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Eutrophication: a threat to freshwater reservoirs and human health

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ABSTRACT Eutrophication is an environmental problem that results from the increment of chemical nutrients (Phosphorous and Nitrogen) in a water body, transforming from oligotrophic into eutrophic, and in worst cases a hypertrophic stage. This process can occur naturally or due to human action. When the occurrence is natural, this phenomenon occurs slowly due to increase of organic matter by natural runoff from the soil and rock sediments. The anthropic actions generate punctual and diffuse pollution, this phenomenon favor aggravation of eutrophication process. The increment chemical induces a quickly increase of primary production of photosynthetic organisms in the aquatic systems, like phytoplankton and cyanobacteria, decreasing the light availability by increase of organic matter and consequently depletion of oxygen, resulting in loss of biodiversity. Eutrophication causes loss of water quality that is essential for human survival and development of social and economic activities. The eutrophic reservoirs usually present toxins, undesirable taste and odor, and DBPs formation in drinking water, the purification of the contaminated water might be complex and require long-term measures, turning the process quite costly. Therefore, actions to prevent the eutrophication of ecosystems are preferable. Sometimes the restoration of a disturbed environment is necessary, although expensive and complex, for which we present some methods of treatment of some chemical substances.

KEYWORDS: *environment; eutrophication; water quality*

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Eutrofização: uma ameaça aos reservatórios de água doce e à saúde humana

RESUMO A eutrofização é um problema ambiental que resulta do incremento de nutrientes químicos (Fósforo e Nitrogênio) em um corpo hídrico, transformando de oligotrófico em eutrófico e, no pior dos casos, um estágio hipertrófico. Este processo pode ocorrer naturalmente ou devido à ação humana. Quando a ocorrência é natural, esse fenômeno ocorre lentamente devido ao aumento da matéria orgânica pelo escoamento natural do solo e pelos sedimentos das rochas. As ações antrópicas geram poluição pontual e difusa, fenômeno que favorece o agravamento do processo de eutrofização. O incremento químico induz um rápido aumento da produção primária de organismos fotossintéticos nos sistemas aquáticos, como fitoplâncton e cianobactérias, diminuindo a disponibilidade de luz pelo aumento da matéria orgânica e consequente depleção de oxigênio, resultando em perda de biodiversidade. A eutrofização causa perda da qualidade da água, essencial para a sobrevivência humana e o desenvolvimento de atividades sociais e econômicas. Os reservatórios eutróficos geralmente apresentam toxinas, gosto e odor indesejáveis e formação de DBPs na água potável, a purificação da água contaminada pode ser complexa e exigir medidas de longo prazo, tornando o processo bastante custoso. Portanto, ações para evitar a eutrofização dos ecossistemas são preferíveis. Às vezes a restauração de um ambiente perturbado é necessária, embora cara e complexa, para a qual apresentamos alguns métodos de tratamento de algumas substâncias químicas.

PALAVRAS-CHAVE: eutrofização; meio ambiente; qualidade da água

Introduction

Eutrophication can be defined as being an environmental problem resulted by the increment of some chemical, for instance, Phosphorous (P) and Nitrogen (N), in aquatic environment (Costa et al 2018). This enrichment of nutrients

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(N and P) is the main factor for unwanted changes in water bodies, transforming from oligotrophic into eutrophic and in worst situation a hypertrophic stage (Khan and Mohammed 2014). This process can occur naturally mainly in lakes and ponds, where the water flow is low and the residence time is higher than rivers. Naturally, this phenomenon occurs slowly due to the increase of organic matter by ecological succession (Rathore et al 2016). However, many water bodies around the world have accelerated this problem due to punctual and diffuse pollution (Shaw et al 2003) and it has called attention of both the governments and population (Yang et al 2008). Human actions on the environment that cause eutrophication include the inflow of urban and industrial wastewaters and atmospheric emissions (Buzancic et al 2016).

Nutrients are well recognized as factors that induce a quickly increase of primary production of photosynthetic organisms in aquatic systems. In eutrophication, this increase in phytoplankton contributes to the depletion of oxygen and decrease in light availability, potentially resulting in loss of biodiversity (Messyasz et al 2015; Costa et al 2018). Consequently, eutrophication is a serious problem for water resource management and a hazard for water supply, landscape, fisheries and agriculture.

Because of population growth, agricultural production (hence use of fertilizers), land use alteration and nutrient recycling the water bodies can change their trophic stage from oligotrophic until hypertrophic (Figure 1). Oligotrophic condition is stable due to low phosphorous recycling from sediments. Differently, in eutrophic condition, the sediments acts returning higher phosphorous concentrations to the water column (Carpenter 2005). In addition, eutrophic condition is described as an uncontrolled growth of primary producers (Khan and Mohammed 2014) by large accumulation of plant nutrients (Yang et al 2008).

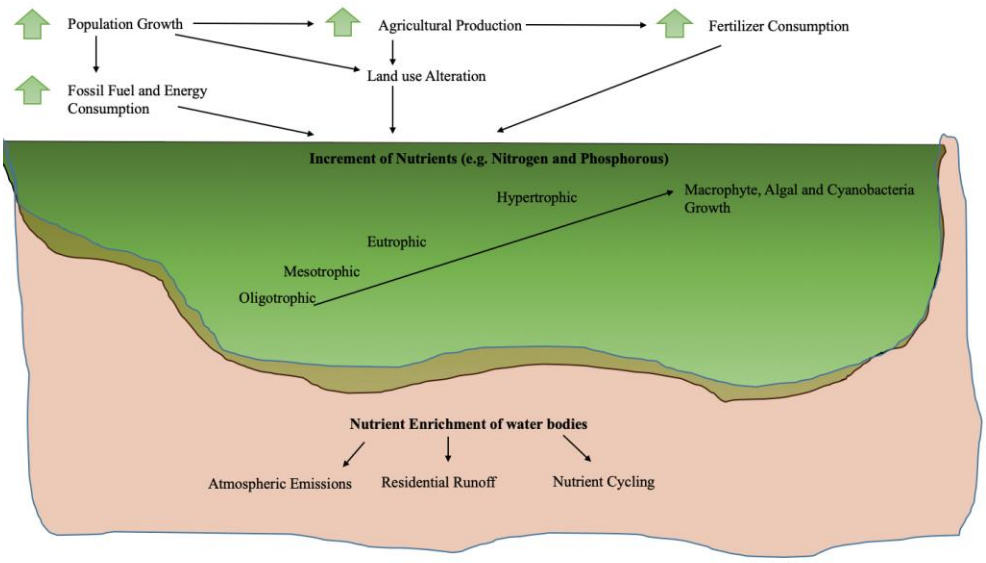

Figure 1 Representation of the factors that can contribute to eutrophication artificial process.
Adapted from: Khan and Mohammed 2014

Nutrients dynamics

Nutrients are the major factors that control the process of eutrophication in water bodies. It is related mainly to the essential components in proteins structures, cell membranes, as well as other molecules responsible for capture and use of light to produce biomass in autotrophic organisms (Shinde and Gawande 2016). Nitrogen is very important for the metabolism of autotroph organisms, however, the excessive phosphorus concentration is the major factor to eutrophication in aquatic systems (Corell 1998).

Phosphorous is a chemical element present in DNA and RNA structures. This element is also important in the conversion of solar energy to biomass. Therefore, autotroph organisms need phosphorous for their metabolism, being orthophosphate the only P-form that they can assimilate (Correll 1998). Discharging high concentrations of phosphorous in water bodies makes the phosphorous stand many years in the sediment, which could result in phosphorous recycling, and hence causing eutrophication of the aquatic systems (Carpenter 2005).

Naturally, weathering process on rocks can carry Nitrogen and Phosphorous to water bodies due to runoff from the soil and rock sediments. However, the natural input many times is not sufficient to change the trophic stage of a water body, and it would take a long time for the phenomenon of eutrophication (Shinde and Gawande 2016).

Anthropogenic inputs of nitrogen and phosphorous include: runoff of inorganic fertilizer (nitrates and phosphates) and manure (nitrates, phosphates and ammonia) from farms, discharge of detergents (phosphates) in waters, discharge of domestic sewage (nitrates, phosphates), fossil fuel sources (Yang et al 2008; Shinde and Gawande 2016).

Eutrophication effects in water quality

It is well known that drinking water is essential for human survival and development of social and economic activities. Therefore, the provision of drinking water is a vital service in any society. However, some human activities, and their consequences can compromise this process. Eutrophication represents a typical example of human activity's effect on freshwater quality.

The water quality is defined as the suitability of water to sustain a use or process (Meybeck et al 1996). In eutrophicated surfaces reservoirs cases, the water quality is considered poor in terms of human water-uses, because eutrophication increases cyanobacterial, algal, and plant biomass (Codd 2000).

In general, the undue accumulation of algal biomass is the symptom of eutrophication that is most easily detected and most disliked by the public due to the increased turbidity, particulate matter, and the condemnable taste/odor in drinking water (Smith 2003). The organoleptic deterioration and filter blockage caused by this excess of organic matter in drinking water implies in higher water treatment costs (Cooke and Kennedy 2001).

The increased organic matter can also be detrimental because disinfection byproducts (DBPs) can be formed after reactions between the disinfection agent and the organic matter. The DBP formation can play a negative role in drinking water safety, increasing treatment costs even more and decreasing human health (Cunha et al 2016).

Eutrophication may also cause dilution of contaminants in increasing the amounts of biomass, the sedimentation of contaminants, the uptake in the food chain, the contaminant scavenging by dissolved organic carbon, and profound effects on the natural attenuation of sediment-bound contaminants (Gunnarsson et al 1995; Koelmans et al 2001; Taylor et al 1991, 1996).

Even with all those bad consequences mentioned above, the frequent dominance by cyanobacteria in eutrophic waters is of additional concern to water quality considerations because of the ability of these organisms to produce toxins (Liyanage et al 2016). Most poisoning by cyanobacteria involves acute hepatotoxicosis caused by a structurally similar group of small molecular weight, cyclic hepta and pentapeptides referred to as microcystins and nodularins, respectively (Carmichael et al 1988).

Human health incidents associated with these toxins can include skin irritations, allergic responses, mucosa blistering, muscular and joint pains, gastroenteritis, pulmonary consolidation, a range of neurological effects and acute or chronic toxic injury to the liver and other tissues (Codd 2000, Falconer 2005). They are also potent liver tumor promoters through their inhibition of protein phosphatases (Carmichael 2001). Among these cyanotoxins, the one called Microcystin-LR was classified as a possible human carcinogen by the International Agency for Research on Cancer (Lone et al 2015).

Freshwater eutrophication combating strategies

Regarding damage to biodiversity, it has rarely been sufficient by itself to attract resources for eutrophication management. However, cases where eutrophicated reservoirs caused the presence of toxins, undesirable taste and odor and DBPs formation in drinking water, had better approaches to solve the problem and led to a growing interest in alternatives for eutrophication remediation and prevention (Codd 2000; Hong et al 2008; Shen et al 2011; Zamyadi et al 2012).

The purification of the contaminated water might be complex and require long term measures, turning these processes quite costly and economically unfeasible in many large-scale cases (Liu and Qiu 2007; Weller 2013). Thus, preventive actions are preferable.

Prevention

In their review, Liu and Qiu (2007) affirm that the key measure required for the prevention of freshwater reservoirs eutrophication is the control of external nutrient loading. In this study they present many Chinese government's actions to reduce point and non-point source pollution. Among those arrangements we can mention the government's implantation of a series of countermeasures, including: the creation of new sewage collection systems and wastewater treatment plants, the strengthening of management for industrial drainage, the elevation of clean production in plants, the prohibition of phosphorus-containing detergents in some static water areas, the enhancement of farmland management in the watersheds of lakes, the controlling of species and amount of pesticides and water-saving irrigation and ecological agriculture measures encouragement. These measures quoted by Liu and Qiu (2007) seems to reflect the main prevention procedures adopted around the world to manage external nutrient loading in watersheds (Heisler et al 2008).

In situ monitoring tools are also an option to prevent eutrophication. They permit resolution of the antecedent conditions and the time course response to some episodic events. *In situ* probes with telemetry for many key parameters such as salinity, temperature, turbidity, chlorophyll, PH and dissolved oxygen can provide near real-time data for management applications (Heisler et al 2008). Biosensors for the detection of cyanobacterial toxins in water are also desirable for this purpose and there are several studies about their development (Weller 2013).

Restoration

Restoration has been defined as the return of a disturbed system to some pre-disturbance state that is both self-regulating and integrated into the larger landscape (National Research Council, 2000). As it was said before, restoration tasks for eutrophicated waters, although expensive and complex, might be necessary in some cases where prevention actions were not taken or even considered in important freshwater reservoirs.

Once high concentrations of nutrients are found in freshwater reservoirs, one can look for ways to remove those substances from it, even to prevent eutrophication or remediate already eutrophicated reservoirs. In cases of nitrate contamination, which is possibly the most widespread groundwater contaminant in the world due to its high solubility in water, the most common treatment methods used include chemical denitrification using zero-valent iron (Fe^0), zero-valent magnesium (Mg^0), ion exchange (IX), reverse osmosis, electrodialysis, catalytic denitrification and biological denitrification. Nevertheless, adsorption processes can also be viable, as long as the right kind of sorbent is used (Bhatnagar and Sillanpää 2011).

For phosphate contamination cases, adsorption processes are commonly used to restore waterbeds. Alum, calcite, Phoslock™ (lanthanum modified clay) and Modified Zeolite (Z2G1) are materials often used in those scenarios. The lanthanum modified bentonite (Phoslock™) and the and Modified Zeolite (Z2G1) represents the most innovative remediation materials (Copetti et al 2016; Zamparas and Zacharias 2014). A study realized by Huh et al (2016) showed that heated oyster shell powders is also a potential material to reduce the presence of phosphate and nitrogen in eutrophicated waters.

Since nutrients can gradually accumulate in the bottom sediment of lakes, they can be slowly released into the overlying water. Hence, even after controlling external nutrient sources, the nutrients released from the sediment can still maintain its current trophic status. However, there are several countermeasures to control internal source pollution, such as sediment dredging (mechanical removing the lakes surface layer of sediments), water flushing (dilution of eutrophic lakes with clean water from nearby rivers), and aeration technology (liberation of oxygen in water to allow microorganisms to decompose nutrients under aerobic conditions). It's important to say that sediment dredging projects have serious controlling problems, water flushing is only implemented in emergencies as a temporary solution (since the dilution can lead to an even more serious algae growth) and aeration is feasible only in small lakes (Liu and Qiu 2007).

Another option to combat the effects of eutrophication is to treat the water reservoir's great amount of algae. The conventional chemical treatments include peroxidation, algaecide application, biomanipulation or coagulation by inorganic compounds (Huh and Ahn 2017; Paerl 2018). Peroxidation by ozone, chlorine, chlorine dioxide, permanganate or ferrate is effective in promoting the coagulation of algal cells and is widely used in drinking water treatment, but they result in taste and odor occurrences due to higher oxidation strength. Beyond that, chlorine and chlorine dioxide can produce undesirable DBP's, while ozone, chlorine or ferrate can induce release of cyanobacteria toxins. In general, ozone and permanganate are the most used techniques in this sort of water treatment (Huh and Ahn 2017).

The most common algaecides used are copper-containing compounds, and more recently, hydrogen peroxide. They have largely focused on relatively small impoundments because the radius of effectiveness of their application can be quite limited, and they can be expensive to apply, deploy, and maintain. Copper-containing compounds can be effective algaecides, but they are toxic to various aquatic plants and animals, and the copper can precipitate out of the water column or sorb to suspended solids and accumulate in bottom sediments (Huh and Ahn 2017; Paerl 2018). Hydrogen peroxide (H_2O_2), on the other hand, is selective for cyanobacteria and has minimal adverse effects, but the H_2O_2 treatment must be repeated, especially if the potential bloom period is several months away, because its degradation to H_2O is quick (Paerl 2018).

Biomanipulation usually involves introduction of fish or benthic filter feeders as consumers of cyanobacteria, or the introduction of lytic bacteria and viruses. Key elements of biomanipulation are to both reduce algae's biomass and recycling of nutrients. Because of its experimental nature and possible unpredictable outcomes, biomanipulation is recommended only when nutrient reductions alone are not effective in restoring acceptable water quality (Paerl 2018).

The use of inorganic coagulants, such as clays, aluminum sulfate, ferric chloride or lime, is the cheapest and fastest-working method and the most widespread across the world. Their main disadvantage consists on their high price. These products present difficulties to be produced with high quality and purity (Huh and Ahn 2017).

Besides the presence of algae and biomass, which deteriorates freshwater's organoleptic characteristics, eutrophic reservoirs can also present microcystins (toxins produced by cyanobacteria), as it was shown before. To remove these substances from drinking water, treatment plants usually apply processes such as carbon filtration, nanofiltration and chemical/UV catalyzed oxidation (Roegner et al 2014).

Since marginal wetlands significantly influence the water quality of shallow lakes, many studies show that free water-surface constructed wetlands perform well and are suitable for managing eutrophicated waters. These systems can enlarge the vegetated littoral zone, enhance biodiversity, treat eutrophic inflows and retain biomass and nutrients (Calero et al 2015; Martín et al 2013; Rodrigo et al 2018; Sollie et al 2008).

Another biological control approach to recover eutrophicated waters is the growth of aquatic and/or submerged aquatic plants, also known as macrophytes, which are an important part of the biological population. They cause effects on both water and sediments, absorbing nutrients from water during their growth phase, they can restrain the growth of algae by competing for nutrients and sunlight, and their roots work like natural small wastewater treatment units that incorporate both aerobic and anaerobic processes (Liu and Qiu 2007; Wang et al 2017), they can also be used as fertilizers when fully grown. According to the study of Wang et al (2017), the best approach to remedy eutrophic waterbodies is the combination of biological technologies, such as biomanipulation and planting of macrophytes, in a way that each measure complement the others.

Final Considerations

Eutrophication is a phenomenon resulting from the increment of nutrients in water bodies and could be a reflection of lack of actions through water resources management. Naturally, this phenomenon takes long time to modify the water quality of these environments. However, anthropogenic action has contributed to impact the water bodies quickly. Indeed, human activity has impacted the natural environment over the years. As a consequence of eutrophication, the alteration of water quality can impact the human life, therefore, mitigating measures need to be done to preserve the aquatic ecosystem as well as to provide safe drinking water to the population.

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