One Health

Human, Animal, and Environment Triad

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6
Cyanotoxin in Hydrosphere and Human Interface

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6.1 Introduction

Cyanobacteria are ubiquitous, prokaryotic, and the only bacteria capable of photosynthesis. The phylum Cyanobacteria comprises about 150 genera and nearly 2000 species, among which 46 are identified as toxigenic (Magana Arachchi and Wanigatunge 2020). Cyanotoxins, a secondary metabolite produced by cyanobacteria, threaten humans, animals, and the environment. The hydrosphere or the aqua sphere is the total water on the earth in any form, as vapor, liquid, and solid with its dissolved constituents. One Health is a trio that brings humans, animals, and the environment they share as one unit (Figure 6.1). The chapter will outline how cyanotoxins in hydrosphere cause health complications within the "One Health Triad" practice.

6.2 Cyanobacteria and Cyanotoxins

6.2.1 Cyanobacteria and Cyanotoxins

Cyanobacteria are an ancient group of prokaryotic organisms that are more than 3500 million years old and prokaryotic. They are rich in natural products and produce many chemical compounds with different chemical structures as secondary metabolites. Cyanobacteria are microscopic and exhibit high variability in their morphology. They can exist as single cells, in groups, as colonies, or in filamentous forms. They possess specific characteristics of algae, such as cell wall structure and pigments. Hence earlier, they were called blue-green algae. Cyanobacteria are capable of growing in diverse environments, including terrestrial or aquatic habitats. These bacteria can survive under low-light conditions with the help of their accessory pigments, specially phycocyanin, phycobilins, and phycoerythrin.

The favorable environmental conditions and nutrient availability enhance cyanobacteria's proliferation, leading to cyanobacterial blooms (Weralupitiya et al. 2022). They occur naturally in most surface waters in low to moderate numbers. Most of these bloom formers can produce cyanotoxins (Table 6.1). Whether these toxins cause adverse health issues will depend on their genetic composition and the cyanobacterial biomass (Ibelings et al. 2021).

Cyanotoxin production is not limited to freshwater systems, but the highest cyanotoxin levels have been reported from algal blooms and scums in freshwater ecosystems (Benayache et al. 2019; Weralupitiya et al. 2022). Most of the time, the cyanotoxins are kept within the live cells (intracellular). However, both live and dead cyanobacterial cells could release the toxins into the aquatic environments. Certain cyanobacteria, such as *Cylindrospermopsis*, naturally excrete the toxin cylindrospermopsin, into waters. In contrast, others release the toxins when their cell walls rupture, or encounter any stress, or when the cell dies.

These cyanotoxins are hazardous to humans, animals, and the environment. Major cyanotoxins, including microcystins (MCs), cylindrospermopsin (CYN), anatoxins, saxitoxins, lyngbyatoxins, nodularins (NODs), aplysiatoxin, lipopolysaccharides, can be grouped according to their chemical structure (Table 6.1). Different genera of cyanobacteria can produce one single cyanotoxin. Microcystins are produced by multiple cyanobacteria genera, including *Microcystis*, *Dolichospermum* (previously *Anabaena*), *Planktothrix*, *Nostoc*, *Oscillatoria*, and *Anabaenopsis* (Figure 6.2) (Filatova et al. 2021). Microcystins are seven amino acid peptide molecules that contain a characteristic Adda moiety [(2*S*,3*S*,4*E*,6*E*,8*S*,9*S*)-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca 4,6-dienoic acid] or its derivatives. By 2019, around 279 different microcystin isoforms had been identified (Bouaïcha et al. 2019). But the number reached 300 by 2021 (Jones et al. 2021). Cylindrospermopsin is a cyclic guanidine alkaloid mainly produced by freshwater cyanobacteria; *Cylindrospermopsis*, *Anabaena*, *Aphanizo*menon *flos-aquae*, and many other genera. In addition, the other genera *Lyngbya*, *Oscillatoria*, and *Phormidium* can also produce toxins. Mostly, as these are benthic cyanobacteria, they can release toxins when rising to the surface, being attached to the bottom, or while dispersed in the water. *Nodularia*, which is mainly present in marine systems, produces nodularin. This cyclic non-ribosomal pentapeptide cyanotoxin has been identified as a potent toxin affecting the health of humans, wild animals, and the environment. A variety of cyanobacterial species can produce more than one cyanotoxin; *Anabaena* species, for example, produce microcystin, cylindrospermopsin and anatoxins.

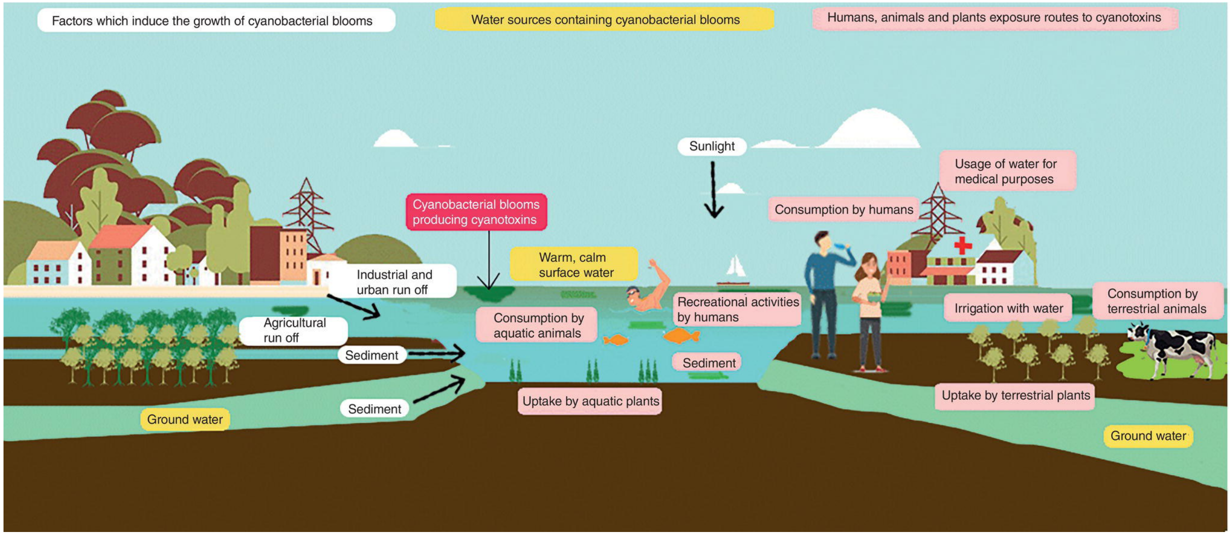
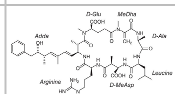
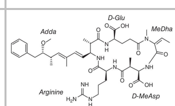
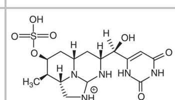
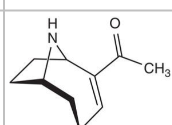
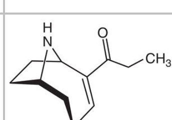
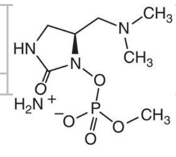
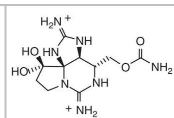
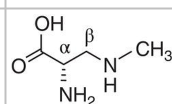


Figure 6.1 A schematic representation of the fate of cyanotoxin in the environment: a growing threat to human and animal health.

Table 6.1 Summary of common cyanotoxins, chemical structures, affecting organs, and producing genera.

Name of cyanotoxin	**Structure**	**Affecting organs**	**Producing genera**	**References**
Microcystins		Lungs, liver, immune system, gastrointestinal tract, cardiovascular system	*Dolichospermum*, *Anabaenopsis*, *Aphanocapsa*, *Arthrospira*, *Hapalosiphon*, *Microcystis*, *Nostoc*, *Oscillatoria*, *Planktothrix*, *Snowella*, *Woronichinia*, *Aphanizomenon*, *Limnothrix*, *Phormidium*	Kubickova et al. (2019), Cao et al. (2019), Abdallah et al. (2021)
Nodularins		Lungs, liver	*Nodularia*	Kubickova et al. (2019)
Cylindrospermopsin		Lungs, liver, kidney, immune system, gastrointestinal tract	*Dolichospermum*, *Aphanizomenon*, *Cylindrospermopsis*, *Raphidiopsis*, *Umezakia*, *Lyngbya*, *Planktothrix*	Kubickova et al. (2019), Abdallah et al. (2021)
Anatoxin-a		Nervous tissue, brain	*Dolichospermum*, *Oscillatoria*, *Cylindrospermum*, *Aphanizomenon*	Kubickova et al. (2019), Abdallah et al. (2021)
Homoanatoxin-a		Nervous tissue, brain	*Phormidium*, *Raphidiopsis*	Kubickova et al. (2019)
Anatoxin-a(s)		Nervous tissue, brain	*Dolichospermum*	Kubickova et al. (2019)

Name of cyanotoxin		**Affecting organs**	**Producing genera**	**References**
Saxitoxin		Nervous tissue, brain	*Dolichospermum*, *Aphanizomenon*, *Cylindrospermopsis*, *Lyngbya*, *Planktothrix*, *Raphidiopsis*, *Fischerella*, *Geitlerinema*, *Scytonema*	Meriluoto et al. (2017), Abdallah et al. (2021)
β-*N*-methylamino-l-alanine		Nervous tissue	*Nostoc, Trichodesmium, Synechococcus, Fischerella*	Meriluoto et al. (2017)

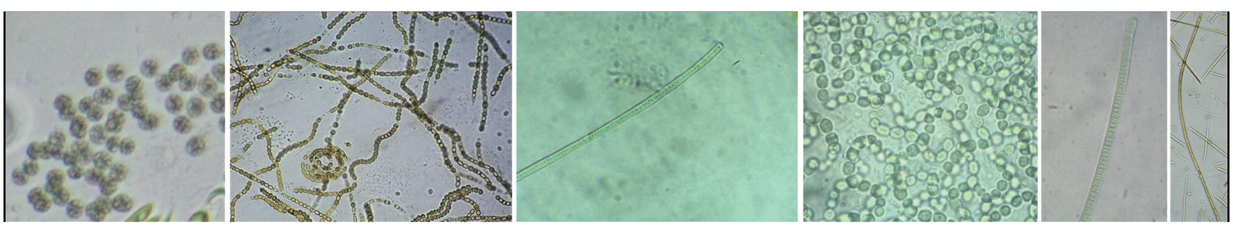


Figure 6.2 Micrographs showing microcystin producing cyanobacteria: (a) *Microcystis* sp., *Dolichospermum* sp. (previously *Anabaena*), *Planktothrix* sp., *Nostoc* sp., *Oscillatoria* sp., and *Anabaenopsis* sp.

Certain cyanobacteria, during optimum conditions, regulate their buoyancy to stay in surface waters or pursue the bottom of the water bodies. The ability to passage through the water column is a plus point for cyanobacteria over other microorganisms that contest for nutrients and light. In addition, their floatation capacities (due to gas vesicles) allow scum-forming cyanobacteria (e.g. *Microcystis* spp.) to occupy the first centimeters of the water column. Floating cyanobacteria, such as *Anabaena* and *Microcystis*, may drift upward when mixing is weak and accumulate in dense surface blooms (Figure 6.3). Benthic cyanobacteria, such as *Lyngbya*, *Oscillatoria*, and *Phormidium*, also produce cyanotoxins and, therefore, may be hazardous if they detach and rise to the surface or disperse in the water.

Figure 6.3 Photographs showing dense cyanobacterial blooms in surface waters of Lake Beria and Gregory Lake, Sri Lanka.

6.2.2 Occurrence of Cyanobacteria in the Hydrosphere

Scientific studies on the ecology and fate of cyanotoxins in temperate freshwater environments are abundant, whereas limited studies have been reported from humid tropics. A review article by Svirčev et al. (2019) reported 1118 documentations of major cyanotoxins in 869 freshwater ecosystems from 66 countries worldwide, with microcystin being the most commonly detected. They reported ~183 recorded cyanotoxin poisonings in humans and animals. Globally, cyanobacteria have been recorded in many aquatic environments, whether fresh, marine, or brackish. In aquatic environments, cyanobacteria occur in diverse habitats: suspended in dispersed form or as aggregates in the water, on the water surface, on the bottom sediment, or attached to shoreline rocks, sediments, and plants (Meriluoto et al. 2017). According to the literature, most studies on cyanobacteria and cyanotoxins were conducted by developed countries, while certain countries did not possess any data on the said issue (Svirčev et al. 2019).

During seasonal studies, microcystins and anatoxin-a have been frequently reported from the countries in Europe, spanning from the United Kingdom, Poland, Italy, Poland, Czech Republic, Germany, Russia, France, and the Netherlands (Filatova et al. 2020; Hartnell et al. 2020).

There are many reports about substantial hazards triggered by the moving cyanobacterial blooms from streams to rivers, estuaries, and beaches (Camacho-Munoz et al. 2021). The shellfish and other animals accumulate the cyanotoxins released by these blooms and potentially transfer those toxins into the food web. A study by Camacho-Munoz et al. (2021) mimicking the coastal environment within the laboratory has shown the uptake of the two cyanotoxins, microcystins and nodularins, getting into mussels.

Officially launched in 2016 by the United States and its federal partners, the One Health Harmful Algal Bloom System (OHHABS) is a surveillance system. The system collects information to help Centers for Disease Control and Prevention (CDC) and their partners understand Harmful Algal Blooms (HABs) and prevent humans and animals from getting ill. OHHABS of the United States (18 States of the US) in their report presented 421 harmful cyanobacterial bloom occurrings. Human illnesses included 389 cases, while animal diseases records counted 413 cases. The reporting period was from 2016 to 2018. According to the report, the majority happened from May to October, numbering 413. Among the recorded, 90% were from freshwater bodies. Human and animal illnesses primarily occurred from June to September, numbering 378 (98%), and from May to September, it was 410, which is 100% (Roberts et al. 2020).

6.2.3 Impacts of Climate Changes on Cyanobacterial Occurrence in the Hydrosphere

The prevalence of cyanobacteria is increasing in freshwaters due to climate change. The direct sunlight, rise in water temperatures, pH changes due to biological activities, heavy rainfalls, and flooding are some of the physical parameters that influence the cyanobacterial bloom formation. According to a recent review (Moreira et al. 2022), the effects of climatic changes have been more studied in marine systems. Still, they discussed the factors such as an increase in temperature or global warming and gales accompanying substantial rainfalls that facilitated the cyanobacterial distribution worldwide. In temperate regions, certain cyanotoxin-producing species could be observed in the lakes in the early summer. In contrast, certain others occurred in late summer, when temperatures rose above 20 °C. However, there are records of some cyanobacteria's ability to bloom even in winter by withstanding the cold weather.

A study conducted in Fehérvárcsurgó reservoir in Hungary describes the presence of *Aphanizomenon flos-aquae, Microcystis flos-aquae, Microcystis wesenbergii, Cuspidothrix issatschenkoi, Dolichospermum fos-aquae*, and *Snowella litoralis* in the reservoir. They observed histopathological changes in the gills and kidney tissues of the fish. They witnessed more damage in the summer months, correlating that to increased cyanobacterial biomass and the adverse impact on the ecosystem (Drobac Backović et al. 2021).

According to published data, environmental pressures exerted on ecosystems are the decisive factor in population dynamics and the toxicity of cyanobacterial blooms. Temperature stratifications influence cyanobacterial bloom formation and its accumulation as a surface scum. However, some other lake characteristics, including turbidity of the water, water mixing due to winds, water stagnation, and the nature of the water column, might influence the bloom development or get dissolved (Ibelings et al. 2021).

6.2.4 Impacts of Anthropogenic Activities on Cyanobacterial Occurrence in the Hydrosphere

According to a recent WHO document, primary anthropogenic sources that release nutrients such as nitrogen (N) and phosphorus (P) into water bodies are agricultural runoffs, sewage, and municipal wastewaters (WHO 2020a). These wastes are generated by people while engaged in their daily activities, domestically or during their occupations. Fertilizers, pesticides, and the excretory releases of farming animals contribute to the waste generated due to agricultural activities. The population growth and urbanization have also led to a rapid rise in human activities, releasing a large amount of waste and polluting the environment. All these wastes could be directly dumped or transported via different routes to water bodies, making the aquatic systems rich with nutrients and facilitating the global occurrence and spreading of cyanobacteria.

Cyanobacteria thrive in eutrophic lakes and ponds with phosphorus concentrations >50 µg/l. Theoretically, any nutrient could be limiting, but practically, the two macronutrients P in soluble form or as total, and, in some cases, N is decisive for the amount of cyanobacterial biomass that can occur in a particular water body (Chorus and Zessner 2021). Considerable cyanobacterial biomasses can often be found in mesotrophic ecosystems when the total phosphorus concentrations are between 20 and 50 µg/l. The *Planktothrix rubescens* growing in deep sub-alpine lakes is one such example (Humbert and Fastner 2017).

In general, many physicochemical and biotic factors and processes are recognized as influencing the population dynamics of cyanobacteria and their vertical and horizontal distribution in water bodies (Humbert and Fastner 2017).

6.3 Modes of Human Exposure to Cyanotoxins and Illnesses Associated with Cyanotoxins

6.3.1 Modes of Human Exposure to Cyanotoxins

Eutrophication paves the way for harmful cyanobacterial blooms, enhancing the risk of surface freshwater contamination. It causes significant health issues in humans and animals.

Recently WHO-updated guideline values have been finalized for the four cyanotoxins: microcystins, cylindrospermopsins, anatoxin-a, and saxitoxins. The previous WHO guideline value for total microcystins-LR (MC-LR) in drinking water is 1 µg/l. However, the MC-LR value and the total microcystins' content are also considered in the new update. The value for a lifetime is 1 µg/l and for short-term events, 12 μg/l in drinking water (WHO 2020a). Additionally, threshold values for cylindrospermopsin, anatoxin-a, and saxitoxins are now also taken into account, with values of 3, 30, and 3 μg/l in drinking water, respectively (WHO 2020b–d).

The US Environmental Protection Agency (USEPA) has set up a 10-day health guideline for drinking water for microcystin-LR at 1.6 μg/l. For cylindrospermopsin, the limit is 3.0 μg/l for school-age children and adults. In infants, the values are set at 0.3 and 0.7 μg/l (USEPA 2015).

The most common way for humans to become exposed to cyanotoxins is through unintentionally drinking cyanotoxin-contaminated water. Other ingestion routes involve consuming food prepared from toxin-contaminated water, cyanotoxin-accumulated seafood or aquatic fish, mollusks, etc., or cyanotoxin-contaminated edible plant parts (Abdallah et al. 2021; Weralupitiya et al. 2022). It is unclear whether cooking affects cyanotoxins, as most are heat stable and non-volatile (Abdallah et al. 2021). In addition to ingestion, the other exposure routes are dermal contact via participating in recreational activities such as swimming and fishing or even while undergoing medical treatments such as dialysis.

Interestingly, there are records regarding potential cyanotoxin inhalation via dust particles (Abdallah et al. 2021). As cyanotoxins are non-volatile, inhalation can happen during a spray if the liquid is contaminated with cyanotoxins or cells. There is a possibility of inhalation while engaging in certain recreational activities such as water skiing or even swimming (WHO 2020a).

Exposure to cyanotoxins via drinking water differs from country to country and even within a country. Because most people in the developed world drink treated drinking water, and as such, exposure to drinking raw water is minimal. For them, exposure to cyanotoxins is mainly through recreational activities. But around 152 nations are still developing, and people living in some of these countries lack access to clean water. Hence, the water they primarily consume is raw, taken from dug wells, and there is a potential risk of cyanotoxin ingestion via drinking the untreated water.

The accumulation of cyanotoxins in plants is a result of several factors. Cyanotoxin accumulation produces severe toxic effects such as reduced plant growth, seed germination, and enhanced oxidative stress. Additionally, a lowered rate of mineral uptake, a decrease in photosynthetic efficiency, and a loss in chlorophyll content are possible (Weralupitiya et al. 2022). The persistence of cyanotoxins in water used to irrigate plants will lead to bioaccumulation of these cyanotoxins in plants and phytotoxicity, as well as the potential risk of pollution in groundwater (Weralupitiya et al. 2022). Compared to agricultural plants, bioaccumulation of microcystin is three times higher in edible parts of leafy vegetables (Zhang et al. 2021).

Most developed and some developing countries perform quantitative analysis on their food and dietary supplements for cyanotoxin detection as it is a major route for acute food poisoning. A study from Brazil has shown how fish accumulate MCs, and these toxins caused oxidative stress, neurotoxicity, and molecular damage (Calado et al. 2019). The study demonstrated how persistent MCs are within these fish tissues. For more data on cyanotoxins and seafood contamination by cyanotoxins, readers are advised to refer to an up-to-date overview of the contamination of cyanotoxins in food from all the developing nations in Africa, Asia, and Latin America (Abdallah et al. 2021).

6.3.2 Illnesses Associated with Cyanotoxins

6.3.2.1 Human Illnesses

Currently, cyanobacteria are considered a microbial contaminant. In 1998, the cyanotoxins were included in the USEPA drinking water candidate contaminating list (CCL), considering how they transmit through drinking waters (Magana-Arachchi and Wanigatunge 2020).

Cyanotoxins are causative agents for many chronic and acute diseases in humans. Depending on the source, route, and duration of cyanotoxin exposure, the toxicity exerted on the human body could be different and decide whether the illness is acute or chronic.

Acute exposure to cyanobacterial blooms and their toxins can cause various symptoms in humans. Depending on the exposure site, it could be a headache, body aches with muscle and joint pains, allergic reactions, eye irritation, etc. Gastrointestinal discomforts such as vomiting, diarrhea, abdominal pain, and cramps are also possible if ingested. Further, it will cause fever and ulcers in the mouth. According to published reports, there is a possibility of getting acute pneumonia or dermatitis. In severe cases, seizures, damage to the liver, cardiac or respiratory arrest, and death might happen (US EPA 2019). Chronic exposure to cyanotoxin may cause liver and kidney damage and also neurotoxicity (Figure 6.4).

According to a recent publication, a total of 389 human cases of illness due to cyano exposure were reported by the US OHHABS, with 341, ~88% being classified as probable. Among the reported, 51% of the cases were in July, when a single freshwater harmful algal bloom caused the incident. Starting in a large lake, the cyanobacterial bloom spread to connected waterways, such as rivers, canals, and reservoirs, and lasted more than three months (Roberts et al. 2020).

All reported illnesses (~98%) occurred from June to September. The 380 cases displayed various signs and symptoms; among them, gastrointestinal problems were frequent (67%). Further, ~43% had symptoms such as headache, fever, or lethargy; 27% had skin-related issues; and 16% displayed ear, nose, or throat-related symptoms. There were no deaths. Time to the onset of initial signs or symptoms was available for 124 people with a one-time exposure ranging from one minute to eight days (Roberts et al. 2020).

The documented and scientifically proven human deaths due to cyanotoxins are limited. Though guidelines could be imposed for the protection of public water supply systems, rules and regulations cannot be applied to privately owned wells. Most developing countries use well water for their drinking, and it is the same in most parts of Sri Lanka. Chronic Kidney Disease of unknown etiology (CKDu) has been a major health problem in Sri Lanka for the last three decades, and more than 2500 patients have died due to the disease. Most patients are from the dry zone of Sri Lanka, where people consume well water to satisfy their thirst. Research from Sri Lanka has shown the presence of cyanobacteria with toxin-generating ability in well waters in the dry zone of the country and an increased risk for chronic renal disease for people living in the dry zone of Sri Lanka (Liyanage et al. 2016).

MCs employ diverse cellular mechanisms in inducing severe organ impairments. These include enhanced oxidative stress, cytoskeletal disruption, endoplasmic reticulum dysfunction, mitochondrial dysfunction, DNA damage, and apoptosis (Cao et al. 2019; Xu et al. 2020). The kidney is another target of MC toxicity in humans. Severe cytotoxic effects are induced in the renal tissues due to MC toxicity in humans. In a reported case study from Montevideo, Uruguay, a 20-month-old infant was hospitalized following repeated recreational exposure to *Microcystis* blooms containing MCs at up to 8200 μg/l (Vidal et al. 2017). The infant's liver was excised and subjected to histopathological examination. It was revealed that heavy bleeding was involved with severe damage to the liver and nodular degeneration without inflammation. A liver sample was extracted with methanol, and the presence of MC-LR and [D-Leu1] MC-LR in substantial amounts confirmed the toxicity experienced by the infant (Vidal et al. 2017).

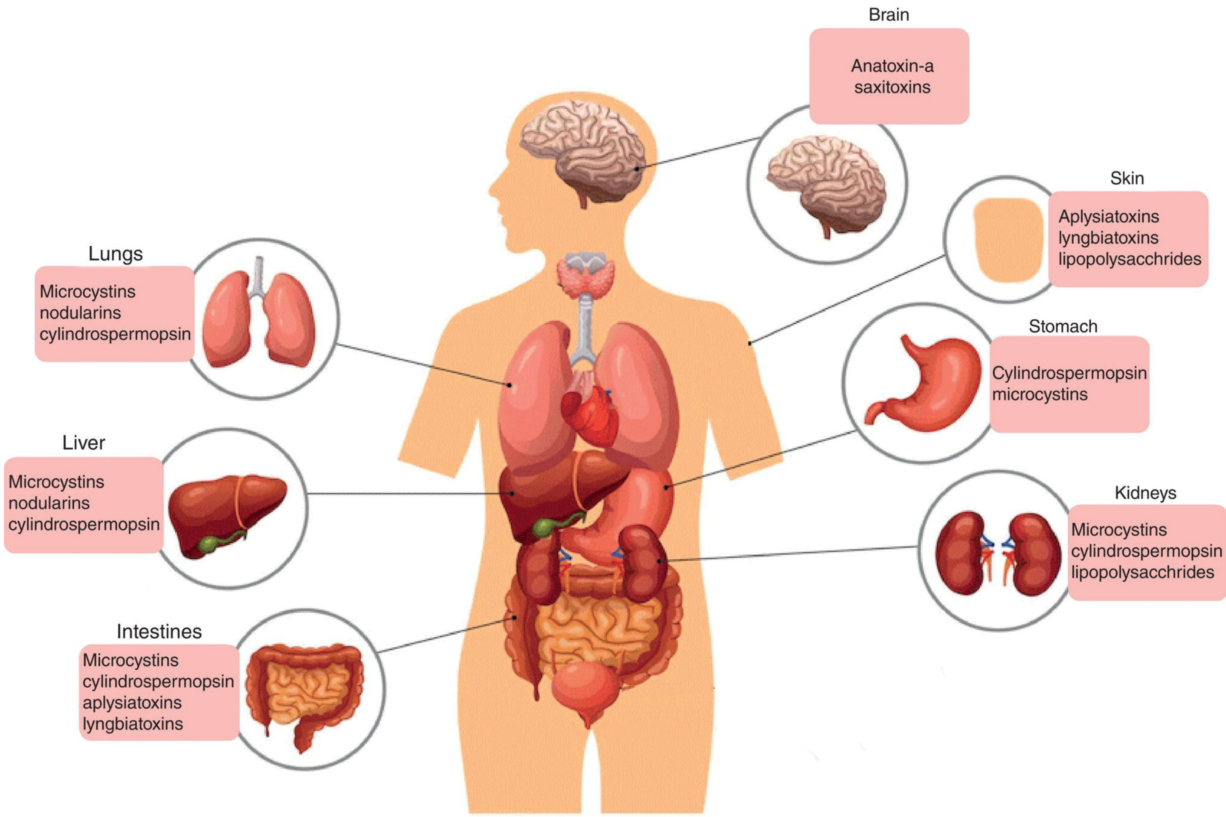


Figure 6.4 Possible target organs affected by different cyanotoxins.

Certain Chinese studies have shown a relationship between the frequency of cyanobacterial blooms and cancers in the digestive tract and prostate gland. Still, more concrete evidence is needed for a conclusion. Though there are records of cyanobacterial presence in the human gut, it has not yet been proven that cyanobacteria multiply within the human body. As such, there is no release of cyanotoxins within the human body.

When published data are considered, the human data are inadequate due to a lack of quantitative exposure information and potential coexposure to other microorganisms and contaminants. There are no long-term studies of MC carcinogenicity (WHO 2020a).

6.3.2.2 Animal Intoxications

There are many records of animal intoxications due to cyanotoxins. A recent review discusses an incident where Portugal had encountered the death of farmed cows, and when investigating the deaths, it was recorded that cows had microcystins in their kidneys. Interestingly, the adjacent water bodies that these animals used for drinking had cyanobacterial blooms (Moreira et al. 2022). The decay of cyanobacterial blooms consumes the oxygen in the water, creating hypoxic conditions in water bodies leading to animal and plant deaths.

Based on OHHABS 64 animal case reports, at least 413 animals became ill, and around 89% perished. Most (81%) animal cases of illness were classified as suspected. About 89% of the animals were exposed while being in fresh waters. Even one giant bird died. Around 73% of cases happened in May 2018. Around 99% of illnesses occurred from May to September. Domestic pets accounted for 52 cases. Livestock affected was 42, while wildlife accounted for 319. Among them, 96% were dogs, 86% cattle, and 97% birds. (Roberts et al. 2020).

6.4 The Future Directions for Effective Risk Management of Toxic Cyanobacteria

Many countries around the globe have taken steps to protect their people from cyanotoxin exposure, mainly when used as drinking water, whether the source is groundwater wells, lakes, reservoirs, rivers, or any other means. Implementing and adhering to guidelines minimizes cyanotoxins' risks and health hazards. Some of the factors that need attention are

- Need for continuous monitoring programs to detect cyanotoxins in the reservoirs used as drinking water sources.
- Monitoring reservoirs is essential to maintain the ecological balance.
- Efficient management programs are required, including management of water bodies, correct toxicity assessment by accurately identifying toxic cyanobacterial species, and whether the reservoirs adhere to the recommended levels.
- During the summer months, reservoirs in most temperate countries experience cyanobacterial blooms. To understand the seasonal variation of cyanotoxins in the reservoirs, a more-detailed temporal resolution needs to be practiced, with a weekly frequency.
- Analytical methods used for the detection of cyanotoxins should have easy accessibility. Standard protocols must also be used; tests should be rapid, convenient to handle, and low-cost. For example, multiplex PCR could simultaneously identify the presence of genes in potential MCs, CYNs, and NODs, releasing cyanobacteria as a rapid and economical test. However, these can be used only for monitoring, and quantifications are essential for confirming cyanotoxins.
- Studies on other cyanotoxins, such as neurotoxins, dermatotoxins, produced by cyanobacteria to address more health impairments.
- Most developing countries do not practice the correct usage of fertilizers and the amount to be used. As such, farmers could be effectively educated on proper agricultural practices to minimize the excessive use of pesticides and

inorganic fertilizers in farming and how these have to be used without polluting aquatic water bodies.

People need to be concerned about the water used in irrigating grown plants. The plants will take these up if the waters are contaminated with cyanotoxins. Therefore, monitoring of waters that are used in agriculture is vital. It is crucial to refrain from growing leafy vegetables on agricultural lands. However, even if this is done, it is critical to monitor the cultivations for cyanotoxins to prevent the risk of cyanotoxin contamination (Zhang et al. 2021).

Monitoring the aquaculture plants and fish ponds is vital. The effluents are rich in nutrients. When the generated excreta are released into the water bodies, whether directly or treated, the procedures used to remove nutrients from wastewaters must be standardized.

When published literature is considered, most studies are on MCs, describing the occurrence and effects on humans, animals, and the environment. However, it was not the same with other cyanotoxins. The reason might be that a wide range of analytical techniques and standards are easily assessable in detecting MCs. Still, there is adequate data on other cyanotoxins and their effects. Therefore, when managing the risks from cyanobacterial blooms and implementing safety measures, it is vital to consider all the potential cyanotoxin producers and not limit them only to MC-producing taxa (Codd et al. 2020).

6.5 Conclusion

Why do cyanobacteria produce cyanotoxins? This is a global problem for which the answer is not yet known. Hence the topic "Cyanotoxin in hydrosphere and human interface" within the One Health Triad is an important area of research to be involved.

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