WaSAf

Global strategies to control cyanobacterial blooms in African freshwater ecosystems

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A growing number of African water bodies are experiencing cyanobacterial blooms that disturb their functioning and uses. These blooms also have a potential impact on the health of humans and animals due to the ability of cyanobacteria to produce harmful toxins. It is well known that cyanobacterial proliferation mainly occurs in eutrophicated freshwater ecosystems due to the enrichment of water by organic matter and mineral nutrients (phosphorus and nitrogen). In addition, climate change also contributes to amplifying eutrophication and the associated cyanobacterial blooms. As observed in developed countries, two kinds of strategies have been used to fight cyanobacteria. The first is based on the use of chemical products or devices to kill them. The second is based on the control of nutrient inputs into freshwater ecosystems to reduce the phosphorus and nitrogen concentrations and consequently the cyanobacterial biomasses.

I. Brief summary of the root causes of cyanobacterial blooms

In all terrestrial and aquatic ecosystems, primary productivity is controlled by nutrient availability, but the limiting nutrients can be different depending on the ecosystem (for example, marine or freshwater). In freshwater ecosystems, the main limiting factor is phosphorus, followed by nitrogen. Consequently, the larger the phosphorus and nitrogen inputs in these ecosystems, the greater are the biomasses of the phytoplankton communities. Under these conditions, cyanobacteria frequently dominate phytoplankton communities because they are able to occupy the surface of the water bodies where light is available.

It is now well established that eutrophication has become a major threat to freshwater ecosystems due to human population growth and to the resulting increase in human activities. In Europe and North America, peak eutrophication was observed in the second half of the 20th century. In developing countries, particularly in Africa, where population growth is still very high, it is likely that eutrophication, as well as the frequency of cyanobacterial blooms, will continue to increase in the coming years (see, for example, Figure 1).

Fig 1. Cyanobacterial bloom in a freshwater lagoon located on the Ivory Coast

II. Sustainable strategies to reduce the occurrence of cyanobacterial blooms by controlling nutrient inputs into freshwater ecosystems

Controlling nutrient intake, whether in the organic or mineral form, is the only sustainable strategy allowing the protection of water bodies from eutrophication and therefore from cyanobacterial blooms. This strategy first requires identification of the main sources of nutrients and distinction of the point sources (e.g., a sewer collector that flows into a river feeding a water body) from the nonpoint sources (e.g., runoff on soils in agricultural landscapes).

Point sources of nutrients are considered easy to identify, monitor and regulate, while nonpoint sources are more difficult to identify and control. As illustrated by phosphorus pollution in Europe, the improvement of wastewater treatment and the prohibition of phosphates in washing powders have led to a significant decrease in phosphorus concentrations in European freshwater ecosystems. Conversely, nitrogen pollution of water, which mostly results from diffuse pollution, still remains high in European waters, despite large investments aiming at reducing nitrogen inputs in freshwater ecosystems.

In Africa, the partial or total lack of domestic and industrial wastewater collection and treatment in urban and peri-urban areas is one of the main sources of nutrient pollution for freshwater ecosystems (Figure 2). This phenomenon is illustrated, for example, by the hypereutrophication and large cyanobacterial blooms found in several bays and gulfs located around Lake Victoria in East Africa, which host large cities on their shore, such as Kampala (Uganda), Mwanza (Tanzania) or Kisumu (Kenya). The management of domestic and industrial wastewaters is therefore a key challenge for the protection and/or restoration of water quality in African freshwater ecosystems.

Phosphorus and nitrogen pollution of freshwater ecosystems in Africa also results from the development of agriculture induced by population growth.

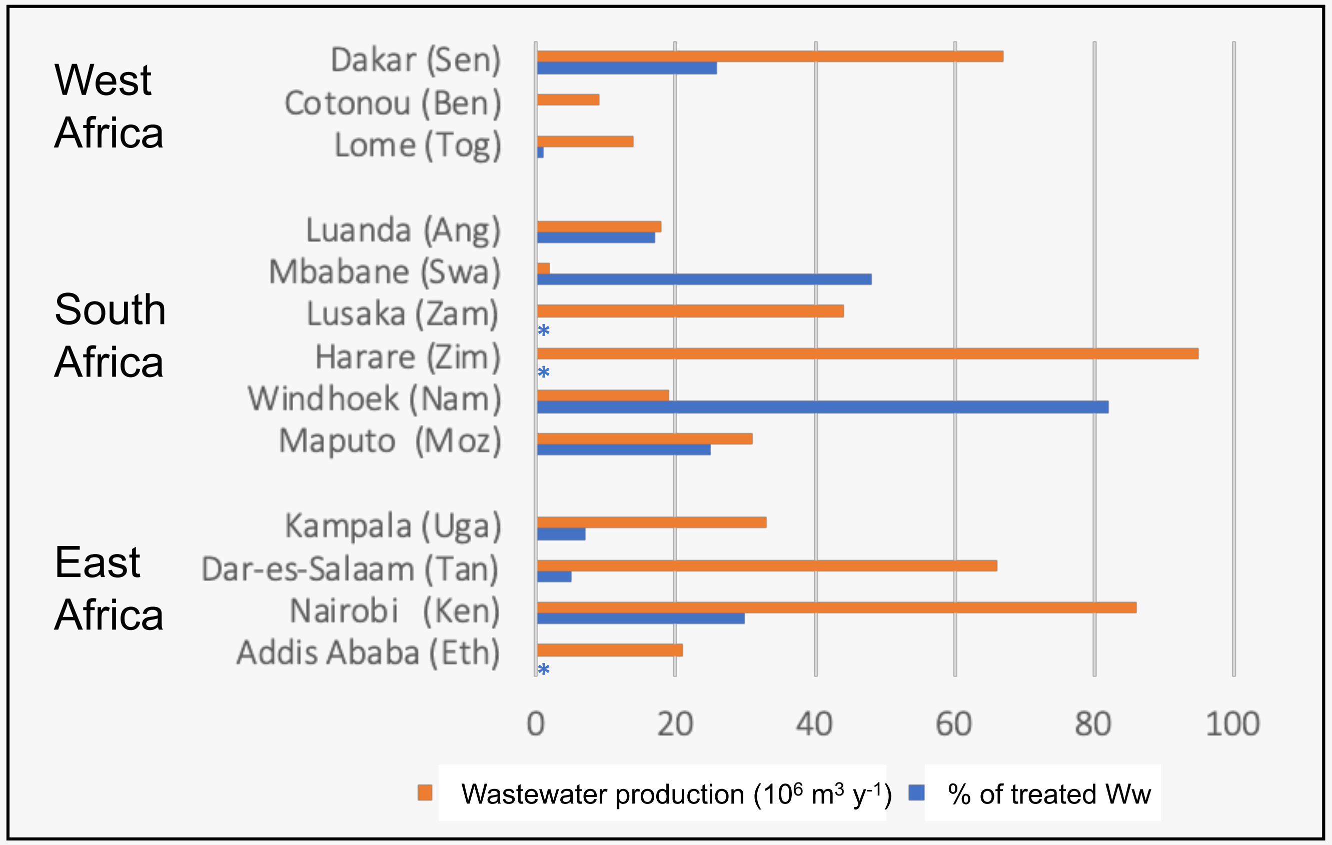

Fig 2. Estimates of wastewater annual production and proportion of treated wastewater in several African large cities (data from Nyenje et al., 2010) *: No data

First, deforestation and some cultural practices leaving the soils uncovered for long periods of time result, during rainfall events, in massive erosion and significant surface runoff, which contribute to the nutrient enrichment of aquatic ecosystems. Soil erosion can be controlled through the development and restoration of plant cover at the regional scale and the introduction of conservation measures in the areas at greatest risk.

Second, while the use of fertilizers (in particular nitrogen) is still limited in Africa compared with developed countries, the increase in agro-industrial projects is already accompanied by an increasing use of these fertilizers. In this regard, it is very important to promote good cultural practices and to implement buffer strips, which allow reduced amounts of nutrients to reach water bodies from runoff or leaching. In the same way, the collection of drainage water in agricultural areas and their treatment in lagoon systems would enable a significant decrease in the nitrogen concentrations in water.

Third, direct livestock watering of cattle should be avoided in small freshwater ecosystems, as this practice can be a significant source of organic and mineral pollution. Restriction of access to shores and installation of drinking facilities for livestock should facilitate the reduction in this pollution.

In addition to all these actions, the protection and/or restoration of wetlands could also contribute to reducing nutrient inputs into water bodies.

It has been shown that creating and restoring wetlands significantly reduces the total nitrogen and phosphorus in treated wastewater and urban and agricultural runoff; thus, it may be effective in counteracting eutrophication.

Finally, for water bodies connected to a river and for those that could be connected, reduction in the residence time of water by increasing the volumes of water entering/leaving them could permit the prevention or contain cyanobacteria blooms at an acceptable level.

All these actions aimed at reducing nutrient inputs will not immediately result in changes in the functioning of water bodies, particularly in a decrease in cyanobacterial blooms. It is well known that it can take time for three main reasons:

1. If nutrient inputs were very high, their partial reduction would have no significant limiting impact on primary production (as long as the threshold in the nutrient concentrations limiting phytoplankton growth was not reached).
2. The internal stocks of nutrients present in the water bodies (in water and in the sediments) can support high primary production, even under decreasing levels of nutrient external inputs. The progressive decrease in these stocks will depend on the residence time of the water in the lake. A high residence time will result in a longer delay before observing the effect of the decrease in nutrient inputs. It will also depend on the nutrient load and release of nutrients contained in the sediments.
3. Climatic changes can also counteract management initiatives for the control of nutrient inputs. In particular, it has been shown that extreme rainfall events result in

the inputs of large quantities of nutrients in freshwater ecosystems, leading to cyanobacterial blooms within the next few weeks (as observed, for example, in Lake Erie, USA).

The successful restoration of the water quality in Leman Lake (Switzerland-France) and in the Great North American Lakes

Leman lake is the largest lake in Europe. It was highly eutrophicated at the end of the 1970s, with total phosphorus concentrations >80 µg L-1. After a 50-year struggle against eutrophication, the total phosphorus concentrations now reach approximately 15 µg L-1. This reduction in phosphorus concentrations is mainly attributed to the following:
- The construction of numerous wastewater treatment plants able to remove phosphorus and to treat wastewater from 93% of the population in the watershed of the lake (7% of the population still uses individual wastewater treatment).
- The prohibition of phosphate in washing powders (in 1986 in Switzerland and in 2007 in France) has also permitted a dramatic decrease in pollution of the lake by wastewater.
- The awareness of farming communities on the use of phosphate fertilizers and of all people concerned by this issue has also contributed to the successful reduction of eutrophication in the lake.

The same strategy for the control of point-source pollution (e.g., phosphorus restrictions in commercial detergents, enhancements of sewage treatment plants) also permitted the reduction of phosphorus concentrations in the Great North American Lakes (e.g., Lake Erie) between the beginning of the 1970s and the end of the1980s. However, due the combined impact of changes in agricultural/farm practices and in climate (increasing storm events), phosphorus concentrations increased sharply after the 1990s. The challenge for this lake is now to better control the nonpoint phosphorus sources.

In this context, several strategies have been proposed in the ten past years to reduce nonpoint source pollution of the lake by phosphorus. Among them, the use of multi model approach has permitted the most promising scenarios, including the widespread use of nutrient management practices (especially subsurface application of phosphorus fertilizers in cropland) and the installation of buffer trips.

III. Middle- and short-term strategies to control cyanobacterial blooms by the use of chemical products or devices that kill cyanobacteria

With the goal of maintaining different uses in freshwater ecosystems experiencing recurrent cyanobacteria blooms, short-term actions designed to kill cyanobacteria have been proposed by private companies in the past 20 years. These solutions mainly concern the use of chemical products (for example, copper sulfate or hydrogen peroxide) and/or electronic devices such as those based on the use of ultrasounds.

These short-term solutions (STSs) are subject to many debates in the scientific community working on cyanobacteria and between scientists and people in charge of the management of freshwater ecosystems. People supporting their use argue that they permit the maintenance of some uses that became impossible due to cyanobacterial blooms and that they are less costly than solutions aiming to reduce the nutrient load in freshwater ecosystems. Consequently, these STSs are frequently presented as complementary to sustainable strategies aiming to reduce nutrient loads in freshwater ecosystems.

Conversely, many scientists consider these solutions improper for the following reasons:

1. The efficiency of some STSs is highly questionable. It has been shown, for instance, that ultrasound devices are not truly efficient in natural conditions. Moreover, when these solutions are effective (use of chemicals, for example), they must be applied several times a year, and their application has to be renewed every year, eventually making them very costly.
2. STSs have an impact on the biodiversity and functioning of freshwater ecosystems, and consequently, they constitute an additional stress for them. It has been shown, for example, that depending on the conditions of use, chemical products can cause the death of nontarget microorganisms (e.g., microalgae) and macroorganisms (e.g., zooplankton).
3. Several difficulties have been identified in the field application of STSs. For example, it is difficult to estimate, in natural ecosystems, the optimal doses of chemical products to be applied to prevent or reduce the development of cyanobacterial blooms while limiting the adverse effects on nontarget organisms. Thus, overdosing may occur, with consequences for these nontarget organisms. Another problem in the application of STSs is that by inducing cell lysis of cyanobacteria, they lead to the massive release of free toxins into water, which can be very harmful to bathers and can make it difficult to produce safe water. Consequently, the use of chemical products must be avoided during cyanobacterial blooms in freshwater ecosystems used for bathing activities or for the production of drinking water. Nevertheless, it has been shown in France, for example, that ecosystem managers do not always follow this recommendation.
4. There is often competition between the use of STSs

and the implementation of long-term strategies aiming to reduce nutrient inputs. STSs constitute a lucrative and growing market for many companies that attempt to convince freshwater ecosystem managers that the use of their solutions will lead to rapid results. Many decision-makers prefer investing in STSs instead of implementing long-term actions aimed at reducing nutrient inputs.

Finally, middle-term solutions have also been tested to control cyanobacterial blooms. These solutions concern, for example, the use of devices (aerators) that allow mixing of the water column, use of compounds that absorb or precipitate phosphorus, or biomanipulation of trophic networks. These solutions are not very efficient in large and/or hypereutrophic ecosystems.

IV. Conclusions

The issue of cyanobacterial bloom management has, until recently, mostly concerned developed countries and some developing countries, such as China and Brazil. However, human population growth and associated activities mean that an increasing number of developing countries, in particular on the African continent, will face increasing problems with cyanobacterial blooms. In countries where numerous people have limited access to treated water and where the production cost and the availability of treated water have consequences on its use by local populations, the sustainable management of water bodies is a crucial issue, and the uncontrolled use of STSs might have dramatic consequences for human and environmental health.

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