Chapter 10
Availability, Pollution and Eutrophication of Waters

Corina Sidagis Galli and Donato Seiji Abe

Abstract Population growth coupled with the diversification of multiple uses, permanent intake of water for various purposes and the loss of the mechanisms of water retention has decreased their availability and produced numerous shortages. In urban areas this situation is worsened by the growth of irregular occupation and lack of sanitation system, which enhance the degradation of water quality and affecting the water systems as sources of water supply. These and other aspects related to availability and degradation of water resources by human activities are discussed in the present chapter.

Keywords Eutrophication • Pollution • Water availability and demand

Demand and Availability of Water in Brazil

Brazil stands out for its massive discharge of freshwater from rivers in its territory, whose average annual flow is of 179,000 $m^3 s^{-1}$, which corresponds to approximately 12 % of the world's water availability. However, due to the continental dimensions of the country, there are considerable regional disparities in terms of surface water availability. The Amazonian region holds, as an example, about 70 % of the surface water availability in an area equivalent to 44 % of the entire national territory, occupied by 4.5 % of the Brazilian population. The coastal region of the Eastern Northeast, occupied by 13 % of the population, only has 0.5 % of the available water, whereas in the coastal region of the Southeast occupied by 15 % of the population, there is only 2 % of water. Other regions, despite having elevated water availability, also have deficiencies. The Paraná hydrographic division, classified as comfortable with regards to demand versus water availability (MMA 2006), shows some critical areas,

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C.S. Galli (✉) • D.S. Abe
Associação Instituto Internacional de Ecologia e Gerenciamento Ambiental,
Rua Bento Carlos, no 750, 13560-660 São Carlos, SP, Brazil
e-mail: corina.mvd@gmail.com

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mainly in the state of São Paulo. A typical example is the Upper Tietê River basin, whose average annual rainfall is high, corresponding to 1410 mm (CETESB 2009), however, whose water demand is extremely high due to its elevated demographic density, seeing that since the Metropolitan Region of São Paulo, that has about 18 million inhabitants, is almost totally immersed in this basin. In addition, due to the soil having low porosity of the soil, typical of crystalline massifs, with low capacity to retain rain water, enhanced by the imperviousness resulting from intense urbanization, the volumes of water which are extracted from the watercourse and from ground water are hardly ever replenished, and as a consequence, the cities around the basin suffer floods during strong rainfall seasons. Aside from the soil low capacity of retention, there is also the problem of degradation of the waters resulting from the deficiency in collection and treatment of sewage produced in the basin, given the large irregular occupations that have precarious sanitation systems, even in areas of watershed protection. This combination of factors results in water availability per inhabitant per year in the Upper Tietê River basin being extremely reduced, of about only 200 m^3 $inhab^{-1}$ $year^{-1}$, in other words, very distant from the actual demand for consumption of the population residing on the basin, whilst the critical index as per the World Health Organization is of 1.500 m^3 $inhab^{-1}$ $year^{-1}$ (Jacobi et al. 2009). A similar situation can be seen in the Piracicaba-Jundiaí hydrographic basin (Fig. 10.1), also densely occupied, and therefore suffering the same consequences. This hydrographic basin unit, in addition, had the aggravating circumstance of having part of the waters of the basin being deviated to supply the water deficit of the Metropolitan Region of São Paulo, from the Cantareira supply system, that serves half of the population that lives there (Table 10.1).

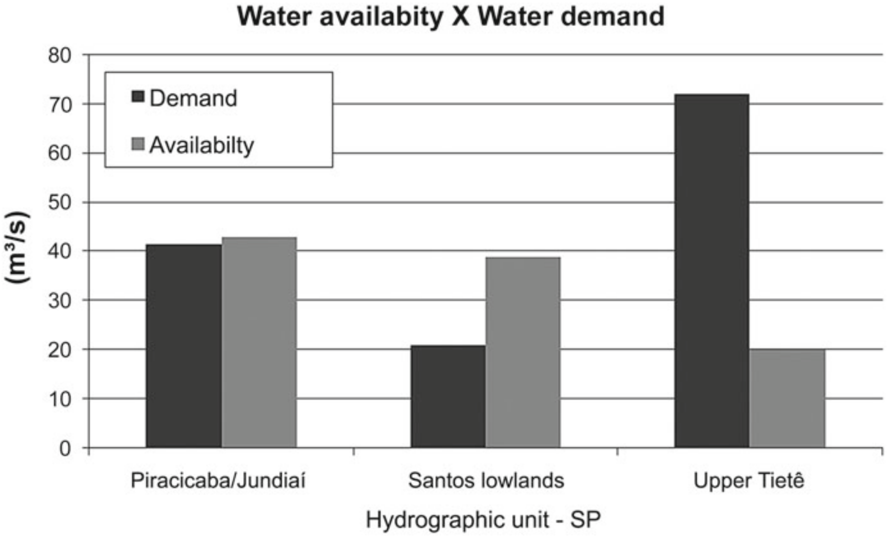

Fig. 10.1 Water availability and demand in the basin management units of Piracicaba-Jundiaí, Alto Tietê, Baixada Santista, State of São Paulo. *Source*: Mancini (2008)

Table 10.1 Water availability and demand in the hydrographic basin divisions of the Brazilian territory

National hydrographical division	Availability (m^3 s^{-1})	Demand (m^3 s^{-1})	Ratio demand/availability (%)	Classification
Amazônia	73,748	47	0.06	Excellent
East Atlantic	305	68	22.30	Critical
Occidental NE Atlantic	328	15	4.57	Excellent
Oriental NE Atlantic	91	170	186.81	Very critical
Southeast Atlantic	1108	168	15.16	Worrying
South Atlantic	671	240	35.77	Critical
Paraguay	785	19	2.42	Excellent
Paraná	5792	479	8.27	Confortable
Paraíba	379	19	5.01	Confortable
São Francisco	1886	166	8.80	Confortable
Tocantins-Araguaia	5362	55	1.03	Excellent
Uruguay	565	146	25.84	Critical

Paraíba do Sul River Basin

The Paraíba do Sul River basin stands out for its location between the largest industrial and population hubs of the country and, as a consequence, presents multiple uses of water, generating conflicts. In the São Paulo portion alone, the Paraíba do Sul basin is home to about two million inhabitants, which corresponds to almost 5 % of the population of the State. Another important aspect of the Paraíba do Sul basin is the deviation of its waters to the hydrographic basin of the Guandu River, where the Guandu Water Treatment Station is located. This station treats about 45 m^3 s^{-1} of water for 8.5 million inhabitants of the Metropolitan Region of Rio de Janeiro (MMA 2006). The Santa Cecília Pumping Station, which became operational in 1952, has the capacity of deviating up to 160 m^3 s^{-1} of water from the Paraíba do Sul River, which is equivalent to about 54 % of the river's natural flow whose influx is guaranteed by several reservoirs located upstream, such as the Paraibuna, Santa Branca, Jaguari and Funil. According to MMA (2006), the division between the pumped flow to the Guandu basin and to the downstream of the Paraiba do Sul River, generates scarcity and conflicts over the use of the water resources, seeing that, on one side there is the need to supply the Metropolitan Region of Rio de Janeiro aside from industries and other users; and on the other side, there are several cities and users, especially in the path located immediately downstream of the station, in critical inflow situation, with low flows and consequent deterioration of the water quality. Users upstream are in turn conditioned upon being supplied by the flow sent to Santa Cecilia. Following the creation of the Brazilian Water Agency (ANA), operational conditions have been defined by this agency and shared with the National Operator of the Electric System (NOS), in a joint effort with the basin committees and with all the other areas involved, such as water resource users, the government in all its spheres and the agencies of the civil society.

Increase in water consumption embedded in the production of food and industrialized products, the virtual water.

Based on the predictions presented in the Worldwide Water Assessment Program (UNESCO 2009), the greatest controlling factors of the worldwide water resources, generated by human activities, will be the demographic alterations and the increase of the standards of consumption, resulting from the increase of income "per capita" especially in the countries with increasing economic growths and with current elevated populations. The increase in income will allow for a greater general consumption on behalf of the population and additional water will be needed for the production of food and other goods and services. In this perspective, according to Tucci (2009), water will become an important merchandise commodity in the world's market, embedded in the production of food and industrialized products (virtual water), leading countries like Brazil, with availability of land, water and productive capacity, to have their markets valued. However, the author pointed out the fact that management has not yet rendered the necessary importance to this product within the productive chain, being this, the main challenge to be faced, aiming at a greater efficiency, sustainability and financial return.

Pollution of Waters

The environmental health of a water body of water is affected by human activities developed within its hydrographic basin watershed, including: (1) launching discharge of domestic sewage; (2) receiving of rainwater that runs off agricultural areas and over soils subject to erosion; (3) receiving of rain water that comes from regions with atmospheric pollution, such as, for example acid rains; (4) percolation of leachate from landfills close to bodies of water bodies; (5) toxic compounds from pesticides used in agriculture and in reforestation; and (6) waters contaminated by xenobiotics, resistant organic compounds and traces of pharmaceutical products (Bernhardt 1990). All these factors induce the degradation of water quality, the loss of biological diversity and the waste of water resources (Straškraba and Tundisi 2008). According to these same authors, there is a strong relationship between the degree of pollution and the density of the population and the three factors that govern this relationship are: (1) urbanization, (2) industrialization and (3) development of agriculture on a large scale. Population increase and the consequent urbanization reduce, together with the increase of agricultural areas, the capacity of hydrographic basins retaining water and their natural capacity of retaining pollutants.

In Brazil, the use of surface waters as a source of public supply continues to be the mostly used watershed alternative. Based on information from ANA (2003), 56 % of the total amount of cities in the country, use surface water as at least one of their watershed alternatives. However, it has been observed that this alternative is the most exposed to the sources of pollution and contamination. One can observe, for example, one or more ways of pollution and contamination in 26.7 % of the total amount of cities with surface catchments, of which 14.24 % of them present contamination due to domestic sewage discharge and 16.22 % of them due to agro toxic residues. One of the consequences of this fact is the elevated level of hypertrophy seen in some surface bodies of water, especially those located in metropolitan regions, which continuously receive an excessive amount of organic matter. The remaining domestic organic load estimated for the country is of 6377 ton DBO day^{-1}, of which only two of the main population centers of the country, the metropolitan regions of São Paulo and Rio de Janeiro, are responsible for about 20 % of this total. With regards to the organic loads of animal origin, it is important to mention those from pig farming, especially in the hydrographic region of Uruguay, where the biggest Brazilian herd is located. In this region, the organic load generated by swine and discharged into the bodies of water is greater than that of human origin.

Cost of Treatment

The increase of the degradation of water directly affects the cost of treatment. The immediate consequence is the increase of the quality of chemical products necessary to treat this water, given the need to maintain water quality for supply. In the Guarapiranga System for example, where the production of treated water is of 14 m^3 s^{-1} to supply 3.8 million people from the Metropolitan Region of São Paulo, there was an increase in the quantity of chemical products of 20 % from 2001 to 2004 (Fig. 10.2), thus, elevating the cost, which is reflected on the price to the final consumer. A totally different situation can be seen in the Cantareira System, where the quantity of chemical products for treatment did not have a considerable increase, seeing that human occupation on the basin did not grow as significantly during the same period.

However, aside from the increase in the quantity of chemical products being used for treatment, degradation of the water quality require more sophisticated treatment processes, such as the use of activated carbon to remove the taste and odor from the water and the use of potassium permanganate for degradation of organic matter. These processes make the costs for treatment of water even higher.

Eutrophication

Eutrophication of inland water bodies of waters consists of the enrichment of water by nutrients, especially phosphorus and nitrogen, which come as solutes and are transformed into organic and inorganic particles. The accelerated growth and the greater abundance of aquatic plants frequently cause deterioration of the water quality and growth of a large volume of algae, including potentially toxic cyanobacteria, becoming a risk to the health of the ecosystems, aside from resulting in an increase of cost for water treatment for supply.

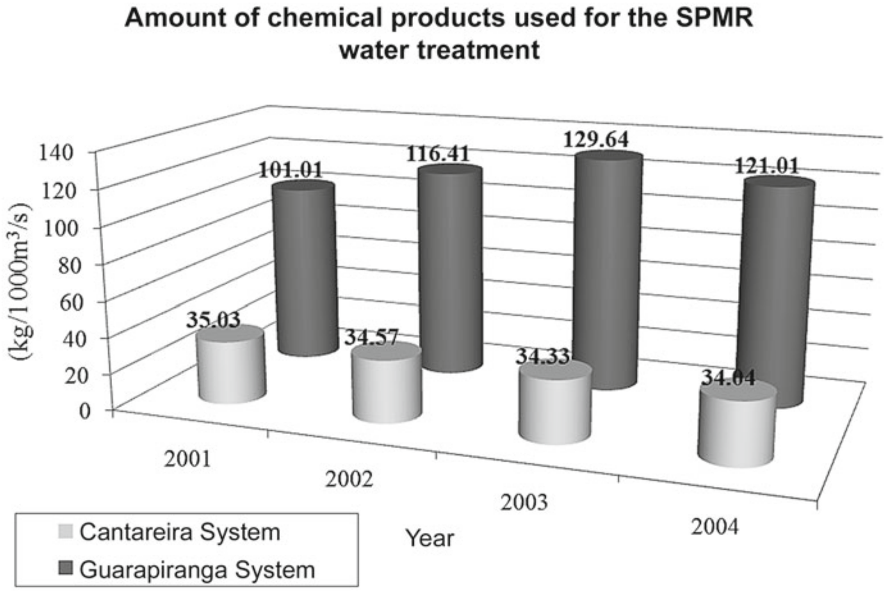

Fig. 10.2 Quantity of chemical products used for water treatment in the Metropolitan Region of São Paulo between 2001 and 2004. *Source*: SABESP

The increased load of nutrients in the water usually occurs due to changes in the watersheds, such as: removal of forests, agricultural and industrial development, but mostly, due to the increase of urbanization (UNEP-IETC 2001). The relationship between urbanization and eutrophication became evident in the "Waters of Brazil Project", in which 1162 locations were identified in water bodies in Brazilian territory by using an amphibious airplane. The highest concentrations of total phosphorous were observed in the Northeast Eastern, Southern Coastal, Southeastern Coastal, Paraná and Eastern Coastal Basins, which show greater demographic densities and where the population represents 75 % of the country's total (Abe et al. 2006) (Fig. 10.3).

One of the most evident consequences of the increase of the trophic state of a water body is the booming of algae, which affects the treatment process and alter the taste and odor of treated water.

Some species, especially of cyanobacteria, are potentially toxic and can make the use of water bodies of impracticable for public supply and other essential uses, due to the risk of causing serious impacts to human health. This phenomenon is not restricted to watersheds of large cities. Researchers have already identified the presence of several species of cyanobacteria in dams of the Northeastern semi-arid region of Brazil due to elevated temperatures and due to deficiencies of the sanitation system in the region (Bouvy et al. 2000; Costa et al. 2006; Panosso et al. 2007). In fact, studies have revealed favored conditions for cyanobacteria and toxic blooming in temperate lakes in Europe with the increase of temperatures during

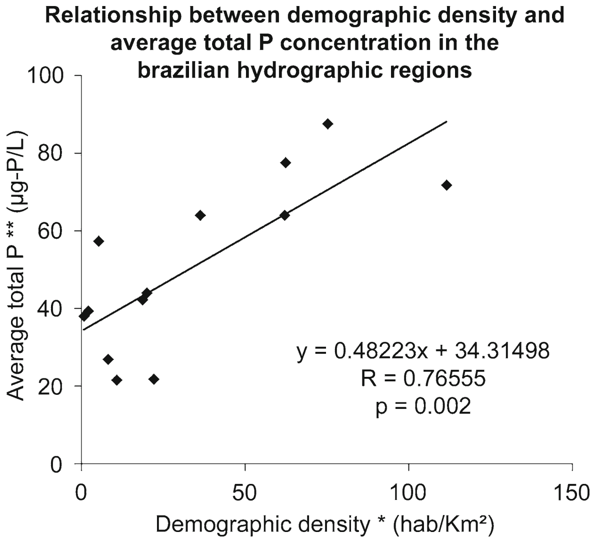

Fig. 10.3 Relationship between demographic density and total phosphorous mean concentration in Brazilian basins. (*) data from the 2000 IBGE Census. (**) data from 1162 stations in water bodies of the Brazilian Territory by the Waters of Brazil Project. Adapted from Abe et al. (2006)

the summer, under the influence of global warming (Bicudo and Bicudo 2008), even after having undergone restoration processes with the reduction of the load of phosphorous. These studies indicated the worsening of eutrophication and a lower efficiency of the recovery processes of the continental lentic systems as a result of global warming.

A recent review performed by Smith and Schindler (2009) specified cultural eutrophication as the greatest problem of current times in surface bodies of water, considering it to be one of the most visible examples of alterations caused by man to the biosphere. Aside from the effects already amply described caused by the excessive intake of phosphorous and nitrogen in lakes, reservoirs and rivers (Table 10.2), the authors describe other direct and indirect effects caused by cultural eutrophication. As an example, in several bodies of water, the increase in the intake of N and P can accelerate the biodegradation process of petrochemical products, aromatic hydrocarbons and pesticides, seeing that the increase of the trophic state encourages the increase of bacterial biomass and, as a consequence, an increase in the diversity of organic substrates, which bacteria are able to metabolize. At the same time, the increased intake of nutrients can influence abundance, composition, virulence and the survival of pathogens which reside in aquatic ecosystems. The increase of the availability of N and P in the water for example, promotes the increased rate of water virus replication. Likewise, the increase of eutrophication can promote the increase in the abundance of *Vibrio cholerae* vectors and of some copepod species thus influencing the probability of the occurrence of cholera epidemic in human populations susceptible to the disease.

Table 10.2 Potential effects of cultural eutrophication caused by the excessive intake of nitrogen and phosphorous in lakes, reservoirs and coastal regions

Eutrophication effects
• Phytoplankton and aquatic macrophytes biomass increase.
• Consumers' biomass increase.
• Biomass increase of potentially toxic or not edible algal species.
• Benthic and epiphytic algal species biomass increase.
• Modification in the macrophytes species composition.
• Fish death frequency increase.
• Decrease of cultivating fish and mollusks' biomass.
• Decrease of species diversity.
• Decrease of water transparency
• Flavor and odor and problems in the supply water treatment.
• Depletion of dissolved oxygen.
• Decrease of the water body aesthetic value.

Adapted by Smith and Schindler (2009)

Effects of Eutrophication

1. Increased biomass of phytoplankton and macrophyte vegetation.
2. Increased biomass of consumer species.
3. Shifts to bloom-forming algal species that might be toxic or inedible.
4. Increased biomass of benthic and epiphytic algae.
5. Changes in species composition of macrophyte vegetation.
6. Increased incidence of fish kills.
7. Reductions in harvestable fish and shellfish biomass.
8. Reductions in species diversity.
9. Decreases in water transparency.
10. Taste, odor and drinking water treatment problems.
11. Oxygen depletion.
12. Decreases in perceived aesthetic value of the water body.

Eutrophication and Greenhouse Gas Emission

The increased load of organic matter and nutrients in the bodies of water also causes an increase in the emission of greenhouse gases into the atmosphere. With the increase of the production of biomass due to increase of intake of nutrients, there is also an increase in the quantity of biomass formed by dead organisms or by fecal particles that sink and accumulate in the sediments of reservoirs. With this accumulation of organic matter in sediments, there is an increase in nutrient cycling, especially of carbon, nitrogen and phosphorous, which is mediated by microorganisms that ultimately results in the production, accumulation and emission of gasses such as CO_2, CH_4 e N_2O. Studies performed by Abe et al. (2008) show that more eutrophic reservoirs have higher diffusive fluxes of greenhouse gasses when compared to less eutrophic reservoirs. In the Furnas Reservoir, in the state of Minas Gerais for example, one can find superior concentrations of organic matter, total nitrogen Kjeldahl and total phosphorous in the Sapucaí branch when compared to the values observed in the Grande branch. The Sapucaí branch of the Furnas Reservoir receives a greater impact than the Grande branch due to the large human occupation on its watershed. As a consequence, superior diffusive fluxes of CO_2 and CH_4 were observed in the Sapucaí branch of the Furnas Reservoir in comparison to the values of the Grande branch.

In the reservoirs of the Middle Tietê River, in the state of São Paulo, a study was performed to verify if the trophic state of the reservoirs is related to the emission of greenhouse gasses in the interface water-air (Abe et al. 2009). Bearing in mind that the reservoirs of the Middle Tietê River, displayed in cascades provide a decreasing gradient of eutrophication, in other words, the Barra Bonita Reservoir is classified as eutrophic-hypereutrophic, the Ibitinga Reservoir as eutrophic and the Promissão Reservoir as oligotrophic-mesotrophic, the authors noticed that the maximum fluxes of CH_4, CO_2 and N_2O were observed in the Barra Bonita Reservoir, i.e. the most eutrophic of the two, and the lowest fluxes in the Promissão Reservoir (Fig. 10.4). The authors also observed that the diffuse fluxes of CH_4 and N_2O presented a high correlation with the concentrations of total nitrogen and total phosphorous in the different reservoirs, which clearly demonstrates that the levels of emission of these gases are directly related to the level of eutrophication of the system.

It is essential to realize that the high emissions of greenhouse gases in the reservoirs of the Middle Tietê River originate in the mismanagement of the water resources in the basin upstream and not by the existence of the reservoir itself. If there were satisfactory treatment of domestic and industrial sewage in the Metropolitan Region of São Paulo, for example, such emission in the Barra Bonita Reservoir would be similar or even lower to those observed in the Promissão Reservoir (Fig. 10.4). These results showed that the management of water resources focused on reducing eutrophication has become imperative not only to avoid the evident impacts, such as the reduction of the aquatic biodiversity, fish mortality and blooming of potentially toxic cyanobacteria, but also in order to avoid the emission of greenhouse gasses to the atmosphere and consequently to decrease global warming.

Final Considerations

As addressed in this chapter, Brazil shows great regional disparities in terms of surface water availability. The situation becomes critical in regions of elevated demographic density due to the high demand for water. However, it becomes even more severe due to the deterioration process of the water quality which results from

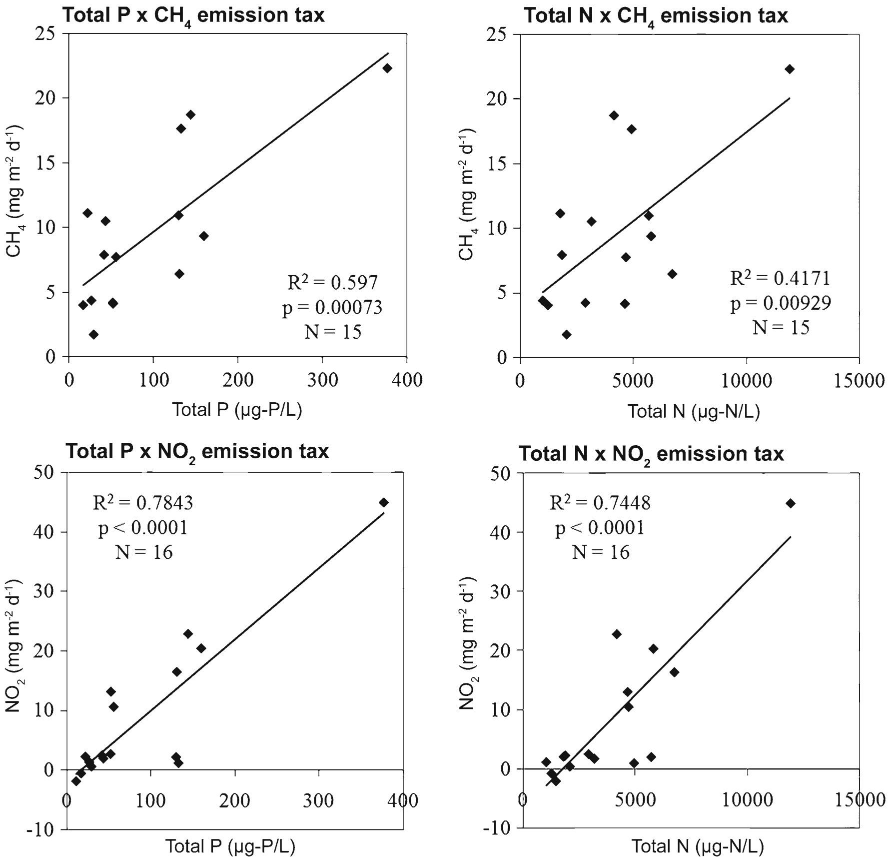

Fig. 10.4 Correlation between total nitrogen, total phosphorus and the rates of emission of CH_4 and N_2O through the water-air interface in the Medium Tietê River reservoirs. *Source*: Abe et al. (2008)

anthropogenic activities that exist in the watershed, resulting in an increase in the costs of treatment or even making the use of the water for supply impracticable.

The most evident degradation process of water resources in the Brazilian territory is that which results from the domestic sewage loading, since the level of treatment is still very low, thus worsening the process of eutrophication. Aside from resulting in known impacts, such as the loss of aquatic biodiversity, the blooming of potentially toxic cyanobacteria, the excessive growth of aquatic macrophytes, anoxia and fish mortality, the increase of eutrophication, mainly in reservoirs, results in the increase of greenhouse gas emission, which consequence is the aggravation of the global warming process. With this in mind, urgent action needs to be taken to minimize the effects of eutrophication in the aquatic systems, above all with regards to the treatment of domestic sewage, supported by strategic programs linking scientific knowledge with public policies. Such actions are already being taken and have shown positive results in the European Union, based on the specification of goals to improve the ecological quality of waters.

References

Abe, D. S., Sidagis-Galli, C., Matsumura-Tundisi, T., Tundisi, J. E. M., Grimberg, D. E., Medeiros, G. R., et al. (2009). The effect of eutrophication on greenhouse gas emissions in three reservoirs of the Middle Tietê River, Southeastern Brazil. *Verhandlungen des Internationalen Verein Limnologie, 30*, 822–825.

Abe, D. S., Sidagis-Galli, C., & Tundisi, J. G. (2008). Emissões de gases de efeito estufa em reservatórios de hidrelétricas. In M. Straškraba & J. G. Tundisi (Eds.), *Diretrizes para o Gerenciamento de lagos: Gerenciamento da qualidade da água de represas* (2nd ed., Vol. 9, pp. 249–272). São Carlos: Instituto Internacional de Ecologia.

Abe, D. S., Tundisi, J. G., Matsumura-Tundisi, T., Tundisi, J. E. M., Sidagis Galli, C., Teixeira-Silva, V., et al. (2006). Monitoramento da qualidade ecológica das águas interiores superficiais e do potencial trófico em escala continental no Brasil com o uso de tecnologias inovadoras. In J. G. Tundisi, T. Matsumura-Tundisi, & C. Sidagis-Galli (Eds.), *Eutrofização na América do Sul: Causas, consequências e tecnologias para gerenciamento e controle* (pp. 225–239). São Carlos: Instituto Internacional de Ecologia.

ANA. (2003). Plano Nacional de Recursos Hídricos. Agência Nacional de Águas, Superintendência de Planejamento de Recursos Hídricos. Retrieved April 21, 2009, from http://www.ana.gov.br/pnrh/ index.htm.

Bernhardt, H. (1990). Control of reservoir water quality. In H. H. Hahn & R. Klute (Eds.), *Chemical water and wastewater treatment*. Berlin: Springer.

Bicudo, C. E. M., & Bicudo, D. C. (2008). Mudanças climáticas globais: Efeitos sobre as águas continentais. In M. S. Buckeridge (Ed.), *Biologia e mudanças climáticas no Brasil* (pp. 151–165). São Carlos: RiMa Editora.

Bouvy, M., Falcão, D., Marinho, M., Pagano, M., & Moura, A. (2000). Occurrence of *Cylindrospermopsis* (Cyanobacteria) in 39 Brazilian tropical reservoirs during the 1998 drought. *Aquatic Microbial Ecology, 23*, 13–27.

CETESB. (2009). *Relatório de qualidade das águas interiores do Estado de São Paulo 2008*. São Paulo: CETESB. 528 p.

Costa, I. A. S., Azevedo, S. M. F. O., Senna, P. A., Bernando, R. R., Costa, S. M., & Chellappa, N. T. (2006). The occurrence of toxin-producing cyanobacteria blooms in a Brazilian semi-arid reservoir. *Brazilian Journal of Biology, 66*, 211–219.

Jacobi, P. R., Fracalanza, A. P., & Campos, V. N. O. (2009). Bacia Hidrográfica do Alto Tietê. GovÁgua USP. Retrieved October 18, 2009, from http://www.usp.br/procam/govagua/altotiete.php.

Mancini, R. M. (2008). Gestão de recursos hídricos no Estado. Palestra apresentada no Urban Age São Paulo Workshop, 04 April 2008, São Paulo.

MMA. (2006). *Plano Nacional de Recursos Hídricos: Síntese executiva*. Brasília: Ministério do Meio Ambiente, Secretaria de Recursos Hídricos. 135 p.

Panosso, R., Costa, I. A. S., Souiza, N. R., Attayde, J. L., Cunha, S. R. S., & Gomes, F. C. F. (2007). Cianobactérias e cianotoxinas em reservatórios do estado do Rio Grande do Norte e o potencial controle das florações pela tilápia do Nilo (*Oreochromis niloticus*). *Oecologia Brasiliensia, 11*, 433–449.

Smith, V. H., & Schindler, D. W. (2009). Eutrophication science: Where do we go from here? *Trends in Ecology and Evolution, 24*, 201–207.

Straškraba, M., & Tundisi, J. G. (Eds.). (2008). *Diretrizes para o gerenciamento de lagos: Gerenciamento da qualidade da água de represas* (2nd ed., Vol. 9). São Carlos: Instituto Internacional de Ecologia. 300 p.

Tucci, C. E. M. (2009). Crise da água e desafios reais. Blog do Tucci. Retrieved July 18, 2009, from http://blog.rhama.net/2009/06/28/crise-da-agua-e-desafios-reais.

UNEP-IETC. (2001). *Planejamento e gerenciamento de lagos e represas: Uma abordagem integrada ao problema de eutrofização*. São Carlos: Programa das Nações Unidas para o Meio Ambiente Instituto Internacional de Ecologia. 385 p. (Portuguese edition).

UNESCO. (2009). *Water in a changing world. The United Nations, World Water Development Report 3*. Paris: UNESCO Publishing. 318 p.