within an area. *Microcystis aeruginosa* and *Anabaena* sp. are the more dominant species in reported toxic blooms across the country, with *Oscillatoria* spp. also dominant in certain reports. Reports of *Cylindrospermopsis raciborskii* particularly in the Northern part of South Africa have also been made in the past decade, with increased cell numbers since the early 2000s (Janse van Vuuren and Kriel, 2008). A list of toxic bloom outbreaks and findings up to the year 2000, has been listed in a review by Oberholster et al. (2005).

Since then, more reports of cyanobacterial blooms have been reported in Lake Krugersdrift, over summer months in 2004 coinciding with fish kills, as well as microcystin levels reaching as high as 43 $\mu g.L^{-1}$ in some sites in 2005-2006 (Oberholster *et al.*, 2009b). Reports of microcystin concentrations exceeding 20,000 $\mu g.L^{-1}$ in 2007 resulted in the death of wildlife in the Kruger National Park Nhlangezwane Dam, which is a water source for wildlife in the conservation park (Oberholster *et al.*, 2009c).

Cyanobacterial blooms have also been reported beyond the last decade in Hartebeespoort Dam in 2002 (Oberholster *et al.*, 2004) and has since been plagued with toxic blooms due to nutrient loading from wastewater effluent from the upper catchment. The dominant species in toxic algal blooms has previously been reported as *Microcystis aeruginosa* however a more recent study by Ballot *et al*. (2014) indicates the diversity and abundance of the blooms in Hartebeespoort may have been underestimated, with 96% of the microbial biomass comprising cyanobacteria, with *Nostoc* spp. and *Oscillatoria* spp. forming part of the diversity among other species.

Although typically known to occur in the warmer months, reports of a winter bloom of *Microcystis* in Lake Midmar (Pietermaritzburg, KwaZulu Natal) in 2007 have been a cause for concern (Oberholster and Botha, 2007). *Microcystis* blooms have also been reported in Loskop Dam (Oberholster, 2009; Nchabeleng et al., 2014), with blooms killing wildlife. These blooms also pose a threat to the eco-tourism industry, due to the contamination of water bodies in national parks, killing wildlife (Oberholster et al., 2009c). Of greater concern, are recent reports of *Anabaena* blooms, which were originally not linked to microcystin production, showing prevalence in winter and containing microcystin L-R, in Theewaterskloof, Cape Town (Oberholster et al., 2015).

An illustration of toxic bloom occurrences (Figure 2) in the major water sources indicates that the blooms have occurred in nearly all of the known water sources in South Africa. This places cyanobacterial blooms amongst the main issues that threaten water quality.

### *4.7 Zimbabwe*

In Zimbabwe, most of the water crises facing the country are due both to mismanagement as well as climate change (Brown et al., 2012). Lake Chivero is one of the main water sources and previously researched eutrophic lakes in Zimbabwe. The lake has been classified as eutrophic for decades, with recorded blooms of *Microcystis* spp. and *Anabaena* sp. in earlier years (1960s), which were more recently (2003) dominated by *Microcystis* spp. due to changing nitrogen levels in the water (Mhlanga et al., 2006). Another study of Lake Chivero found toxic algal blooms with a mean microcystin concentration of 19.86 $\mu g.L^{-1}$ in the year

2003. The bloom was caused by the inflow of sewage waste upstream of the lake. Although the findings were not linked to any fish or animal deaths, earlier studies found a link between gastroenteritis in infants and the occurrence of blooms in Lake Chivero. (Ndebele and Magadza, 2006). Between the years 2004-2005, Tendaupenyu (2012) assessed five impoundments, of which Lake Chivero was among the five. Interestingly, Lake Chivero had the highest diversity of phytoplankton in November, although the majority was cyanobacteria, namely *Microcystis* and *Anabaena* spp. This might indicate that the nitrogen level changes previously referred to by Mhlanga *et al.* (2006) may have been favourable for *Anabaena* in the rainy season at the time of Tendaupenyu's assessment. These different findings on Lake Chivero indicate how crucial season and time are to the phytoplankton diversity at any given time. Further work supporting the increasing eutrophication, hence cyanobacteria, in Lake Chivero was a study by Zengeya and Marshall (2007), markedly showing the shift in diet from various fish species. Fish that were typically feeding on diatoms in the 1960s have changed their diet to incorporate more cyanobacteria, specifically resulting in decreases of other fish species and adapting to eutrophic conditions. A 2007 study of a Mazowe River tributary, the Chinyika River, indicated that nutrient loading in this river needed monitoring as many people in the rural areas of Zimbabwe depend on this water for consumption (Bere, 2007). Although reports in the past decade are not as extensive, eutrophication and toxic blooms are a known issue in Zimbabwe.

## *5. Eastern Africa*

Similarly to Southern Africa, there have been documented reports of blooms and research in East Africa. This part of the continent is not necessarily water scarce, with most of the countries having average rainfall slightly lower than 860mm per year, which is the global average (Turton, 2008). An assessment of cyanobacterial diversity in East Africa reported that in comparison to South Africa, Kenya and Morocco, the occurrence and toxicity of cyanobacterial blooms in the continent was poorly reported or realised as an area of concern (Haande et al., 2007)

### *5.1 Ethiopia*

An IFRC (International Federation of Red Cross and Red Crescent Societies) report (2011) describes Ethiopia and other countries in the horn of Africa as some of the poorest, drought-prone areas. In Ethiopia, Lake Tana is the largest water body and had reports of *Microcystis aeruginosa* occurrences, with microcystin concentrations of up to 2.65 $\mu g.L^{-1}$ (Mankiewicz-Boczek et al., 2014).

Earlier studies also indicated the presence of microcystin producing strains in seven rift valley lakes, where analyses were conducted to determine whether prior animal deaths were due to cyanotoxins. They found microcystins using HPLC and ELISA detection, with Lake Koka being a high risk lake with cyanobacterial cell numbers exceeding 100 000 $cells.mL^{-1}$. This was found in an area of the lake used by human and animals, with *Microcystis* sp. occurring in all the lakes, although various other cyanobacteria were also identified in each lake. (Willen et al.,2011).

### *5.2 Kenya*

In 2005, a report by Ballot et al. indicated the presence of cyanotoxins in Lake Sonachi and Lake Simbi, in which the main toxin-producing species were *Arthrospira* and *Anabaenopsis*. Microcystin levels of 12 and 39 $\mu g.g^{-1}$ were detected in Lake Sonachi and Simbi respectively. These species were also found to produce anatoxin-a. This particular report is interesting as it is one of the few reporting these species as the main toxin producers in Kenyan waters.

The high nutrient loading from sewage and agriculture activities creates optimal conditions for cyanobacterial blooms. Lake Nakuru, which acts as a water source for endangered wildlife species and other animals in the National Park, has experienced nutrient loading due to effluent flowing in from settlements around the area, hence causing excessive cyanobacterial blooms. Although the study found non-toxin producing strains of *Microcystis*, the potential threat of exposure to microcystins by toxin producing strains of *Microcystis* remains (Kotut et al., 2010).

Lake Victoria, the largest lake in Africa runs through three countries: Kenya, Uganda and Tanzania. Reports on the Nyanza Gulf of Lake Victoria, which borders Kenya, state that toxic algal blooms have been observed from the 1980s, which resulted in massive fish kills. An analysis of the Gulf four years ago revealed that *Microcystis* and *Anabaena* sp. were the dominant microcystin producing species; comprising over 50% of the phytoplankton during cyanobacterial blooms. Blooms and microcystin concentrations were found to be higher in the wet season than in the dry season (Sitoki et al., 2012).

### *5.3 Malawi*

Gondwe et al. (2008) reported the presence of *Anabaena* sp. heterocysts in Lake Malawi, indicating one of the very few reports of cyanobacterial occurrences in this country.

Not much in the area of technological advances in toxic bloom management has been reported in East Africa. A study by Okello et al. (2010) assessed the various types of microcystins present in the lakes of Uganda, linking the microcystin production to the environmental conditions in water samples. *Anabaena, Aphanocapsa, Chroococcus, Merismopedia, Microcystis, Planktolyngbya, and Pseudanabaena* spp. are examples of the phytoplankton genera found in these waters. The study further indicated that *Microcystis* sp.

has the advantage of being able to out-compete other phytoplankton and remain in waters for longer periods of time while shallow waters are more favourable for bloom conditions.

### *5.4 Uganda*

Lake Victoria also runs through Uganda and the Ugandan portion of this lake is highly polluted. Fishing is one of the main means to generate income in Uganda. For decades, hundreds of people have made their living through the fishing of the Nile perch (*Lates niloticus*). The introduction of this species into Lake Victoria as well as its overfishing has led to excessive algal blooms (Kayombo and Jorgensen, 2006). Regulations to curb the overfishing of the Nile perch directly threaten the food security of the residents in Uganda as most of them are not skilled in any other areas and make their living through fishing. The overfishing also results in the overgrowth of algae, which is further promoted by increases in phosphorus concentrations from external pollutants (Kayombo and Jorgensen, 2006). As a result, certain parts of Lake Victoria can no longer sustain life and residents rely directly on the water from the lake as a potable water supply. This has led to a chain reaction of various disease outbreaks, which then contributes to nutrient loading, which is coupled with cyanobacterial abundance (Muyodi et al., 2009). *Anabaena* and *Microcystis* spp. were found to be the abundant cyanobacteria in the Ugandan portion of Lake Victoria (Haande et al., 2011).

Other water sources in Uganda have been affected by cyanobacterial blooms as well. Lake Mburo and Lake Kachera, which are water sources for residents and animals in the mid-western region of Uganda have also been classified as eutrophic, with *Microcystis* sp. and *Anabaena* sp. being the most dominant and present in all sites sampled in the lakes. Being shallow lakes, the issue of blooms can persist for years (Havens, 2008). The concern in these lakes is from the presence of hippos, which then deposit nutrient rich wastes into the water as well as the upstream deposit of cattle farm wastes into the lakes. No cyanobacterial toxicity was recorded in the lakes during the study however, the presence of the cyanobacteria is a possible threat to the water quality and consequently human and animal life that consume the water from these lakes (Nyakoojoo and Byarujali, 2010).

A previous study by Ndebele-Murisa et al. (2010) assessing the great lakes of East Africa (Lake Victoria, Malawi and Tanganyika) has indicated that cyanobacterial blooms are mostly an issue in Lake Victoria and that preventative measures should be taken to preserve the water quality in Lake Malawi and Tanganyika, which borders Tanzania and Malawi. Limited literature is available on the cyanobacteria prevalence in other countries in this region (Ndebele-Murisa et al., 2010), with Sekadende et al. (2005) reporting on the presence of microcystin-producing *Microcystis* and *Anabaena* species, although the recorded toxin level was not more than 1 μg.L$^{-1}$.

## *6. West Africa*

### *6.1 Burkina Faso*

h In Burkina Fso, a toxic bloom reported in 2003 found *Microcystis* and *Oscillatoria* as the dominant species (Boelee et al., 2009). A majority of the reports related to cyanobacteria are not accessible in English however according to Boelee et al. (2009), a study assessing 23 lakes and reservoirs by Cecchi et al (2009), found cyanobacteria present in over 20 of the water sources and five potentially toxic species were located in 19 of them. Another 2009 publication by Cecchi et al. (2009) offers a practical management tool for cyanobacteria monitoring, in which it also shows the major water sources affected by cyanobacteria.

### *6.2 Ghana*

With Ghana sewage water treatment works failing to supply enough treated water and losing over 40% of water through illegal access to water (Osumanu et al., 2010), it is not surprising to have disease outbreaks or indications of cyanobacterial occurrences (Addico et al., 2006), although the toxicity of the microcystin R-R found in the Weija and Kpong reservoir did not exceed 3.21 $\mu g.L^{-1}$.

### *6.3 Nigeria*

In West Africa, Nigeria's Cross River is a major source of fish and shrimp for daily consumption as well as on a larger supply scale. The river is one of the biggest in Nigeria although information on cyanobacteria occurrence is recent (early 2000s). The need for this knowledge is particularly due to the need to protect the fish and aquatic fauna from potential toxic blooms (Okogwu and Ugwumba, 2008) The same study found that cyanobacterial abundance was higher in the rainy season, with cyanobacteria outcompeting other algae due to increased phosphorous levels in the water-due to anthropogenic activity-and cladocerans feeding on other more palatable algae species. Phosphate levels in this river were recorded to be 10-fold higher in 2008 as compared to the last recording in 1992. Similar studies were conducted in the Nigerian Guinea Savanna. The Savanna is an area of Nigeria which is subject to dry spells; this means that water contamination becomes a crisis during those conditions. A study of the cyanobacterial diversity and trends also found higher cyanobacterial loads of *Microcystis* during the wet season, with recommendations for further monitoring. The Samaru stream in Nigeria also showed an abundance of cyanobacteria species during the wet season and more green algae in the dry season (Tisseer et al., 2008). *Oscillatoria* was the most abundant species in Lekki lagoon during a study conducted by Abosede and Igekwu (2010). This study indicated that the increase or changes in the phytoplankton community in the lagoon may be due to physiological changes and not necessarily nutrient loading in the waters, although no toxicity was reported. However, a study of the microcystin concentrations in aquaculture ponds in Northern Nigeria found microcystin concentrations reaching 5.8 µg.L$^{-1}$, which is a cause for concern if the microcystins bioaccumulate in the fish tissues (Chia et al., 2009). This is one of the few reports assessing the toxicity and microcystin related aspects of cyanobacterial blooms. A review of the cyanobacterial diversity by Akin-Oriola et al. (2006) highlighted the lack of priority in understanding and reporting of cyanobacteria in sub-Saharan Africa. Most of the recorded reports of the blooms in this report were mostly from the 1990s, with only one study conducted in 2005, on Kuramo waters, with *Microcystis* being the prevalent cyanobacteria genus. The most recent study of the Niger Delta rivers found that over fifteen species of cyanobacteria were present in these waters, with *Anabaena* sp. being the most dominant and *Microcystis* the most ubiquitous. Although both species are toxin producers, their abundance in the water was at 100 000 cells.mL$^{-1}$, which is at moderate probability of adverse health effects according to WHO regulations (WHO 2011). This calls for monitoring of the changes in diversity, however no toxicity was recorded. The lack of phosphorous was one of the indicated factors that inhibited blooms of the toxic species (Odokuma and Alex, 2015).In 2012, a detailed study of the phytoplankton in Lamingo Reservoir found that *Microcystis* and *Nostoc* sp. were among the potentially harmful cyanobacteria, although no toxicity was reported (Ajuzie, 2012). Within the same year, Jegede (2012) analysed the use of the green algae *Chlorella* spp. and cyanobacteria in the production of biofuels. The scarcity of information on cyanobacteria in the country of late may be due to blooms not being a nuisance in the country or they are currently not considered a priority.

### *6.4 Senegal*

Lake Guiers in Senegal is the most frequently reported water source in the area with cyanobacterial blooms. This lake is the largest reservoir supplying freshwater to the capital city of the country. Although reports are not extensive on blooms in the past ten years, toxic blooms have been recorded in Lake Guiers. In most of Africa, *Microcystis* and *Anabaena* species appear to be the most common cause of nuisance blooms. Senegal, however, is plagued mainly by *Cylindrospermopsis raciborskii* (Berger et al., 2006). This species has not been widely reported in the previously mentioned countries.

A study in 2006 assessing the toxicity of *Cylindrospermopsis* sp. found that no toxins were produced over the study period in winter. Instead the diatom *Fragilaria* sp. was more abundant than *Cylindrospermopsis*. The authors considered that the low levels of phosphorous within the water to have been the limiting factor on bloom formation and toxicity of this species (Berger *et al.,* 2006, Bouvy et al., 2006). A similar study in the same year of Lake Guiers found that the diversity of the lakes was altered after the impoundment of certain parts of Lake Guiers. The Northern part of Lake Guiers was found to be more eutrophic, with cyanobacteria being the dominant species and cladocerans being less abundant in that region. This was a marked risk to water quality due to the water usage dependence on the lake (Ka et al., 2006).

Two years later, a study by Quiblier et al. (2008) assessing the phytoplankton trends in 2002-2003, found that the cyanobacteria *Cylindrospermopsis* was dominant in higher water temperatures, with *Lyngbya* sp. being dominant in lower temperatures. The dominance of *Cylindrospermopsis* has also been attributed to the reduction in grazing of cyanobacteria by predators, caused by the impoundment of the dam in the 1990s. A more recent study of *Cylindrospermopsis* toxin production reported the adaptation of this strain to more temperate regions as opposed to the tropical conditions they were more typically found in. Buford and Davis (2011) also found that distinguishing between toxin producing and non-toxin producing strains of these species is difficult as it is not microscopically possible and the toxin concentrations found in water do not correlate to the number of toxin producing cell numbers.

## ***7. Northern Africa***

In Northern Africa, reports on cyanobacterial blooms include countries such as Morocco, Algeria and Egypt. Morocco is classified as a freshwater scarce country, with water being re-used from human consumption practices (Social Watch, 2012).

### *7.1. Algeria*

Nasri et al. (2004) first reported on a microcystin containing strain of *Microcystis* spp. in Lake Oubeira, which is a major drinking water source in east Algeria. The study was conducted over the period 2000 and 2001, between spring and summer. The highest microcystin concentrations were measured in the late spring and summer months, with an increase in 2001. The study found four microcystin variants using MALDI-TOF MS, with concentrations of microcystin L-R reaching as high as 29,163 $\mu g.L^{-1}$ in August 2001. As a result, the water from this lake is no longer used as a drinking water source but is still applied in irrigation and aquaculture, which is a potential health risk. In the same year, Bouïacha and Nasri (2004) also reported on the presence of *Cylindrospermopsis raciborskii*, in co-dominance with *Microcystis aeruginosa* in Lake Oubeira. Unlike *Microcystis*, *C. raciborskii* peaked in the winter of 2001 (10.2 x $10^5$ trichomes per litre) and November (autumn) of 2000 (43 x $10^5$ trichomes per litre), with lower densities in summer. Two morphotypes of these species were identified during this study microscopically. The presence of this strain in colder months is an indication of climate change, as *Cylindrospermopsis* is generally described to occur in typically tropical areas.

Further work by Nasri et al. (2007) found a morphotype of *Microcystis aeruginosa* in the Cheffia water dam, which was not nearly as toxic as that discovered in Lake Oubeira. The recorded peak in microcystin concentrations was in October 2004, where levels reached 28.9 $\mu g.L^{-1}$. Microcystin concentrations in the study were found to correlate with the cell abundance, with the toxicity far lower than Lake Oubeira's peak microcystin concentrations. In addition, the removal of microcystins was applied through coagulation and flocculation as well as powder activated carbon. When applied, this treatment was able to remove up to 99% of microcystins in some instances.

A 2008 study reported 12 turtle deaths linked to microcystins in Lake Oubeira, during a toxic *Microcystis* spp. bloom that occurred in 2005, which was the first report of this nature in Lake Oubeira. Upon further investigation, the death of the terrapins was confirmed to be due to the direct ingestion of microcystins, with accumulation in the liver and muscle tissues (Nasri et al., 2008). A water assessment of the Seybouse River in north-east Algeria lists some of the main water issues as wastewater infiltration, which further strains the limited water resources available in the country.

### *7.2 Egypt*

Investigations into the irrigation system applied in the country found that this current system results in losses of approximately 3 billion litres of water per year (Abebe, 2014). Moreover, economy development through farming further strains the water supply. In addition to this, the developing economy through farming also adds strain to water supply.

Pollution from direct dumping of wastes into the river is one of the main contributors to nutrient loading. With this in mind, the rise of cyanobacterial blooms is not surprising. Extensive research has been done in the area of cyanobacterial blooms in Egypt.

Earlier studies have been conducted on the feeding of *Daphnia* species on *Microcystis* spp. and found that *Daphnia* sp. were able to feed on cyanobacteria, however it is not the first preference in phytoplankton feed. These filter feeders were able to consume the cyanobacteria without any observed toxic effects and up to 1.78 µg of microcystins were accumulated per 25 daphnids (Mohamed, 2001). Other earlier studies include the assessment of allelopathic relations between *Spirogyra* species that were found to stimulate the toxin production and blooms of *Oscillatoria agardhii* in irrigation canals. The finding indicated that certain cyanobacteria species produce toxins or thrive better in the presence of other phytoplankton (Mohamed, 2002).

In the last decade, reports on microcystins being produced in oligotrophic waters have been noted in Egypt. Benthic mats of 19 cyanobacterial species were found to produce toxins in the Nile River, which is the main water source in the country (Mohamed et al., 2006). Another interesting study conducted in the same year showed how tilapia fish, under laboratory conditions, were able to ingest and excrete microcystins up to 1.12mg/g dry weight. Although the more toxic microcystin L-R was not present in the profile of microcystins, the fish were able to depurate microcystin R-R, Y-R and W-R and excrete them through bile into the aquatic environment (Mohamed and Hussein, 2006). This study is an interesting indication of the ability of some aquatic life to be sustained even in the presence of toxic cyanobacterial blooms, which is then a cause of concern, firstly because the presence of live fish does not alert to the toxicity of the water, as well as the fact that the toxins are released back into the water after being excreted by the fish.

In 2007, Mohamed reported on the presence of *Cylindrospermopsis raciborskii* and *Raphidiopsis mediterranea*, which are hepatotoxic and neurotoxic, respectively in the El-Dowyrat fish pond in Egypt. Toxicity was observed on mice, with the peaks in biomass occurring in the highest temperature months of May to August. Reasons such as warmth of the water and the stagnancy of the pond may have contributed to the blooming of these toxic cyanobacteria. Another study in 2008, by El-Gammal, found that certain concentrations of potassium sulphate were inhibitory to *Microcystis* at concentrations as low as 1.5mM.

More recent studies in Egypt include the assessment of allelopathic macrophytes as an inhibitor against toxic cyanobacteria. The study by Ghobrial et al. (2015) investigated the effects of previously reported macrophyte extracts against *Microcystis*, *Anabaena* and *Oscillatoria* spp. The study found that the choice of solvent (acetone/ethanol) influenced the inhibitory effect of the extracts and that based on allelopathy, these extracts may potentially be applied in place of algaecides to control cyanobacterial blooms. Interestingly, the study also highlighted that these allelopathic extracts were not effective under eutrophic conditions, which calls for further investigation into the area of algaecides from macrophytes.

A recent assessment of a hypersaline lagoon in Northern Sinai, found very little cyanobacteria forming part of the phytoplankton and the lagoon was noted as oligotrophic and one of the cleaner water sources in Egypt. This is positive information, considering the economic value of fish exported from this lagoon to European countries. However, the lake is nutritionally poor, which poses a threat to the ecosystem diversity. The solution may be introduction of nutrients or fertilizers, which would also imply the potential formation of harmful algal blooms, which have not occurred under the current conditions (El-Kassas et al., 2016).

### *7.3 Morocco*

Publications by Oudra in the early 2000s showed the presence of microcystins from *Microcystis* in the eutrophic Lake Lalla Takerkoust in Morocco. The toxicity of the microcystins in this water was found to be high (> 4 $mg.kg^{-1}$ body weight), with factors such as low zooplankton grazing and climate change contributing to blooms lasting all year round in some parts of the lake (Oudra et al., 2001).

Further work by Oudra et al., in 2002 confirmed the presence of toxic cyanobacteria in drinking water and reservoirs in Morocco, with toxicity ranging from moderate to high. *Microcystis* was found to be more toxic than the other 18 strains found in the drinking and recreational waters. Of interest in this publication is the proposed revision of water treatment guidelines in the use of algal species as this was partly what introduced toxic cyanobacteria into treated effluents. Additionally, there were reports of toxic nano-pico cyanobacteria, *Synechococcus* sp. and *Synechocystis* sp., which are not often reported. Recommendations for a monitoring programme in the occurrence of cyanobacterial blooms were also made.

Sabour et al. (2002) reported on non-toxic strains of *Microcystis ichthyoblabe* in Lake Oued Mellah, with slight toxicities occurring during the active bloom. $LD_{50}$ concentrations were 518 and 1924 mg $kg^{-1}$ (dry weight). More recent reports in 2009 by Oudra et al. discuss the presence of hepatotoxic *Nostoc muscorum* in the Oukaïmeden waters. These *Nostoc* mats produced high toxicity similar to previously reported strains of *Microcystis* spp. in Morocco, with hepatotoxic and diarrhoeic effects on mice 15 minutes after being injected with the cyanobacterial extract. These toxic *Nostoc* species were found in clear, oligotrophic, which challenged the general theory that toxic cyanobacteria normally proliferate in eutrophic waters. This drew further attention to benthic cyanobacteria as contributors to toxicity and a potential health hazard in waters. The current strains on water supply have led to the estimation that Morocco will be chronically water stressed by the year 2025 (Social Watch, 2012).

### *7.4 Tunisia*

A review of Mediterranean countries and their water scarcity issues lists Tunisia among the countries that have been hampered by drought, being in northern Africa, it is also generally dry (Iglesias et al, 2007). Two relevant publications to this review detail the occurrence of cyanobacteria in Tunisia. The first assessed the seasonal occurrence of toxic *Microcystis* spp. and *Oscillatoria* spp in the Lebna Dam. The findings were: that a variety of factors influenced the diversity of cyanobacteria and that the presence of these toxic strains did not correspond to high chlorophyll concentrations as expected. The diversity was attributed to nutrient changes in the water, although it was not clear on the exact factors that contributed to particular species abundance (El Herry, 2008a). In another study, three morphospecies of *Microcystis* were found in the Lebna Dam and found to be potentially toxigenic using the PP2A inhibition assay. These strains also had *myc*A, B and C genes present, which is an indication of microcystin producers. Through the use of restriction fragment length polymorphisms (RFLP), these isolates showed similarity to *Microcystis* (El Herry et al., 2008b). Another study in 2009 found *Microcystis novacekii* in Tunisian waters, which had also been previously reported in Northern Africa (El Herry et al., 2009).

### *Central Africa and Western Indian Ocean Islands*

In central Africa, Cameroon is one of the few countries where information regarding cyanobacteria is readily available. One of the last recorded blooms was in 2006, where various species of potentially harmful cyanobacteria were isolated along the coast of Guinea and Cameroon. Prior to this, a publication in the 1970s reported cyanobacterial occurrences in Cameroon however no toxicity was recorded (Mowe et al., 2015). There is limited available information regarding cyanobacterial blooms in this region of the continent. Language and perhaps local publishing within the countries may have limited the accessibility of research.

In the Western Indian Ocean islands, Andrianasolo et al. (2007) isolated mitsoamide, a cytotoxic polypeptide which has potential carcinogenic effects, from *Geitlerinema* sp., in Madagascan waters, which was a novel discovery. Sporadic seasonal occurrences of blooms have been reported with no toxicity in Mauritius and Madagascar (Uz, 2007).

## 8. Discussion

It is clear, based on Figure 1, that most of the information available is from 20 countries, in the peripheral parts of the continent, with a large information gap in the more central countries. This is an improved tally of information in comparison to the 2005 Cyanonet report (Codd et al, 2005), which tabulated more information for approximately 8 countries, including Burundi, which has no publications recorded within the scope of this review.

The more water-stressed countries such as Egypt and South Africa are at the forefront of research related to cyanobacterial blooms, as opposed to countries with more available water such as Angola. Research on the occurrence and frequency of civil war among other issues indicates that Africa is more likely to continue having civil wars due to social differences (e.g. religion) as well as economic constraints (Collier and Hoeffler, 2002). Considering that this assessment of Africa was conducted in the early 2000s, it is evident that civil wars still play a major role in the delayed progression of Africa and inevitably in the area of cyanobacterial research.

In African countries, the issue of toxic blooms is a compounding one in addition to existing water issues and challenges. It is not surprising therefore, that there is a lag in research in this area. An additional consideration may be the language of research publications in some countries, since French and Portuguese are among the common languages spoken in Africa (Lewis et al., 2016).

### ***8.2 Scientific trends observed under bloom conditions***

#### *8.2.1 Nitrogen and phosphorous*

Of the available information, some trends are evident in the scientific data of reported blooms. Data was taken from all the above mentioned literature from different countries and physicochemical characteristics of the water sources were tabulated and compared. About thirty bloom reports were used, of which 70% reported total phosphorous and nitrogen. The available information on toxic blooms in most countries has been expressed as microcystin or cyanotoxin concentrations in water samples (µg.L$^{-1}$) or as the dry weight of cyanotoxins (mg.g$^{-1}$). To compare these, they have been plotted against a log scale in comparison to nutrient, temperature and pH measurements (Figure 3). Scientific assessment of any trends and ratios in the reported blooms (Figure 3) showed that nitrogen is linked to the toxicity of the blooms. It appears in most cases, high nitrogen lower phosphorous values are consistent with toxicity in waters. In addition, the TN:TP ratios measured in most of the blooms were relatively low (<29), with a majority being lower than 12. Two of these occurrences had TN:TP ratios of 50 (Loskop Dam B) and 300 (Makhohlolo) however toxicity was below 1 µg.L$^{-1}$ at similar temperatures for both of them. These findings are in line with earlier studies that low TN:TP ratios favour blue green algae and that at ratios beyond 29, they are not dominant phytoplankton (Smith, 1983). The highest toxicity was recorded in Nhlangazwane Dam in South Africa, where TN:TP ratios were 11.2, at ambient temperature and neutral pH. At temperatures beyond 15°C, toxiticy which is in line with earlier findings of low TN:TP ratios being suitable conditions for bloom formation. This confirms previous reports by Davis et al. (2015) and Gobler et al. (2016) that toxicity, or microcystin concentrations, increase with nitrogen and phosphorous inputs.

Previous publications have mentioned the significance of low nitrogen to phosphorous ratios in determining optimal conditions for cyanobacterial blooms. A study by Xie et al. (2003) found that the low TN:TP ratios were not necessarily a cause of *Microcystis* blooms but a consequence, Xie et al. (2003) also maintained that these ratios are not applicable in highly eutrophic conditions. It is of interest to note that only one site in Figure 4 had phosphorous concentrations indicative of eutrophic waters (30 mg.L$^{-1}$). The findings in this review support that of Takamura et al., (1992) which indicated TN: TP ratios of around 10 and lower are favourable for *Microcystis*, as seen in most of the occurrences. A study by Oberholster et al. (2007) found that microcystin content in cyanobacteria was lower at lower nitrogen concentrations. Dolman et al. (2012) indicated the significance of nitrogen phosphorous ratios. Since a number of cyanobacterial species are nitrogen fixers, they easily dominate phytoplankton under low nitrogen conditions. This holds true although it has become evident that certain species have higher toxicity and dominance at higher nitrogen ratios. The variation in response to the nitrogen phosphorous ratios indicates that different species react uniquely to nitrogen and phosphorous loading. Earlier studies similarly supported the presence of nitrogen as a contributor to toxicity or microcystin content, with a direct correlation between the two (Lee et al., 2000), the same trend is seen in Figure 3. So although low nitrogen to phosphorous ratios offers nitrogen fixing cyanobacteria a competitive advantage, nitrogen is also linked to higher toxicity or cyanotoxin abundance. Based on the trend in Figure 3, it appears that most of the reported sites showed toxicity relating to higher nitrogen concentrations. Moreover, the trend is evident in the dry weight of microcystins as well as the external microcystin concentration (μg.L$^{-1}$). Toxicity is evident in sites that have low phosphorous concentrations (lower than the indicated phosphorous concentrations for eutrophic lakes), indicating the significance of nitrogen in toxicity.

### *8.2.2 Distribution of cyanobacteria*

Previously mentioned reports in this review indicate that *Anabaena* species are more commonly reported in the South and Eastern parts of the continent as dominant in blooms. *Cylindrospermopsis* is more prevalent in the hotter drier areas, although it has peaked in winter and autumn in Senegal, as well as the rainy season in Nigeria. However, it occurs in hot drier conditions in Tunisia and Egypt. *Oscillatoria* seldom occurs as the dominant species in a bloom and is more commonly found to be amongst other dominant species. Other species are not as common, with only one report of a toxic *Nostoc* bloom. As a nitrogen fixer, Anabaena is known to be affected by phosphorous inputs in waters, with higher phosphorous leading to higher toxicity (Rapala et al.,1997), this was seen in Lake Sonachi, Lake Simbi and in Theewaterskloof, the dominant isolated genus was *Anabaena*, with temperatures as 25°C and lower (Figure 4). *Microcystis* was the most frequently occurring species. These findings are in agreement with the previous review by Mowe et al. (2015) which found *Microcystis* to be the most dominant genus in the African continent.

### *8.2.3 Temperature and pH*

Based on Figure 3, there was no clear effect of pH on the toxicity of the blooms, with values ranging from circum-nuetral to above 9, whilst the toxicity is varied, although five out of 11 blooms with pH values between 7 and 9 had a microvstin concentration higher than 1 $\mu g.L^{-1}$. Temperature ranges appeared to have a direct proportion to toxicity, which is in line with other study findings (Davis et al., 2009).

Blooms occurred from temperatures as low as 10°C, however toxicities beyond 1 $\mu g.L^{-1}$ were observed at temperatures higher than 15°C. The highest toxicity was measured in Nhlangazwane Dam at a temperature around 30°C.

However, the bloom dominance of *Cylindrospermopsis* in the North Western regions of Africa and in the North Western parts of South Africa indicates that temperature influences the type of cyanobacterial species that are dominant in given water bodies.

In some instances in Nigeria and Senegal, the reported temperatures of water sources where *Cylindrospermopsis* was isolated were relatively high, going beyond 30°C in some instances. Berger et al. (2006) found *Cylindrospermopsis* to be prevalent in the dry seasons, which explains bloom reports in dryer parts of the continent. With optimum growth conditions being beyond ambient temperature, it is not surprising that this genus is prevalent in hot, tropical areas. Moreover, this species also favours alkaline conditions (Antunes et al., 2015).

The distribution of *Microcystis* on all the studied regions of this review is hardly surprising as this specific genus is known for appearing in a variety of water bodies and having a tolerance for unfavourable conditions, particularly the toxic strains. So far there is no definite grasp on the set of parameters that completely exclude the possibility of these blooms in the face of global warming in freshwaters (Marmen et al., 2016).

### *8.2.4 Identification and toxicity estimation methods in Africa*

Of the reviewed literature, it appears that there are quite standard methods in reporting the toxicity of the blooms discussed in this review, a majority of the reports utilize microcystin ELISA kits, HPLC and chlorophyll measurements. A few publications have made use of molecular methods (RFLPs, gene markers) and MALDI-TOF MS to determine the toxicity of the reported cyanobacteria. In addition, bio toxicity assays have also been employed by way of mouse and terrapin bioassays in the North and Southern regions of Africa. A majority of these publications has utilized secchi disk measurements to estimate turbidity and have related these findings to algal biomass.

Monitoring guidelines have also been set out in Burkina Faso (Cecchi et al, 2009) and South Africa (van Ginkel, 2011) for example, with satellite detection of cyanobacterial blooms (Matthews et al., 2014; 2015). In some countries, studies are still first reports of cyanobacteria with recommendations for monitoring guidelines. This shows the wide rift in advancement of cyanobacteria related research in various regions.

Salinity has been linked to cyanobacterial blooms of *Microcystis*; however no link has been made in this review. Overall, despite the missing data from the central region, it is clear that cyanobacterial research is on-going in Africa and that there is awareness of their potential impacts, although they may not be considered among the main water issues.

Due to the variation in measurements and reported parameters, it was not possible to make further conclusions on some of the trends in bloom occurrences thus far.

## 9. Conclusion

Based on the available information and findings, there needs to be a serious effort to consolidate information and technologies available within the continent to aid in curbing the water issues facing Africa. The consolidation of standard measurements and parameters is a key factor in having comparable and informative data on the state of toxic blooms in the continent as a whole. Assessment of standard water physico-chemical parameters and toxicity concentrations during blooms will aid in the understanding and comparability of the occurrences and factors that contribute to certain blooms. Although not fully representative owing to lack of information, the findings of this review indicate that in Africa the most cosmopolitan species is *Microcystis*, with *Cylindrospermopsis* occurring in the dryer, western parts of the continent and *Anabaena* occurring randomly in various parts of the countries, although not as the dominant species, except for in the Malawi reports.

Mowe et al. (2015) have found the occurrence of C*ylindrospermopsis* to be related to higher temperatures and dry seasons in tropical areas, whilst *Microcystis* were more prevalent in wet seasons. The information collected in this review supports these findings, with more reports of *Cylindrospermopsis* being in the warm dessert climate areas.

In the area of technological advances and effective monitoring, most countries are in the early implementation stages and have only recently made efforts into the investigation of cyanobacterial blooms, with identification and toxicity being the primary information screened for. With this, current monitoring plans make reference to WHO regulations. A development of monitoring guidelines specific to particular regions of the continent or of the entire continent may prove very useful and is strongly recommended. The implementation of the guidelines and accessibility is also a needed practical intervention.

Nyenje et al. (2010) reviewed the issue of eutrophication and nutrient loading in Sub-Saharan Africa, identifying a number of intercalating issues linked to this: urban development, inefficient water treatment due to this, no insight into hydrological cycles and micro-pollutant monitoring and fate. The loss of aquatic life, particularly fish, increase in toxic blooms and pathogens are amongst the highlighted issues requiring attention. An offered approach in solving this issue is the systematic assessment of all the processes linked to eutrophication in order to have a practical solution.

With climate change particularly in mind, the challenges facing Africa put the continent against an uphill battle in mitigation. The fact that the continent is heating up faster than the rest of the world (Collier et al., 2008) with pre-existing water challenges as previously mentioned, there are a number of socio-political inputs that may have curbed research and progress in this area. Collectively, the information gathered in this review shows that a lot of measures are not yet in place for the mitigation of cyanobacterial blooms, particularly in the implementation of plans for most countries. Research in Africa has been geared more towards reports and investigations of toxicity in the area of blooms. To say more work needs to be done would be an emphasis of the obvious. In light of Africa's unique vulnerability to climate change, as opposed to other continents, knowledge dissemination and collective research is critical. Initiatives such as CYANONET are crucial in the collection of a more informed picture and the establishment of more collaborative research not only on an intercontinental scale but knowledge sharing within the continent, particularly in the central countries. To our knowledge, this is the first collective review of cyanobacterial blooms in Africa in the past decade.

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## 11. References

Abebe, D., 2014. Egypt, Ethiopia, and the Nile: The economics of international water law. Chi. J. Int'l L. 27.

Abosede, A.T., Ikegwu, N.D., 2010. Cyanobacteria of a tropical lagoon, Nigeria. Nat. Sci. 8 (7), 77-82.

Addico, G., Hardege, J., Komarek, J., Babica, P., de Graft-Johnson, K.A.A., 2006. Cyanobacteria species identified in the Weija and Kpong reservoirs, Ghana and their implications for drinking water quality with respect to microcystin. Afr. J. Mar. Sci. 28, 451-456.

Ajuzie, C.C., 2012. A first survey of phytoplankton community richness in Lamingo Reservoir, Jos, Nigeria: A wake-up call for the continuous monitoring of microalgae in surface waters serving as drinking water sources in Nigeria. New York Sci. J. 5, 1-8.

Akin-Oriola, G.A., Anetekhai, M.A., Oriola, A., 2006. Algal blooms in Nigerian waters: an overview. Afr. J. Mar. Sci. 28 (2), 219-224.

Alexander, K.A., Carzolio, M., Goodin, D., Vance, E., 2013. Climate change is likely to worsen the public health threat of diarrheal disease in Botswana. Int. J. Environ. Res. Public Health. 10, 1202-1230.

Anderson, D.M., Glibert, P.M., Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries 25 (4), 704-726.

Ashton, P.J., 2002. Avoiding conflicts over Africa's water resources. Ambio, 31(3), 236-242

Azevedo, S.M. Carmichael, W.W., Jochimsen, E.M., Rinehart, K.L., Lau, S., Shaw, G.R., Eaglesham, G.K., 2002. Human intoxication by microcystins during renal dialysis treatment in Caruaru Brazil. Toxicol. 181-182, 441-446.

Ballot, A., Krienitz, L., Kotut, K., Wiegand, C., Pflugmacher, S., 2005. Cyanobacteria and cyanobacterial toxins in the alkaline crater lakes Sonachi and Simbi, Kenya. Harmful Algae. 4, 139-150.

Ballot, A., Sandvik, M.,Rundberget,T.,Botha, C.J., Miles, C.O., 2014. Diversity of cyanobacteria and cyanotoxins in Hartebeespoort Dam, South Africa. Mar. Freshwater Res. 65, 175–189.

Batisani, N., Yarnall, B., 2010. Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. Appl. Geogr. 30, 483-489.

Bere, T., 2007. The assessment of nutrient loading and retention in the upper segment of the Chinyika River, Harare: Implications for eutrophication control. Water SA 33(2), 279-284.

Berger, C., Ba, N., Gugger, M., Bouvy, M., Rusconi, F., Coute, A., Troussellier, M., Bernard, C., 2006. Seasonal dynamics and toxicity of Cylindrospermopsis raciborskii in Lake Guiers (Senegal, West Africa). FEMS Microbiol. Ecol. 57, 355-366.

Bláha, L., Babica, P., Maršálek, B., 2009. Toxins produced in cyanobacterial water blooms – toxicity and risks. Interdiscip. Toxicol. 2 (2), 36–41.

Blanco, J., Livramento, F., Rangel, I.S., 2010. Amnesic shellfish poisoning (ASP) toxins in plankton and molluscs from Luanda Bay, Angola. Toxicon 55, 541-546.

Boelee, E., Cecchi, P., Koné, A., 2009. Health impacts of small reservoirs in Burkina Faso. Colombo, Sri Lanka: International Water Management Institute. (IWMI Working Paper 136).

Boschi-Pinto, C., Lanata, C.F., Mendoza, W., Habte, D., 2006. Diarrheal diseases. In: Jamison, D.T., Feachem, R.G.,Makgoba, M.W., Bos, E.R., Baingana, F.K., Hofman, K.J., Rogo, K.O. (Ed) Disease and Mortality in Sub-Saharan Africa, The World Bank, Washington DC pp 107-123.

Bouvy, M., Ba, N., Ka, S., Sane, S., Pagano, M., Arfi, R., 2006. Phytoplankton community structure and species assemblage succession in a shallow tropical lake (Lake Guiers, Senegal). Aquat. Microb. Ecol. 45, 147-161.

Brown, D., Chakanira, R.R., Chatiza, K., Dhliwayo, M., Dodman, D., Masiiwa, M., Muchadenyika, D., Mugabe, P., Zvigadza, S., 2012. Climate change impacts, vulnerability and adaptation in Zimbabwe. IIED Climate Change Working Paper No. 3.

Buford, M.A., Davis, T.W., 2011. Physical and chemical processes promoting dominance of the toxic cyanobacterium Cylindrospermopsis raciborskii Chin. J. Oceanol. Limnol. 29 (4), 883-891.

Carpenter, S.R., 2005. Eutrophication of aquatic ecosystems: Bistability and soil phosphorus. Proceedings of the National Academy of Sciences of the United States of America, 102 (29), 1002-1005.

Cecchi, P.; Arfi, R.; Berger, C.; Couté, A.; Gugger, M.; Zongo, F. 2009. Cyanobacteria, cyanotoxins and potential health hazards in small tropical reservoirs. In: Small reservoirs toolkit, ed. Andreini, M.; Schuetz, T.; Harrington, L. Battaramulla, Sri Lanka: IWMI, Sri Lanka. 12p. http://www.smallreservoirs.org/full/toolkit

Chia, A.M., Oniye, S.J., Lado, Z., Pia, A.E., Inekwe, A.U., Mmerole, J.U., 2009. A survey for the presence of microcystins in aquaculture ponds in Zaria, Northern-Nigeria: Possible public health implication. Afr J. Biotechnol. 8 (22), 6282-6289.

Clay, R., 1994. A continent in chaos: Africa's environmental issues. Environ. Health Perspect. 102 (12), 1018–1023.

Codd, G.A., Azevedo, S.M.F.O., Bagchi, S.N. Burch, M.D., Carmichael, W.W., Harding, W.R., Kaya, K., Utkilen, H.C., 2005. CYANONET A global network for cyanobacterial bloom and toxin risk management initial situation assessment and recommendations. IHP-VI Technical Documents in Hydrology No. 76 UNESCO, Paris.

Collier, C., Conway, G., Venables, T., 2008. Climate change and Africa. Oxf. Rev. Econ. Pol. 24 (2), 337–353.

Collier, P., Hoeffler, A., 2002. On the Incidence of Civil War in Africa. J. Confl. Resolut. 46 (1), 13-28.

Dadheech, P.K., Cassamata, D.A., Casper, P., Krienitz, L., 2013. Phormidium etoshii sp. nov. (Oscillatoriales, Cyanobacteria) described from the Etosha Pan, Namibia, based on morphological, molecular and ecological features. Fottea 13(2), 235–244.

Davis, T.W., Berry, D.L., Boyer, G.L., Gobler, C.J., 2009. The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of Microcystis during cyanobacteria blooms, Harmful Algae, 8 (5), 715-725

Davis, T.W., Bullerjahn, G.S., Tuttle, T., McKay, R.M., Watson, S.B., 2015. Effects of increasing nitrogen and phosphorus concentrations on phytoplankton community growth and toxicity during Planktothrix blooms in Sandusky Bay, Lake Erie. Environ. Sci. Technol., 49, 7197–7207.

Dolman, A.M., Rücker, J., Pick, F.R., Fastner, J., Rohrlack, T., Mischke, U., Wiedner, C., 2012. Cyanobacteria and cyanotoxins: the influence of nitrogen versus phosphorus. PLoS ONE 7(6), e38757.

El-Gammal, M.A.M.I., 2008. Potassium fertilizer inhibits the growth of cyanobacteria (Microcystis aeruginosa) in fishpond. 8th International Symposium on Tilapia in Aquaculture.

El-Kassas, H.Y., Nassar, M.Z.A., Gharib, S.M., 2016. Study of phytoplankton in a natural hypersaline lagoon in a desert area (Bardawil Lagoon in Northern Sinai, Egypt). Rend. Lincei. 1-11.

El-Herry, S., Fathallib, A., Rejebb, A.J., Bouaïcha, 2008a. Seasonal occurrence and toxicity of Microcystis spp. and Oscillatoria tenuis in the Lebna Dam, Tunisia. Water Res. 42, 1263–1273.

El Herry, S., Nasri, H., Bouaïcha, N., 2008b. Morphological and phylogenetic analysis of colonies of Microcystis morphospecies isolated from the Lebna Dam, Tunisia. Afr. J. Microbiol. 2 (12), 340-348.

El Herry, S., Nasri, H., Bouaïcha, N., 2009. Morphological characteristics and phylogenetic analyses of unusual morphospecies of Microcystis novacekii forming bloom in the Cheffia Dam (Algeria). J. Limnol., 68 (2), 242-250.

Falkenmark, M., 1989. The massive water scarcity now threatening africa: why isn't it being addressed? Ambio. 18 (2), 112-118.

Gewald, J.M., 2001. El Negro, El Niño, witchcraft and the absence of rain in Botswana. Afr. Aff. 100 (401), 555-580.

Ghobrial, M.G., Nassr, H.S., Kassir, A.W., 2015. Bioactivity effect of two macrophyte extracts on growth performance of two bloom-forming cyanophytes. Egypt J. Aquat. Res. 41, 69-81.

Gobler, C.J., Burkholder, J.M., Davis, T.W., Harke, M.J., Johengen, T., Stow, C.A., Van Der Wall, D.B., 2016. The dual role of nitrogen supply in controlling the growth and toxicity of cyanobacterial blooms. Harmful Algae. 54, 87-97.

Gondwe, M.J., Guildford, S.J., Hecky, R.E., 2008. Planktonic nitrogen fixation in Lake Malawi/Nyasa. Hydrobiologia 596, 251-267.

Gunnarson, H., Sanseovic, A.M., 2001. Possible linkages between algae toxins in drinking water and related illnesses in Windhoek, Namibia. Bachelor's degree project, School of Engineering, Kristiand University.

Haande, S., Ballot, A., Rohrlack, T., Fastner, J., Wiedner, C., Edvardsen, B., 2007. Diversity of Microcystis aeruginosa isolates (Chroococcales, Cyanobacteria) from East-African water bodies. Arch. Microbiol. 188, 15-25.

Haande, S., Rohrlack, T., Semyalo, R.P., Brettum, P., Edvardsen, B., Lyche-Solheim, A., Sørensen, K., Larsson, P., 2011. Phytoplankton dynamics and cyanobacterial dominance in Murchison Bay of Lake Victoria (Uganda) in relation to environmental conditions. Limnologica 41, 20-29.

Havens, K.E., 2008. Cyanobacteria blooms: effects on aquatic ecosystems. Adv. Exp. Med. Biol. 619, 733-747.

Heyns, P., 2008. Water-resources management in Southern Africa in eds Nakayama, M., International waters in Southern Africa, UN Press.

Ibrahim, B., Karambiri, H., Polcher, J., Yacouba, H., Ribstein, P., 2014. Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models. Clim Dyn 42, 1363–1381

International Federation of Red Cross and Red Crescent Societies, 2011. Drought in the Horn of Africa: Preventing the next disaster.

International Joint Commission, 2014. A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms. Report of the Lake Erie Ecosystem Priority

Jegede, A.O., 2012. Anaerobic digestion of cyanobacteria and chlorella to produce methane for biofuel. Int J Agric & Biol Eng. 5 (3), 1-8.

Janse van Vuuren, S., Kriel, G.P., 2008. Cylindrospermopsis raciborskii, a toxic invasive cyanobacterium in South African fresh waters, Afr. J. of Aquat. Sci. 33(1), 17-26.

Ka, S., Pagano, M., Ba, N., Bouvy, M., Leboulanger, C., Arfi, R., Thiaw, O.T., Ndour, E.H.M., Corbin, D., Defaye, D., Cuoc, C., Kouassi,E., 2006. Zooplankton distribution related to environmental factors and phytoplankton in a shallow tropical lake (Lake Guiers, Senegal, West Africa). Internat. Rev. Hydrobiol. 91 (5) 389-405.

Kayombo, S., Jorgensen, S.E., 2006. Lake Victoria experience and lessons learned brief. Lake Basement Management Initiative 431-446.

Kotut, K., Ballot, A., Wiegand, C., Krienitz, L., 2010. Toxic cyanobacteria at Nakuru sewage oxidation ponds- a potential threat to wildlife. Limnologica 40, 47-53.

Lee, S.J., Jang, M.H., Kim, H.S., 2000. Variation of microcystin content of Microcystis aeruginosa relative to medium N:P ratio and growthstage. J. Appl. Microbiol. 89, 323-329.

Lefebvre, K.A., Quakenbush, L., Frame, E., Huntington, K.B., Sheffieldd, G., Stimmelmayre, R., Bryan, A., Kendricka, P., Ziel, H., Goldstein, T., Snyder, J.A., Gelatt, Gulland, F., Dickerson, B., Gill, V., 2016. Prevalence of algal toxins in Alaskan marine mammals foraging in a changing arctic and subarctic environment. Harmful Algae 55, 13-24.

Lewis, M.P., Simons, G.F., Fennig, C.D. 2016. Ethnologue: Languages of the World, Nineteenth edition. Dallas, Texas: SIL International. Online version: http://www.ethnologue.com.

Lusweti, E., Shushu, D.D., Siame, A.B., 2010. The algae of Gaborone wastewater stabilization ponds: Implications for effluent quality. Botswana Journal of Technology 19 (1).

Ma, J., Brookes, J.D., Qin, B., Paerl, H.W., Gao, G., Wu, P., Zhang, W., Deng, J., Zhu, G.,Zhang, Y., Xu, H., Niu, H., 2014. Environmental factors controlling colony formation in blooms of the cyanobacteria Microcystis spp. in Lake Taihu, China. Harmful Algae. 31,136-142.

Manda, M.A.Z., 2009. Water and sanitation in urban Malawi: Can the Millennium Development Goals be met? A study of informal settlements in three cities. Human Settlements Working Paper Series, Theme 7- Water.

Mankiewicz-Boczek, J.,Gazgał, I., Jurczak, T., Urbaniak, M., Negussie, Y.Z., Zalewski, M., 2014. Incidence of microcystin-producing cyanobacteria in Lake Tana, the largest waterbody in Ethiopia. Afr. J. Ecol. 53, 54–63.

Marmen, S., Aharonovich, D., Grossowicz, M., Blank, L., Yacobi, Y.Z., Sher, D.J., 2016. Distribution and habitat specificity of potentially-toxic Microcystis across climate, land, and water use gradients. Front Microbiol. 7 (271).

Massoud, M.A., Al-Abady, A., Jurdi, M., Nuwayhid, I., 2010. The challenges of sustainable access to safe drinking water in rural areas of developing countries: case of Zawtar El-Charkieh, Southern Lebanon. J. Environ. Health. 72 (10), 24-30.

Matthews, M.W., 2014. Eutrophication and cyanobacterial blooms in South African inland water: 10 years of MERIS observations. Remote Sens. Environ. 155, 161-177.

Matthews, M.W., Bernard, S., 2015. Eutrophication and cyanobacteria in South Africa's standing water bodies: A view from space. S. Afr. J. Sci. 111, (5/6).

Mhlanga, L., Day, J., Cronberg, G., Chimbari, M., Siziba, N., Annadotter, H., 2006. Cyanobacteria and cyanotoxins in the source water from Lake Chivero, Harare, Zimbabwe, and the presence of cyanotoxins in drinking water. Afr. J. Aquat. Sci. 31 (2), 165-173.

Mohale, L.R., 2011. Impact of cyanobacterial toxins on water quality and supply. MSc Thesis, University of the Free State.

Mohamed, Z.A., 2001. Accumulation of cyanobacterial hepatotoxins by daphnia in some Egyptian irrigation canals. Ecotoxicol. Environ. Safe. 50, 4-8.

Mohamed, Z.A., 2002. Allelopathic activity of Spirogyra sp.: stimulating bloom formation and toxin production by Oscillatoria aghardii in some irrigation canals, Egypt. J. Plankton Res. 24 (2) 137-141.

Mohamed, Z.A., 2007. First report of toxic Cylindrospermopsis raciborskii and Raphidiopsismediterranea (Cyanoprokaryota) in Egyptian freshwaters. FEMS Microbiol. Ecol. 59, 741-761.

Mohamed, Z.A., El-Sharouny, H.M., Ali, W.S.M., 2006. Microcystin production in benthic mats of cyanobacteria in the Nile River and irrigation canals, Egypt. Toxicon 47, 584-590.

Mohamed, Z.A., Hussein, A.A., 2006. Depuration of microcystins in tilapia fish exposed to natural populations of toxic cyanobacteria: a laboratory study. Ecotoxicol Environ Safe. 63 (3), 424-429.

Momba, M.N.B., Tyafa, Z., Makala, N., Brouckaert, B.M., Obi, C.L., 2006. Safe drinking water still a dream in rural areas of South Africa. Case Study: The Eastern Cape Province. Water SA. 32 (5), 715-720.

Mowe, M.A.D., Mitrovic, S.M., Lim, R.P.,Furey, A., Yeo, D.C.J., 2015. Tropical cyanobacterial blooms: a review of prevalence, problem taxa, toxins and influencing environmental factors. J. Limnol. 74(2), 205-224.

Muyodi, F.J., Hecky, R.E., Kitamirike J.M., Odong, R., 2009. Trends in health risks from water-related diseases and cyanotoxins in Ugandan portion of Lake Victoria basin. Lake Reserv. Manage 14, 247-257.

Nasri, A.B., Bouaïcha, N., Fastner, J., 2004. First report of a microcystin-containing bloom of the cyanobacteria Microcystis spp. in Lake Oubeira, Eastern Algeria. Arch. Environ. Contam. Toxicol. 46, 197–202.

Nasri, H., Bouaïcha, N., Harche, M.K., 2007. A new morphospecies of Microcystis sp. forming bloom in the Cheffia Dam (Algeria):seasonal variation of microcystin concentrations in raw water and their removal in a full-scale treatment plant. Environ. Toxicol. 22 (4), 347-56.

Nasri, H., El Herry, S., Bouaïcha, N., 2008. First reported case of turtle deaths during a toxic Microcystis spp. bloom in Lake Oubeira, Algeria. Ecotoxicol. Environ. Safe. 71, 535-544.

Nchabeleng, T., Cheng, P., Oberholster, P.J, Botha, A.M., Smit, W.J, Luus-Powell, W.J., 2014. Microcystin-LR equivalent concentrations in fish tissue during a postbloom Microcystis exposure in Loskop Dam, South Africa. Afr. J. Aquat. Sci. 39 (4).

Ndebele, H.R., Magadza, C.H.D., 2006. The occurrence of microcystin-LR in Lake Chivero, Zimbabwe. Lake Reserv. Manage. 11:57-62.

Ndebele-Murisa, M., Musil, C.F., Raitt, L., 2010. A review of phytoplankton dynamics in tropical African lakes. S. Afr. J. Sci. 106, 1/2 13-18.

Nyakoojoo, C., Byarujali, S.M., 2010. An ecological study of two shallow, equatorial lakes: Lake Mburo and Lake Kachera. Afr. J. Ecol. 48, 860-864.

Nyenje, P.M., Foppen, J.W., Uhlenbrook, S., Kulabako, R., Muwanga, A., 2010. Eutrophication and nutrient release in urban areas of sub-Saharan Africa — A review. Sci. Total Environ. 408, 447-455.

O'Neil, J.M., Davis, T.W., Burford, M.A., Gobler, C.J., 2012. The rise of harmful cyanobacteria blooms: The potential roles of eutrophication and climate change. Harmful Algae 14, 313-334.

Oben, P.M., Oben, B.O, Fonge ,B., 2006. High incidence of cyanobacterial blooms along the coast of the Cameroon Gulf of Guinea and their effects on human health and amenities. Trop. Freshwat. Biol 15 (1), 33-42.

Oberholster, P.J, Myburgh, J.G., Govender, D., Bengis, R., Botha, A., 2009c. Identification of toxigenic Microcystis strains after incidents of wild animal mortalities in the Kruger National Park, South Africa. Ecotoxicol. Environ. Safe. 72, 1177–1182.

Oberholster, P.J., 2009. Impact on ecotourism by water pollution in the Olifants River catchment, South Africa. SIL News. 55, 8-9.

Oberholster, P.J., Ashton, P.J., 2008. State of the nation report: An overview of the current status of water quality and eutrophication in South African rivers and reservoirs. CSIR/NRE/WR/IR/2008/0075/C, 1-15.

Oberholster, P.J., Botha, A., 2007. Use of PCR based technologies for risk assessment of a winter cyanobacterial bloom in Lake Midmar, South Africa. Afr. J. Biotechnol. 6 (15), 1794-1805.

Oberholster, P.J., Botha, A., Ashton, P.J., 2009b. The influence of a toxic cyanobacterial bloom and water hydrology on algal populations and macroinvertebrate abundance in the upper littoral zone of Lake Krugersdrift, South Africa. Ecotoxicol. 18, 34-46.

Oberholster, P.J., Botha, A., Grobbelar, J.U. 2004. Microcystis aeruginosa: source of toxic microcystins in drinking water. Afr. J. Biotechnol. 3 (3), 159-168.

Oberholster, P.J., Botha, A., Myburgh, J.G., 2009a. Linking climate change and progressive eutrophication to incidents of clustered animal mortalities in different geographical regions of South Africa. Afr. J. Biotechnol. 8 (21).

Oberholster, P.J., Botha, A.M., 2010. Use of remote sensing and molecular markers to detect toxic cyanobacterial hyperscum crust: A case study on Lake Hartbeespoort, South Africa. Afr. J. Biotechnol. 9 (51), 8791-8799.

Oberholster, P.J., Dabrowski, J., Botha, A.M., 2013. Using modified multiple phosphorus sensitivity indices for mitigation and management of phosphorus loads on a catchment level. Fundam. Appl. Limnol 182 (1), 1-16.

Oberholster, P.J., Jappie, S., Cheng, P.H., Botha, A.M., Matthews, M.W., 2015. First report of an Anabaena Bory strain containing microcystin-LR in a freshwater body in Africa. Afr. J. Aquat. Sci. 40 (1), 21–36.

Odokuma, L.O., Alex, F., 2015. Composition of cyanobacteria in relation to physico chemical characteristics of four rivers in the Niger Delta. Journal of Natural Sciences Research 5 (2), 1-9.

Okello, W., Portmann, C., Erhard, M., Gademann, K., Kurmayer, R., 2010. Occurrence of microcystin-producing cyanobacteria in Ugandan freshwater habitats. Environ Toxicol. (4), 367-380.

Okogwu, O.I., Ugwumba, A.O., 2008. Cyanobacteria abundance and its relationship to water quality in the Mid-Cross River floodplain, Nigeria. Rev. Biol. Trop. 57 (1-2), 33-43.

Osumanu, K.I., Abdul-Rahim, L., Songsore, J., Braimah, F.R., Mulenga, M., 2010. Urban water and sanitation in Ghana: How local action is making a difference. Human Settlements Working Paper Series, IIED. http://www.iied.org/pubs/display.php?o=10586 IIED.

Oudra, B., Loudiki, M., Sbiyyaa, B., Martins, R., Vasconcelos, V., Namikoshi, N., 2001. Isolation, characterization and quantification of microcystins (heptapeptides hepatotoxins) in Microcystis aeruginosa dominated bloom of Lalla Takerkoust lake-reservoir (Morocco). Toxicon 39, 1375-1381.

Oudra, B., Loudiki, M., Vasconcelos, V., Sabour, B., Sbiyyaa, B., Oufdou, Kh., Mezrioui, N., 2002. Detection and quantification of microcystins from cyanobacteria strains isolated from reservoirs and ponds in Morocco. Environ. Toxicol. 17 (1), 32-39.

Oudra, B., Andaloussi, M.D. Vasconcelos, V.M., 2009. Identification and quantification of microcystins from a Nostoc muscorum bloom occurring in Oukaïmeden River (High-Atlas mountains of Marrakech, Morocco)

Paerl, H.W., Fulton, R.S., Moisander, P.H., Dyble, J., 2001. Harmful freshwater algal blooms, with an emphasis on cyanobacteria. Scientific World J. 4 (1), 76-113.

Paerl, H., Huisman, J., 2008. Blooms like it hot. Science 320, 57-58.

Paerl, H.W., Huisman, J., 2009. Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environ. Microbiol. Rep. 1 (1), 27-37.

Pedro, O., Correia, D., Lie1, E., Skåre, J.,, Leão, J.,Neves, L., Sandvik, M., Berdal, K.G. 2011. Polymerase chain reaction (PCR) detection of the predominant microcystin-producing genotype of cyanobacteria in Mozambican lakes. Afr. J. Biotechnol. 10 (83), 19299-19308.

Quiblier, C., Leboulanger, C., Sane, S., Dufour, P., 2008. Phytoplankton growth control and risk of cyanobacterial blooms in the lower Senegal River delta region. Water Res. 42, 1023-1034.

Sabour, B., Loudiki, M., Oudra, B., Vasconcelos, V., Martins, R., Oubraim, S., Fawzi, B., 2002. Toxicology of a Microcystis ichthyoblabe waterbloom from Lake Oued Mellah (Morocco). Environ. Toxicol. 17 (1), 24-31.

Schaedel, A., 2011. Oregon DEQ Harmful Algal Bloom (HAB) Strategy. State of Oregon Department of Environmental Quality.

Sekadende, B.C., Lyimo, T.J., Kurmayer, R., 2005. Microcystin production by cyanobacteria in the Mwanza Gulf (Lake Victoria, Tanzania). Hydrobiologia, 543, 299-304.

Sitoki, L., Kurmayer, R., Rott, E., 2012. Spatial variation of phytoplankton composition, biovolume, and resulting microcystin concentrations in the Nyanza Gulf (Lake Victoria, Kenya). Hydrobiologia, 691, 109-122.

Social Watch, 2012. Morocco: A thirsty future. National Report.

Stocks, H.S., 2013. A Survey of the Taxonomy of the Cyanobacteria from Northeast Florida, Descriptions of Novel Taxa, and an Investigation into the Factors Which Influence the Epibenthic Cyanobacterial Community. UNF Theses and Dissertations. Paper 480

Takamura, N. Otsuki, A. Aizaki, M., Nojiri, Y.,1992. Phytoplankton species shift accompanied by transition from nitrogen dependence to phosphorus dependence of primary production in lake Kasumigaura, Japan. Arch Hydrobiol, 124, 129–148.

Tendaupenyu, P., 2012. Nutrient limitation of phytoplankton in five impoundments on the Manyame River, Zimbabwe. Water SA 38 (1), 97-104.

Turton, A., 2008. The state of water resources in Southern Africa: What the beverage industry needs to know. CSIR Technical Report.

USAID, 2012. Famine Early Warning Systems Network—Informing Climate Change Adaptation Series, A Climate Trend Analysis of Burkina Faso. Fact Sheet 2012–3084.

Uz, B.M., 2007. What causes the sporadic phytoplankton bloom southeast of Madagascar?, J. Geophys. Res. 112.

Vale, P., Rangel, I.S., Silva, B., Coelho, P., Vilar, A., 2009. Atypical profiles of paralytic shellfish poisoning toxins in shellfish from Luanda and Mussulo Bays, Angola. Toxicon 53, 176-183.

Van Ginkel, C.E., 2011. Eutrophication: present reality and future challenges for South Africa. Water SA. 37 (5).

Vörösmarty, C.J., McIntyre, P.B.,Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann,C., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature. 467, 555-561.

WHO., 1998. Guidelines for drinking-water quality, 2nd ed. Addendum to Vol. 2. Health criteria and other supporting information.

WHO., 2011. Technical Brief. Technical management of cyanobacteria in drinking-water supplies: Information for regulators and water suppliers.

Willén, E., Ahlgren, G., Tilahun, G., Spoof, L., Neffling, M., Meriluoto, J., 2011. Cyanotoxin production in seven Ethiopian Rift Valley lakes. Inland Waters 1, 89-91.

Xie, L., Xie, P., Li, S., Tang, H., Liu, H., 2003. The low TN:TP ratio, a cause or a result of Microcystis blooms? Water Res. 37 (9), 2073-2080.

Yang, X., Wu, X., Hao, H., He, Z., 2008. Mechanisms and assessment of water eutrophication. J Zhejiang Univ Sci B, 9 (3), 197-209.

Zengeya, T.A., Marshall, B.E., 2007. Trophic interrelationships amongst cichlid fishes in a tropical African reservoir (Lake Chivero, Zimbabwe). Hydrobiologia 592, 175-192.

Ziervogel, G., Calder, R., 2003. Climate variability and rural livelihoods: assessing the impact of seasonal climate forecasts in Lesotho. Area, 35 (4), 403–417.

Zingone, A., Enevoldsen, H.O., 2000. The diversity of harmful algal blooms: a challenge for science and management. Ocean. Coast. Manage. 43 (8-9), 725-748.

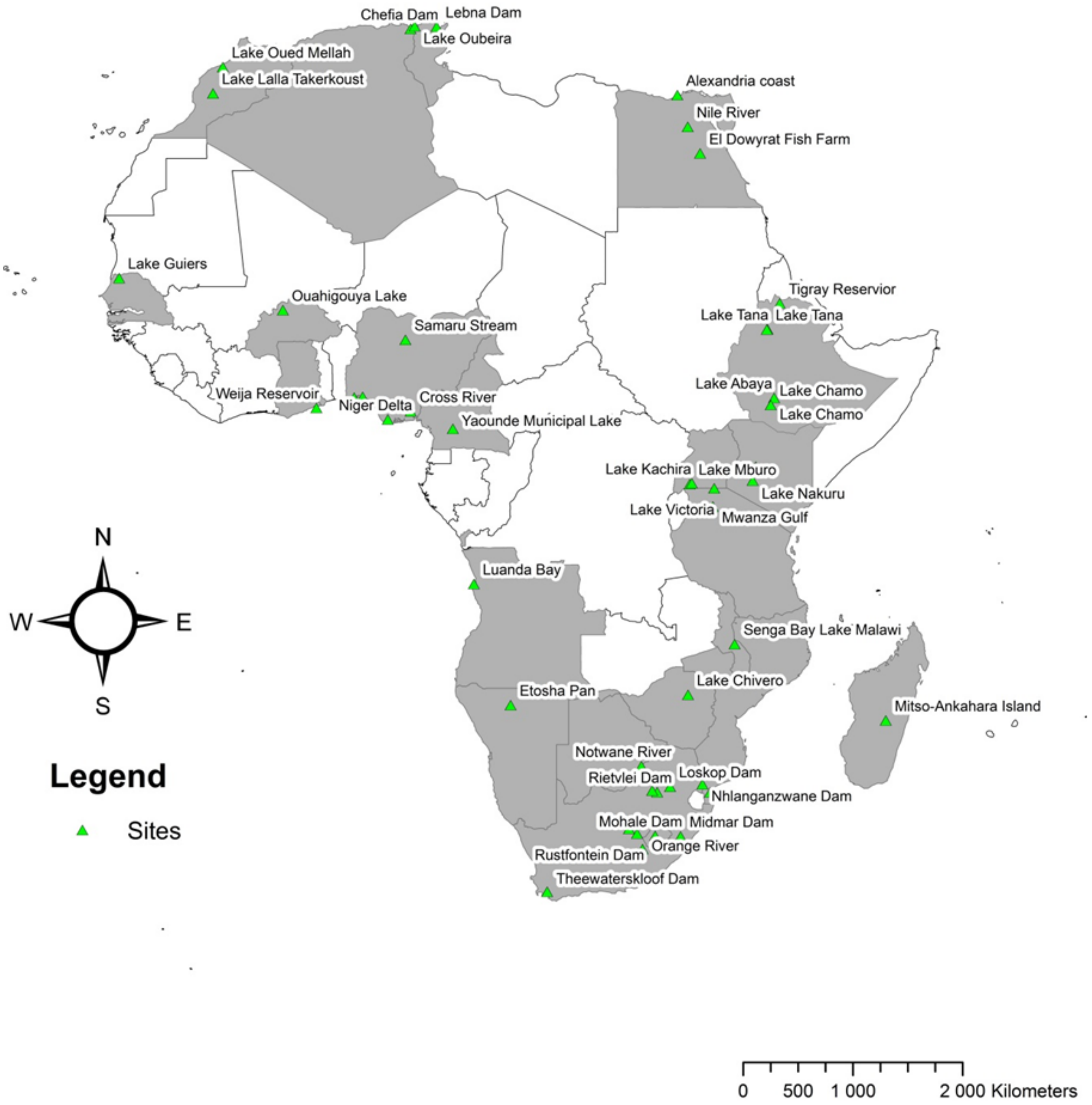
**Figure 1: Summary of areas affected by cyanobacteria blooms in Africa**

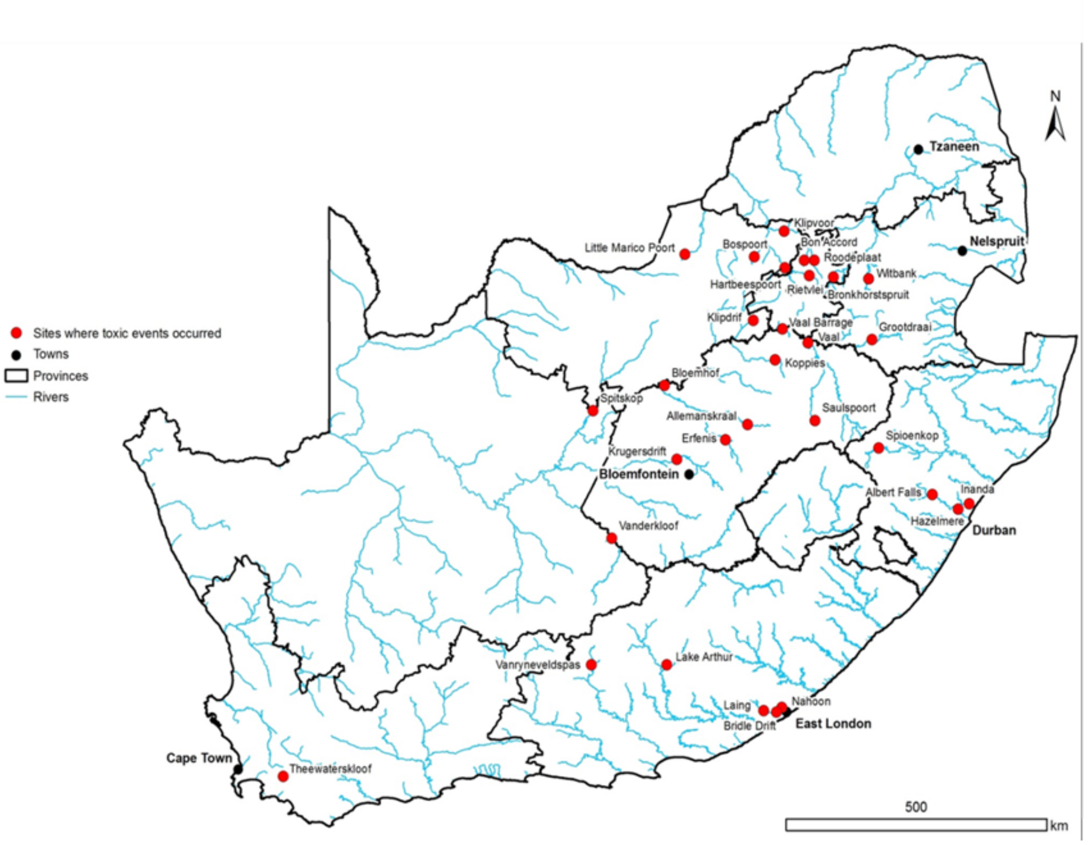
**Table 1: Brief profiles of African regions relating to water and cyanobacteria**

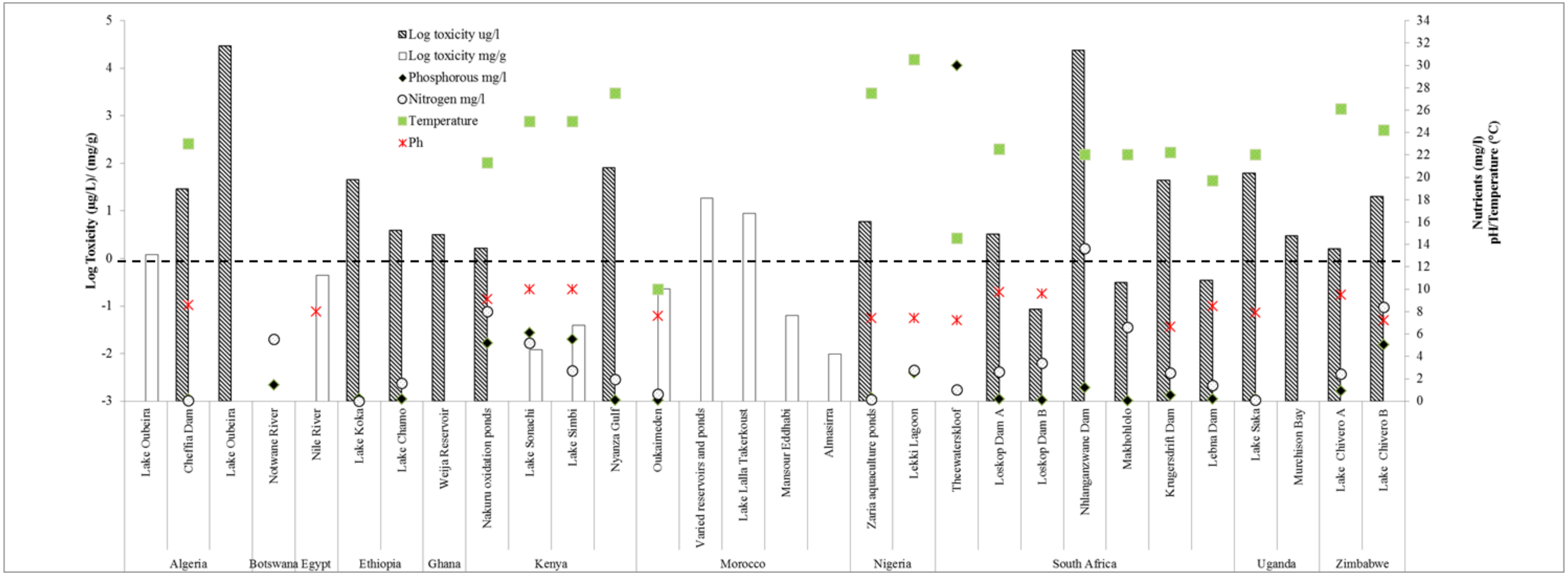
**Table 2: Overview of toxic cyanobacterial occurrences in Africa from the early 2000s**

**Figure 2: Cyanobacteria occurrences in South Africa**

**Figure 3: Nutrient concentrations (phosphorous and nitrogen), temperature and pH measurements during cyanobacterial blooms across Africa in the past decade.** The dotted line indicates toxicity of 1 mg per gram or 1 µg per litre, comparable to the other parameters. The diamond represents phosphorous, the white circles represent nitrogen, the squares represent temperature and the asterisk represents pH measurements.


Chefia Dam
Lebna Dam
Lake Oubeira
Lake Oued Mellah
Lake Lalla Takerkoust
Alexandria coast
Nile River
El Dowyrat Fish Farm
Lake Guiers
Ouahigouya Lake
Tigray Reservior
Lake Tana
Lake Tana
Samaru Stream
Lake Abaya
Lake Chamo
Lake Chamo
Weija Reservoir
Niger Delta
Cross River
Yaounde Municipal Lake
Lake Kachira
Lake Mburo
Lake Nakuru
Lake Victoria
Mwanza Gulf
N
W
E
S
Luanda Bay
Senga Bay Lake Malawi
Lake Chivero
Etosha Pan
Mitso-Ankahara Island
Legend
Sites
Notwane River
Rietvlei Dam
Loskop Dam
Nhlanganzwane Dam
Mohale Dam
Midmar Dam
Orange River
Rustfontein Dam
Theewaterskloof Dam
0
500
1 000
2 000 Kilometers


Sites where toxic events occurred
Towns
Provinces
Rivers
N
Tzaneen
Klipvoor
Little Marico Poort
Bospoort
Bon Accord
Roodeplaat
Nelspruit
Witbank
Hartbeespoort
Rietvlei
Bronkhorstspruit
Klipdrif
Vaal Barrage
Vaal
Grootdraai
Koppies
Bloemhof
Spitskop
Saulspoort
Allemanskraal
Erfenis
Spioenkop
Krugersdrift
Bloemfontein
Albert Falls
Inanda
Hazelmere
Durban
Vanderkloof
Vanryneveldspas
Lake Arthur
Laing
Nahoon
Bridle Drift
East London
Cape Town
Theewaterskloof
500
km


Log Toxicity (µg/L)/ (mg/g)
5
4
3
2
1
0
-1
-2
-3
▨ Log toxicity ug/l
□ Log toxicity mg/g
◆ Phosphorous mg/l
○ Nitrogen mg/l
🟩 Temperature
✕ Ph
Nutrients (mg/l)
pH/Temperature (°C)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Lake Oubeira
Cheffia Dam
Lake Oubeira
Notwane River
Nile River
Lake Koka
Lake Chamo
Weija Reservoir
Nakuru oxidation ponds
Lake Sonachi
Lake Simbi
Nyanza Gulf
Oukaimeden
Varied reservoirs and ponds
Lake Lalla Takerkoust
Mansour Eddhabi
Almasirra
Zaria aquaculture ponds
Lekki Lagoon
Theewaterskloof
Loskop Dam A
Loskop Dam B
Nhlanganzwane Dam
Makhohlolo
Krugersdrift Dam
Lebna Dam
Lake Saka
Murchison Bay
Lake Chivero A
Lake Chivero B
Algeria
Botswana
Egypt
Ethiopia
Ghana
Kenya
Morocco
Nigeria
South Africa
Uganda
Zimbabwe

| **African Region** | **Countries with cyanobacteria reports** | **Water access (%)** | **Rainfall (mm/yr)** |
|---|---|---|---|
| Southern | 7 | 67.7 | 721 |
| Central | 1 | 55.86 | 1757 |
| Eastern | 4 | 77.97 | 767 |
| Western | 4 | 69.42 | 1059 |
| Northern | 4 | 79.67 | 194 |
| Western Indian Ocean Islands | 1 | 83.75 | 1696 |

| Country | Water source | Year reported | Cyanobacteria | Description of occurrence |
|---|---|---|---|---|
| **Algeria** | Lake Oubeira | 2008 | *Microcystis spp* | Turtle death reports |
| | Cheffia Dam | 2007 | *Microcystis sp morphospecies* | Occurred in treatment plant |
| | Lake Oubeira | 2004 | *Microcystis sp* | First report in drinking water source |
| | Lake Oubeira | 2004 | *Cylindrospermopsis raciborskii, Microcystis spp.* | First report in freshwaters |
| **Botswana** | Notwane River | 2014 | *Merismopaedia, Microcystis, Oscillatoria spp.* | Presence of toxin producing cyanobacteria in treated sewage receiving river |
| **Burkina Faso** | Ouahigouya Lake | 2010 | *Microcystis sp* | Assessment of sub-saharan cyanobacteria strains |
| **Cameroon** | Gulf of Guinea coast | 2006 | *Phormidium, Heterocapsa, Rivularia, Trichodesmium* | Harmful cyanobacteria occurrences |
| | Yaounde Municipal Lake | 2003 | *Planktothrix mougeotii, Oscillatoria putrida,* | Cyanobacteria in a hypertrophic |

| | | | | |
|---|---|---|---|---|
| | | | *Microcystis aeruginosa* | lake |
| **Egypt** | Domestic water reservoirs | 2016 | *Microcystis aeruginosa* | Occurrence of toxic strains in domestic water storage reservoirs |
| | Nile River | 2015 | *Microcystis aeruginosa* | Microcystins in treated and untreated wastewater |
| | El-Khadra | 2014 | *Spirulina, Oscillatoria, Nostoc spp.* | Marine cyanobacteria evaluation |
| | Nile River | 2013 | *Nostoc, Microcystis* | Microcystin-producing Nostoc isolated |
| | Alexandria Coast | 2012 | *Oscillatoria, Lyngbya, Planktothrix spp.* | Benthic bloom associated with fish deaths |
| | Nile Delta | 2008 | *Microcystis wesenbergii, Microcystis aeruginosa, Synechococcus* | Assessment of hepatotoxic cyanobacteria in the Nile Delta |
| | Nile River | 2007 | *Microcystis aeruginosa* | Microcystin measurement and removal |
| | El-Dowyrat Fish farm | 2007 | *Cylindrospermopsis raciborskii* | Occurrence of toxic cyanobacteria in freshwater |

| | | | | |
|---|---|---|---|---|
| **Ethiopia** | Lake Tana | 2015 | *Microcystis aeruginosa* | Cyanotoxin production in larges |
| | Tigray Reservoir | 2011 | *Microcystis* spp | Assessment of Microcystis diversity in reservoir |
| | Lake Chamo, Abaya etc | 2011 | *Microcystis aeruginosa* | Cyanotoxin production in rift valley lakes |
| **Ghana** | Weija Reservoir | 2006 | *Anabaena flos-aquae, Cylindrospermopsis raciborskii, Microcystis aeruginosa,Planktothrix agardhii.* | Toxin producing species in drinking water reservoirs |
| **Kenya** | Nyanza Gulf | 2012 | *Microcystis spp.* | Shallow eutrophic bay in Lake Victoria |
| | Nakuru oxidation ponds | 2010 | *Microcystis, Euglena, unkown coccoid isolates* | Microcystin producers found in oxidation pond |
| | Lake Sonachi | 2005 | *Arthrospira fusiformis* | Occurrence in alkaline and saline lakes |
| | Lake Simbi | 2005 | *A. fusiformis, Anabaenopsis abijatae* | Occurrence in alkaline and saline lakes |

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| **Lesotho** | Rustfontein Dam | 2011 | *Microcystis sp.* | Microcystin L-R production during bloom |
| | Mohale Dam | 2007 | *Microcystis aeruginosa* | Toxic strains found in dam |
| **Madagascar** | Mitso-Ankaraha Island | 2007 | *Geitlerinema sp* | Cytotoxic strain found in island |
| **Morocco** | Mansour Eddhabi | 2010 | *Microcystis aeruginosa* | Microcystins in drinking water reservoirs |
| | Almasirra | 2010 | *Microcystis aeruginosa* | Microcystins in drinking water reservoirs |
| | Oukaimeden | 2009 | *Nostoc muscorum* | Microcystin producer in water source |
| **Mozambique** | Various lakes | 2011 | *Microcystis spp.* | Microcystin producing strains in lakes |
| **Nigeria** | Lekki Lagoon | 2010 | *Oscillatoria, Microcystis aeruginosa, M. flos-aquae, M.wesenbergii and Anabaena flos-aquae* | Bloom-forming strains found in lagoon |
| | Zaria aquaculture ponds | 2009 | *Microcystis, Planktothrix, Nostoc,* | Microcystins in aquaculture ponds |

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| | | | *Anabaena* | |
| **Senegal** | Senegal River delta | 2008 | *Cylindrospermopsis* | Occurrence in drinking water |
| | Lake Guiers | 2006 | *Cylindrospermopsis raciborskii, Lyngbya* | Phytoplankton assemblage analysis |
| **South Africa** | Theewaterskloof | 2015 | *Anabaena ucrainica* | Microcystin containing strain in Theewaterskloof |
| | Loskop Dam | 2014 | *Microcystis aeruginosa* | Microcystin accumulation in fish tissue after a bloom |
| | Nyala Magnesite Mine | 2014 | *Microcystis, Oscillatoria, Phormidium spp.* | Cyanobacterial found in soda pits at mine site |
| | Loskop | 2014 | *Microcystis aueroginosa* | Assessing daphnia exposed to extracellular microcystins |
| | Kruger National Park | 2010 | *Microcystis aeruginosa* | Assessment of bloom toxicity after wildlife deaths |
| | Nhlanganzwane Dam | 2009 | *Microcystis aeruginosa* | Toxigenic strains found after animal mortalities |

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|  | Makhohlolo | 2009 | *Microcystis aeruginosa* | Toxigenic strains found after animal mortalities |
|  | Krugersdrift Dam | 2009 | *Microcystis aeruginosa* | Toxic strain influence assessment on phytoplankton diversity |
|  | Orange River | 2007 | *Cylindrospermopsis raciborskii* |  |
| **Tunisia** | Hot springs | 2013 | *Oscillatoria* spp. | Asessment of thermophillic cyanobacteria |
|  | Lebna Dam | 2008 | *Microcystis* spp. | *Microcystis* morphospecies in dam |
|  |  | 2008 | *Microcystis* spp., *Oscillatoria tenuis* | Assessment of seasonal occurrence in dam waters |
| **Uganda** | Lake Saka | 2011 | *Microcystis, Anabaena, Planktothrix* | Microcystin production in Ugandan freshwater lakes |
|  | Murchison Bay | 2009 | *Microcystis* spp. | Water-related diseases and cyanotoxin trend assessment |
| **Zimbabwe** | Lake Chivero | 2006 | *Microcystis aeruginosa, M. wesenbergii* | Cyanotoxins found in drinking water |

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| Lake  Chivero | 2006 | *Microcystis aeruginosa* | Eutrophic drinking water reservoir |