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Monitoring, regulation and mitigation of cyanotoxins in the environment to protect human health and wildlife

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Cyanotoxin environmental concentrations vary considerably, e.g. smaller than 0.1 to 150 000 μg/L for microcystins, the most common cyanotoxins [1]. Contamination with cyanotoxins presents a growing challenge to human health and agendas of environmental protection worldwide due to the associated adverse health outcomes of exposure to cyanotoxins [2]. Human metabolism can be disrupted and renal system affected at daily intakes smaller than the tolerable daily intakes (2.4 μg microcystin-LR for a 60-kg adult) recommended by the World Health Organization (WHO) [2]. Cyanotoxins also negatively affect animals at exposures lower than the toxicological threshold below which exposures are considered safe [2]. Unregulated cyanotoxins can lead to widespread deaths of wildlife [3].

Toxic cyanobacteria are dominant organisms in harmful algal blooms. Harmful algal blooms have intensified worldwide since the 1980s due to anthropogenic (e.g. fertilizer use, population growth, gross domestic product) and climatic (e.g. temperature, wind speed, atmospheric pressure, and rainfall) factors, and blooms are often more intense in less developed regions, such as in Asia, South America, and Africa [4]. These factors suggest an enhanced risk for increased exposure to cyanotoxins, which differs among regions. Anthropogenic contaminants in the environment can also stimulate the synthesis of cyanotoxins and their release in the environment [4], but recent studies indicated that the ingestion of anthropogenic chemicals by cyanobacteria can lead to the synthesis and release of novel cyanotoxins with the potential to lead to massive deaths of wild animals [3].

Worldwide authorities should routinely monitor cyanotoxin concentrations in the environment while accounting for novel harmful toxins that may be produced by chemical reactions upon contaminant ingestion by cyanobacteria. Continuous active monitoring of cyanotoxin-releasing organisms is also needed to keep their population at low levels, especially during harmful algal blooms when their population and cyanotoxin release can increase considerably. Various sensors have been developed, permitting rapid cyanotoxins detection in real-world water samples. For example, a nanoprobe-based quantum-dot haptens senses MC-LR ≥0.03 μg/L [5]. More advanced fluorescent sensors now also exist, permitting quick detection (within 5 min) and discrimination of multiple common cyanotoxins with smartphones, by integrating aptamers and single-stranded DNA dyes [6]. Such sensors accurately identify and measure widely-occurring cyanotoxins, including anatoxin-*a*, cylindrospermopsin, nodularin and MC-LR, with a low detection limit (<3 nM) close to the WHO's guideline for maximum permissible concentration in drinking water [6]. These recent advances offer an opportunity to address risks from trace concentrations of individual cyanotoxins as well as cyanotoxins mixtures. The use of novel DNA-based nanosensors may facilitate a more effective and faster identification and sensing of cyanotoxins in the future [7]. These could also be coupled with proteomic and transcriptomic analyses of cyanobacteria to characterize potentially new toxins, especially since the current scientific literature lacks such studies at low doses of stress [4]. The active engagement of the public in the monitoring activities of local environmental institutions within a citizen-science approach could help in such programs to expand the coverage of waters regularly observed for harmful algal blooms. Local institutions and citizen scientists could also make observations for potential unusual behavior or death of animals and other organisms, and if known cyanotoxins or other known causes are not identified, chemical research should consider the possibility of newly-formed cyanotoxins [3].

Regulations are urgently needed to limit cyanotoxins in the environment. Some provisional guidelines of exposure exist. For example, the provisional daily limit of ingestion is 1 μg/L, whereas in 2015 the USA EPA issued an advisory guideline for a 10-day ingestion of 1.6 μg/L for all ages except for infants and young children (0.3 μg/L) [1]. To prevent adverse effects on human health and the environment as well as deaths of wildlife that are often hard to identify [3], policies are urgently needed to regulate cyanotoxins in the environment, increase water quality, and minimize associated risks. However, to achieve this, a multi-dimensional approach is required. Policies are needed to set critical levels of cyanotoxins in the environment –at least the most abundant like microcystins- for the protection of human health and wildlife, considering the available science on the effects of cyanotoxins on various organisms.

Developed countries have technologies to treat water for cyanotoxins, but such treatments are expensive and produce waste byproducts that need further treatment for mitigation. Mitigation efforts that should be implemented include the application of existing algaecides at early stages of harmful algal bloom formation, to prevent expansion of cyanobacteria and restrict the synthesis and release of cyanotoxins. There are various effective algaecides, such as $CuSO_4$, H_2O_2, UV, and $KMnO_4$, but careful selection of the most ideal doses is needed to avoid undesired stimulation of cyanobacteria due to insufficiently high doses [4]. This complicates the mitigation efforts because high doses of algaecides might severely affect organisms other than target algal, and thus the selection of doses should be done case-specifically and considering effects on local non-target organisms. To avoid adaptation of cyanobacteria to algaecides [4], combinations of different algaecides should be considered. New algaecides need to be developed within a green chemistry perspective to mitigate harmful algae while minimizing potentially hazardous substances. New technologies with decreased treatment costs, e.g. cyanotoxin-degrading bacteria, should also be developed for the control of harmful cyanobacteria. In addition, intergovernmental cooperation is needed to account for regional differences.

Many drivers of global change such as climate change, eutrophication and anthropogenic chemical contamination may also enhance harmful cyanobacteria, enrich their toxins, further degrade water quality, and enlarge the risk for increased exposure to cyanotoxins [4]. They all decrease the availability and/or quality of water, increasing the dependence on reclaimed water for multiple purposes, and should be taken into account to tackle the issue of cyanotoxin contamination.

Cyanotoxin contamination, regulation and mitigation thus require a multi-dimensional approach from numerous disciplines across physical sciences, engineering, and technology (Fig. 1). Satisfying this requirement adequately will offer an opportunity to improve water quality, protect human and environmental health, and facilitate the achievement of many of the Sustainable Development Goals (SDGs), including the urgent need to provide safely-managed drinking water services to the 2.1 billion people that have not, e.g. >50% of India’s population.

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Supporting Information: References supporting this exposition.

Biography

Evgenios Agathokleous

Evgenios Agathokleous studied crop science (Diploma, February 2013) at the Agricultural University of Athens, Greece. As a scholar of the Japanese government, he continued his studies in Japan, where he received a PhD in Environmental Resources (March 2017) from Hokkaido University. Upon completion of the PhD course he was awarded a fellowship for postdoc research by the Japan Society for the Promotion of Science (JSPS) and continued research at the Forestry and Forest Products Research Institute (FFPRI) and Hokkaido University (April 2017 to March 2019). Then, he moved to Nanjing University of Information Science & Technology (NUIST), China, where he is now a professor of ecology at the School of Applied Meteorology. He teaches various subjects of ecology and general academic matters to students at all levels. He is the principal investigator of a series of research programs and focuses mainly on plant stress and species interactions under various environmental stressors as well as methods for mediating stress effects.

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Figure & caption

Figure 1. A path to reduce cyanotoxin risk.