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Literature Review

Contamination Level of Water Bodies by Cyanotoxins in Africa

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Abstract

This review of the bibliography devoted exclusively to work notifying the production of cyanotoxins in Africa, reveals 17 African countries where the production of cyanotoxins on water bodies is proven. More than half (55 per cent) of publications are concentrated in Southern and Eastern Africa and none in Central Africa. The highest concentrations of cyanotoxins were also detected in southern and central Africa. Microcystins are the most analyzed and detected toxins. However, no publication has mentioned saxitoxin.

Keywords: *Cyanotoxins; Africa; Microcystins*

Introduction

Water (blue gold), a fluid good at the heart of ecosystems, is a non-substitutable vital resource and a symbol of the fragility of life [1]. Access to drinking water is an important challenge for the development of different sectors of a country's economy and for improving the living conditions of households [2]. The global water crisis finds a particular dimension in the African context because it is a vital issue whose magnitude is difficult to appreciate. Environmental impacts are then largely obscured by the urgency of meeting immediate vital needs [3]. Thus, the environments that provide most of the drinking water in Africa are disturbed by climate change and changes in land use due to strong and increasing anthropogenic pressures [4]. Some of the factors attributed to this anthropogenic activity are the different sources of water pollution that cause their enrichment with nutrients (nitrogen and phosphorus) leading to the uncontrolled development of algae, indicating an advanced state of degradation of water quality [5,6]. In addition, the evolution of human activities is directly correlated with the increase in the average amount of carbon dioxide (CO_2) present in the atmosphere, which also results in the development of *Cyanobacteria* blooms in freshwater [7]. *Cyanobacteria* are single-celled photosynthetic organisms that are located at the transition of the phylum of bacteria and that of algae [8]. When environmental conditions are favorable, these organisms can multiply at very high-speed forming aquatic blooms also called blooms or blooms. They then became one of the major environmental and health concerns because of their ability to form these blooms and the toxic nature of many genera [9,10]. Cyanotoxins are divided into three main groups according to their chemical structure: cyclic peptides, alkaloids, and lipopolysaccharides and into five groups according to the mechanism of toxicity for vertebrates, cyanotoxins are classified into hepatotoxins (microcystins, nodularins), neurotoxins (toxoid-a, homoanatoxin, saxitoxin), cytotoxins (cylindrospermopsins), dermatotoxins (lyngbyatoxin) and irritant toxins (lipopolysaccharides) [11]. Microcystins (MCs) with more than 250 variants, are the most sought-after cyanotoxins in the wild [12]. Cyanotoxins have potentially lethal effects on humans and animals exposed to contaminated water [13]. And in the African context, the problem of water contamination by these toxins has a particular dimension, because water is generally consumed by residents without prior treatment, especially in rural areas [14]. The study of cyanotoxins in Africa became crucial.

Thus, the study of *Cyanobacteria* in Africa is recent. Thus, most of the work done on *Cyanobacteria* focuses on their inventory in different water bodies [15-18]. Furthermore, a few studies have included toxin analysis on lakes or reservoirs whose water is used for portable water supply [19-22]. However, some countries are well advanced in this theme, notably those of North Africa, Nigeria, Kenya, and South Africa [23-26]. This review aims to provide an overview of studies conducted on water contamination by cyanotoxins in Africa.

Water bodies

This literature review considered theses and articles published on the work conducted in Africa on cyanotoxins in water bodies. This study was conducted from Google scholar and PubMed.

Most works on *Cyanobacteria* have primarily focused on their inventory in different water bodies [16-18,27]. Moreover, some studies have included toxin analysis on lakes or reservoirs whose water is used for portable water supply [19,20,22,28] (Figure 1). Thus, 55% of the studies were carried out in South and East Africa against 22.5% for each of the zones of North and West Africa (Table 1). The detection, identification and quantification of different types and variants of cyanotoxins is relatively expensive and requires the application of complex and varied analytical methods, training of the personnel in charge and a lot of time [29]. This could be one of the explanations for the high rate of studies carried out in South and North Africa, which are more developed areas than the rest of Africa. South Africa has a long and proud history of research on *Cyanobacteria* and cyanotoxins with several pioneering advances in this field being attributed to South African researchers [30]. The other reason could be the availability of water in these parts of Africa. Southern and northern Areas of Africa are arid territories where rainfall is scarce [3,31].

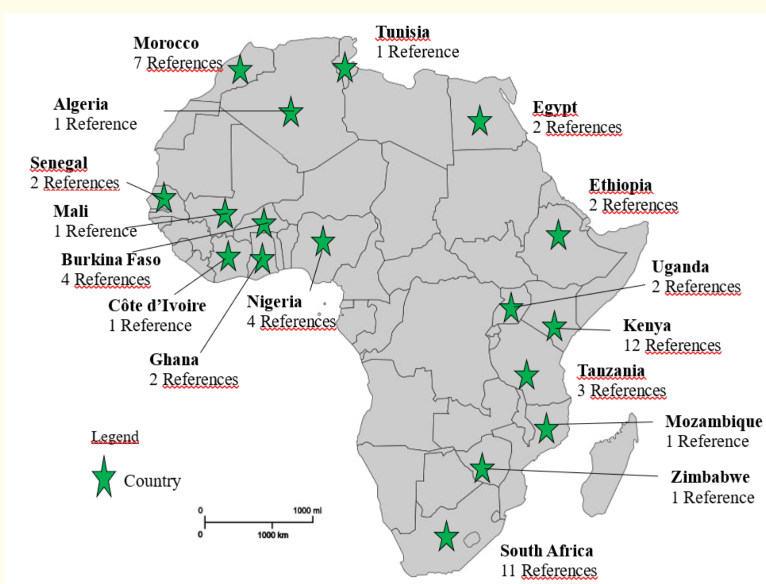

Figure 1: *Summary of areas affected by cyanotoxins in Africa.*

Zone	[MCs] µg/L	[ANTX] µg/g	[NOD] ng/L	[CYN] ng/L	[STX]	Number articles	Percentage %
Northern Africa	0.4-3240	-	-		-	13	22.5
Western Africa	0-8.73	0-1.9	-		-	13	22.5
Southern and Eastern Africa	0-124460	0-1260	0-10.4	0-12.2	-	32	55

Table 1: *Summary of cyanotoxin types quantified by area in Africa.*

Water bodies are more sensitive to anthropogenic pressures correlated with the consequences of global warming, hence the eutrophication of these environments. Contrary to popular belief, West African countries, including those in the Sahel, do not lack water [32].

Microcystins are the most studied and detected type in all studies conducted while toxoid-a, nodularin and cylindrospermopsin have rarely been detected. No article, however, mentions the detection of saxitoxin.

Northern Africa

Cyanotoxins contaminations of Maghreb water bodies is well documented (Table 2). Detection methods are diverse and modern. Researchers use biological methods like bioassays or biochemical methods like ELISA methods. They have also used chromatographies, spectrophotometries or moleculars biologies methods [23,33-35]. The highest amount of toxins in the waters is 4100 µg/g dry weight dosed in sediments of an irrigation canal and in the Nile in Egypt [36].

Western Africa

The studies conducted about *Cyanobacteria* largely concerned their identification in reservoirs and streams [16,18,27]. Some work, however, has started from species identification to the identification and determination of toxins (Table 2). These are about the work of Adicco., *et al*. [19]in Ghana, Coulibaly-Kalpy., *et al*. [21] in Côte d'Ivoire, Gugger and Couté, [22] in Burkina Faso and Berger, [18] in Senegal. In this part of Africa, Nigeria dominates by the diversity of work on *Cyanobacteria* [20,24,37,38]. Most of the water bodies studied contain *Cyanobacteria* and cyanotoxins. The highest concentration of these toxins was recorded in Ghana with 8.73 µg/L [19] followed by Côte d'Ivoire with 8.5 µg/g dry weight [28].

Zone	Site	Toxin	Concentration	Method	Authors
Northern Africa	Oubeira Lake, Algeria	MCs	3 - 29.163 µg /L	MALDI-TOF	Nasri., *et al*. 2004
	Nile River, Egypt	MCs	1.1–3.6 µg/L	ELISA	Mohamed., *et al*. 2015
	Nile River, Egypt	MCs	0.039- 0.092 µg/g	ELISA	Mohamed., *et al*. 2007
	Irrigation canal and Nile River, Egypt	MCs	1.6-4.1 mg/g	ELISA; HPLC	Mohamed., *et al*. 2006
	Nile River, Egypt	MCs	0.4 - 0.78 µg/L	ELISA	Mohamed and Carmichael 2000
	Reservoirs of Tetouan, Morocco	MCs	-(Screening)	GC-MS	Ouhsassi., *et al*. 2021
	Lalla Dam Takerkoust, Morocco	MCs	759-3240 µg.g^{-1} mg^{-1}PS	HPLC-PDA; ELISA	El Gazhali., *et al*. 2011

	Oukaïmeden River, Morocco	MCs	90 µg /g MC-LR equiv	HPLC-PDA	Oudra., *et al*. 2009
	El Kansera Reservoir, Morocco			Bioassays	Naji., *et al*. 2005
	Reservoirs and ponds, Morocco	MCs	26.8 - 1884 µg/g; 2.2 - 994 µg/g	HPLC-PDA; ELISA	Oudra., *et al*. 2002a
	Reservoirs, Morocco	MCs	0,37 - 496 µg/g	CLHP-DBP; ELISA	Oudra., *et al*. 2002b
	Reservoir of Oued Mellah, Morocco	MCs	0.79 - 5.4 µg/g	HPLC-PDA; ELISA	Sabour., *et al*. 2002
	Lebna dam, Tunisia	MCs	0.353 - 0.542 µg/L	LC/ESI–MS/MS, PP2A	El Herry., *et al*. 2008
	Nombamba and Dissin Lakes, Burkina Faso		0.55 and 0.73 µg total MC/mg	MS ; PP2A	Cecchi., *et al*. 2009
	Reservoirs and watersheds, Burkina Faso	MCs	0 - 0.73 µg/mg	MS-PP2A	Gugger and Couté 2006
	Loumbila Reservoir, Burkina Faso	MCs	70 µg /L	ELISA	Cecchi., *et al*. 2004
Western Africa	Bandama River, Comoé River, Kan Reservoir, Aghien Lagoon, Côte d'Ivoire	MCs	0 - 8,5 µg/g PS	HPLC, ELISA	Coulibaly, 2015
	Reservoirs, Ghana	MCs	8.73 µg /L	HPLC	Adicco., *et al*. 2017
	Weija and Kpong Reservoirs, Ghana	MC-RR	0.03 - 3.21 µg /L	HPLC	Adicco., *et al*. 2006
	Bamal River, Mali	MCs, Antx-a	mcyA, anaC	Electrophorese, PCR	Moreira., *et al*. 2021
	Senegal River, Basin and rivers in Burkina Faso	MC-LA, Antx-a	2,6 and 1,8 µg eq MC-LR/mg	ESI-MS, MS/MS, PP2a	Thomazeau, 2010
	Guiers Lake, Senegal	Antx-a, MCs	1.9 µg/mg	Bioassays, HPLC-ESI-MS, MS/MS	Berger 2005
	Zaria Water Source, Nigeria	MCs	0 - 3.16 µg /L	ELISA	Chia and Kwaghe 2015
	Wells of Kano, Nigeria	MCs	-	HPLC	Indabawa 2009
	Aquaculture ponds in Zaria, Nigeria	MCs	0.6 - 5.89 µg /L	ELISA	Chia., *et al*. 2009
	Niger Delta, Nigeria	MCs, ATX, STX, CYN		Mouse bioassay	Odokuma and Isirima 2007

Table 2: *Work done on cyanotoxins in North and West African water bodies.*

Southern and Eastern Africa

Lake Victoria and the Rift Valley lakes are the most studied sites in southern Africa [39-46]. Dams and reservoirs are the most studied sites in South Africa [26,47,48]. The proliferation of *Cyanobacteria* in water bodies in this part of Africa is a matter of concern [49]. Almost all the lakes are contaminated. Table 3 summarizes the work done on *Cyanobacteria* in Africa.

Zone	Site	Toxin	Concentration	Methods	Authors
Eastern and Southern Africa	Legedadi Reservoir, Addis Ababa, Ethiopia	MCs	61.63 - 453.89 µg/L (ExtraC) and 112.34 - 189.29 µg/L (IntraC)	LC–MS/MS	Habtemariam., *et al.* 2021
	Lakes of the Rift Valley, Ethiopia	MCs, CYN	1.3 - 48 µg $L^{-1;0}$	HPLC, ELISA, MS	Willen., *et al.* 2011
	Nyanza Gulf, Kenya	MCs	0.009 - 12.302 µg/L (Household); 0.151 - 13.813 µg/L (Lake)	PP2A	Otoigo., *et al.* 2020
	Naivasha Lake, Kenya	MCs	< 0.1 µg/L	ELISA	Raffoul., *et al.* 2020
	Navaisha Lake, Kenya	MCs	0.001 - 0.041 mg/L	HPLC-PDA, LC–MS/MS	Krienitz., *et al.* 2013
	Pond of Nakuru, Kenya	MCs	551.08 µg/mg	HPLC-PDA; MALDI-TOF	Kotut., *et al.* 2010
	Bogoria Lake, Kenya	MCs, ATX-a	1.6 - 19800 µg/g; 1260 µg/g	HPLC-PDA; MALDI-TOF	Kotut., *et al.* 2006
	Sonabi and Simbi Lakes, Kenya	MCs, ATX-a	1.6 - 39 µg/g; 0 - 2 µg/g	HPLC	Ballot., *et al.* 2005
	Lakes of the Rift Valley, Kenya	MCs	0.18 - 0.39 µg /L		Ndetei and Muhandiki 2005
	Mwanza Gulf, Kenya	MCs	0	HPLC-PDA	Sekadende., *et al.* 2005
	Nairobi Reservoirs, Kenya	MCs	2.85 µg/L	ELISA	Mwaura., *et al.* 2004
	Lakes of the Rift Valley, Kenya	MCs ; ATX-a	155 - 4593 µg/g; 9 - 223 µg/g	HPLC	Ballot., *et al.* 2004
	Baringo Lake, Kenya	MCs ; ATX-a	310 - 19800 µg/g; 270 - 1260 µg/g	HPLC	Ballot., *et al.* 2003
	Bogoria Lake, Kenya	MCs ; ATX-a	221 - 845 µg/g; 10 - 18 µg/g	HPLC-PDA; MALDI-TOF	Krienitz., *et al.* 2003
	Victoria Lake, Kenya	MCs	39.15 - 41.4 µg/g	HPLC-PDA, MALDI-TOF	Krienitz., *et al.* 2002
	Pond (crop), Mozambique	MCs, NOD, ATX	0	HPLC, ELISA	Mussagy., *et al.* 2006
	Water bodies in Uganda and Kenya	MCs	-	ELISA, MALDI-TOF	Haande., *et al.* 2007
	Lakes of Kenya, Uganda and Tanzania	MCs, ATX-a	10 - 845 µg/g; 1 - 18 µg/g	HPLC-PDA; MALDI-TOF	Krienitz., *et al.* 2005
	Victoria Lake, Ukerewe district, Mwanza Tanzania	MCs; CYN; NOD	2.3 - 13 ng/L (MCs); 3.6 - 12.2 ng/L (CYN); 10.4 ng/L (NOD)	UPLC-MS/MS	Mchau, 2020

	Alkaline lakes, Tanzania	Crudes extracts of *Cyanobacteria*	DL_{50} = 1 mg	Mouse bioassay	Lugomela., *et al*. 2006
	Recreational pond of Cape Town and Mpumalanga lagoon, South Africa	CYN; MCs	Pks; mcyE	PCR	Moreira., *et al*. 2021
	Musina Raw Water Supply and Limpopo River Sediment, South Africa	MCs (LR, YR)	6.60 - 46.78 µg/L	HPLC-PDA	Gumbo., *et al*. 2020
	Aquadams in Itsani Matieni, Limpopo, South Africa	MCs	2.20 - 732.58 µg/L	(HPLC)-UV	Gumbo and Tshifura, 2018
	Vaal Reservoir, South Africa	MCs	0.1 - 5 µg/L	ELISA	Recknagel., *et al*. 2017
	Hartbeespoort dam, South Africa	MCs	3.6 µg /L	LC-MS, HPLC	Ballot., *et al*. 2014
	Vaalkop dam and treatment plant, Rustenburg, South Africa	MCs	0.18 - 1.543 µg /L	ELISA	Bezuidenhout, 2013
	Hartbeespoort dam, Roodeplaat, South Africa	MCs	217 - 3200 µg /L	ELISA	Conradie and Barnard 2012
	Nhlanganzwani, Mpanamana, Makhohlola, and Sunset dams, South Africa	MCs	0.1 - 124.46 mg/L	ELISA	Masango., *et al*. 2010
	Nhanganzwane Dam and Makhohlolo Dam, South Africa	MCs	2.1 - 23718 µg/L; 0.317 - 0.581 µg/L	ELISA	Oberholster., *et al*. 2009
	Hartbeespoort dam, South Africa	MCs	3.673 - 86.083 mg/L; 2.993 - 54.900 mg/L	ELISA, PP2A	Masango., *et al*. 2008
	Water containers, Vhembe, South Africa	MCs	0.36 µg/L	ELISA	Fosso-Kankeu., *et al*. 2008
	Chivero Lake, Harare, Zimbabwe	MCs	0.2 - 4.2 µg/L	ELISA	Mhlanga., *et al*. 2006

Table 3: *Work done on cyanotoxins in southern and eastern African water bodies.*

Recapitulation

Thomazeau [50] made a first review of the work carried out in Africa from 1976 to 2010. He referenced 50 works conducted in 12 countries. Only 12 publications described for cyanotoxin production in Africa. In 2016, a similar study conducted by Ndlela., *et al*. [49], mentioned 21 countries in Africa where *Cyanobacteria* blooms were reported. Of the 21 countries, 11 reported cyanotoxin production. The present study, devoted exclusively to work reporting the production of cyanotoxins in Africa, reveals 17 African countries where the production of cyanotoxins on water bodies is proven. We note that the study of the toxicity of *Cyanobacteria* is booming. Although studies on this subject are increasingly numerous in southern and eastern Africa and in North Africa, this theme is increasingly studied in West Africa. However, as reported by Ndlela., *et al*. (2016), we note no publications from Central Africa on cyanotoxins.

Conclusion

To conclude, the study of cyanotoxins has been sparked for the most part around the world, by the occurrence of diseases or even mortalities of animals or people using water sources for their vital needs. These cases of problems related to *Cyanobacteria* are rare or very little recorded in Africa. This could be one of the causes of the low number of works on this subject. In addition, technical difficulties related to the analysis of cyanotoxins would be another cause of Africa's delay in the study of cyanotoxins. Nevertheless, the studies that have been able to hold there have detected mostly microcystins and this work is concentrated for the vast majority in South Africa and around Lake Victoria. The highest concentrations were quantified in this area marked by eutrophication of water sources. Today, economic and demographic development and global warming contribute to the eutrophication of water bodies and the occurrence of *Cyanobacteria* blooms. Integrated management of water bodies with regular publication of data will make it possible to react upstream to avoid the health risks associated with the blooms of these phytoplankton organisms.

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