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Restoration of Lake Pampulha, Brazil by using sanitation and in-lake techniques

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The paper presents a broad view about the measures for restoration of Lake Pampulha, Brazil. This man made reservoir is located in a dense inhabited urban area and constitutes the main touristic attraction of the city of Belo Horizonte. Since several decades the water body receives the discharge of untreated sewage from domestic as well from industrial sources, what leads to severe episodes of algal blooms in the water surface. In order to combat this eutrophication problem some measures have been already carried out and others are planned in a short term. These preventive and corrective techniques provides an efficient association between sanitation processes and the application of in-lake treatment actions. Moreover a hydrodynamic modelling has been also carried out with the purpose of evaluating the water circulation and the water residence time in the compartments of the lake.

Introduction

Lake Pampulha (Figure 1) is a man made reservoir located within the urban area of the city of Belo Horizonte, Brazil. The lake was constructed originally with the objective of water supply, but the degradation of the water quality prevented the further use of this source as such. Presently Lake Pampulha, which is one of the most important tourist attractions of the region, is suitable only for some restricted recreational activities. The lake has an area of approximately 2,6 km^2 and a volume of about 14 million m^3. Its maximum depth is 16 m and the mean depth is 5 m. The drainage area, where 350.000 people live, occupies the significant number of 97 km^2. The relationship between these figures indicate that the lake receives a considerable influence (*diffuse pollution*) from the activities developed in the watershed. The main sources of pollution are the discharge of untreated sewage into the lake, the strong erosion of many areas in the drainage basin, leading to a high volume of settlement material in the waterbody and also the presence of diffuse sources of pollution.

Material and methods

The monitoring programme in Lake Pampulha is carried out by two local organizations:Water Supply Company and Water Management Company, both linked to the administrative sphere of the State of Minas Gerais. The sampling stations (Figure 1) are located inside the reservoir (3 stations) and in each of the direct tributaries to the lake (8 stations). The sampling frequence varies from a weekly monitoring for some most relevant parameters till monthly or bimonthly intervals for other water quality indicators. This regular monitoring programme started at 1997 and presents hence a large data base of results. Moreover several other institutions, including here the Federal University of Minas Gerais, carry out complementary water samplings for research purposes. Annual average precipitation in the drainage basin of Lake Pampulha is around 1500 mm. Rainy season extends from October/November to March/April.

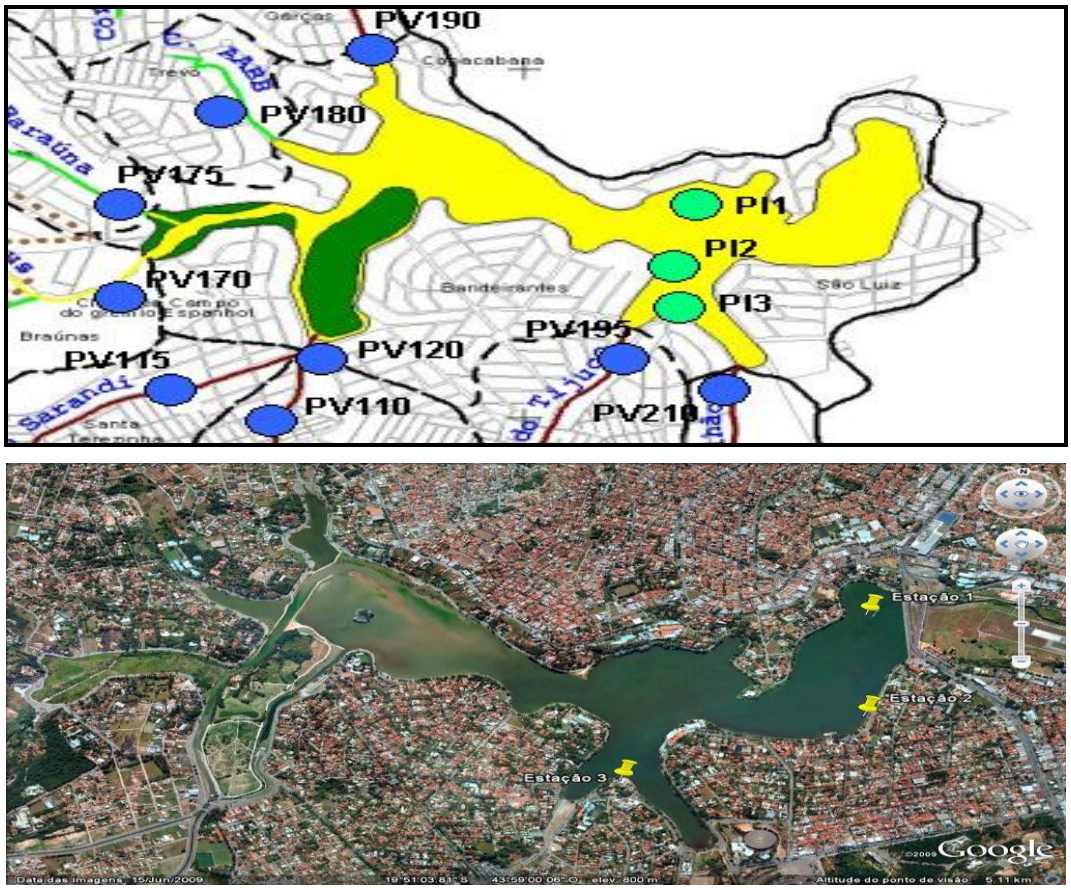

Figure 1. View of Lake Pampulha and location of monitoring stations (outside and inside the lake)

Results and discussion

A summary of water quality data in the period 1997-2010 is presented in this topic. Due to historical discharge of untreated sewage, nutrient concentrations are high in the waters of Lake Pampulha. The average values for total phosphorus range from 0.05 mg/L to 0.2 mg/L, with peaks of 0.45 mg/L (surface) and 0.4 mg/L (bottom). Nitrate concentrations oscillate between 0.2 and 2 mg/L and ammonium between 1 and 8 mg/L. These numbers stress the prevalence of chemical reduced compounds in Lake Pampulha. There is a marked seasonal variation of nutrients, with lower concentrations being detected during the rainy season. The N/P ratio is generally over 40, thus indicating the phosphorus as the limiting nutrient for the algae growth. The intense presence of dissolved salts is reflected in high values of electrical conductivity (200 – 350 µS/cm) (Macedo and Pinto-Coelho, 2000). Some heavy metals are frequently found in Lake Pampulha waters, originated from the discharge of industrial sewage in the neighbour city of Contagem, which is situated in the drainage basin of the lake. The most common heavy metals are cadmium, copper and silver.

Dissolved oxygen values range from anoxia (at the bottom of the lake) till 13 mg/L at the surface (supersaturation due to algal blooms). Higher DO concentrations are registered during the dry season On the other hand BOD (Biological Oxygen Demand) shows higher values at the rainy season, with concentrations till 30 mg/L (in some tributaries they reach occasionally 200 mg/L). COD (Chemical Oxygen Demand) varies from 20 to 60 mg/L. Secchi depth is generally very low (0,3-0,6 m), with higher values (up to 1 m) in the dry season . Chlorides concentrations are found in the range from 10 to 40 mg/L .pH values are always over 7 (max. around 9) as consequence of the intense photosynthetical activity of the phytoplankton. Average concentrations of Total Dissolved Solids are around 200 mg/L. Electrical conductivity values are high for fresh waters (200-300 µS/cm, in some tributaries till 500 µS/cm) reflecting the contamination by sewage discharges. Turbidity is quite variable according to the local climatology while Colour shows

maximum concentrations of 50 mg/L. The bacteriological contamination is reflected in the high counts of Thermotolerant Coliforms (till 30000 MPN/100mL).

Average phytoplankton populations range from 21000 to 27000 ind/m^2, with a strong domination of Cyanophyceae (blue-green algae) and the prevalence of the following genera: *Aphanizomenon, Aphanocapsa, Merismopedia, Microcystis, Planktolyngbya, Pseudoanabaena, Sphaerocavum.* The second algal group in dominance are Cryptophyceae (mainly the genus (*Cryptomonas*). Zooplankton populations are in the amplitude of 300000-800000 ind/m^3 and show the dominance of Rotifera (specially *Brachionus*) and Crustacea (Copepoda). Currently there are no register of the presence of verms of *Schistosoma mansoni* (bilharziasis) in spite of the widespread occupation of snails from genus *Biomphalaria*. Eutrophication problems in Lake Pampulha lead to the occurrence of blooms of aquatic plants. In many cases the green carpet, formed mainly by water hyacinths (*Eichhornia crassipes*) and cyanobacteria, cover one fourth of the surface of the reservoir. Besides water hyacinth other macrophytes can also be found in Lake Pampulha such as *Salvinia molesta* (floating plant) and *Typha latifolia* (rooted plant).

The presence of cyanobacteria in water systems is one of the main pollution problems all over the world. The effects of the eventual release of toxins are potentialized in tropical climates, since warm water conditions clearly may accelerate the dynamics of the eutrophication process. A deep concern is dedicated to cyanobacterial blooms in Brazil, since it was the first country in the world to register human deaths in a dialysis unit caused by the presence of cyanoprocaryota toxins (Azevedo et.al., 1996, Charmichael et.al., 2001).

Since the early 90"s local authorities implemented a broad restorarion program, which was based on the adoption of preventive and corrective techniques for the rehabilitation of the aquatic system. Besides sewage diversion, which is an obvious measure to be adopted for the restoration of eutrophic lakes and probably the most important one, other procedures have been carried out in the last five years. Erosion control was achieved through the use of hydroseeding in the slopes were vegetation has been artificially removed. The regrowth of grass vegetation takes place in the period of only a few weeks, thus minimizing the impacts of the very intensive rainfalls that are typical of the region. Regarding macrophyte removal several attempts have been made in order to reduce efficiently the considerable mass of aquatic plants.The main problem lies in the very high growth rate of water hyacinths, which are frequently far greater than the removal capacity of the equipments. The final destination of the removed material are islands created within the reservoir as a consequence of the dredging operation. These islands now function as recreation site for the population and as field laboratory for ecological studies. At the main entrance of the lake a water treatment plant has been built, which operates by flotating the incoming pollutants. This plant shows an average efficiency of 63 % for BOD, 45 % for sedimented solids and 88 % for phosphorus.

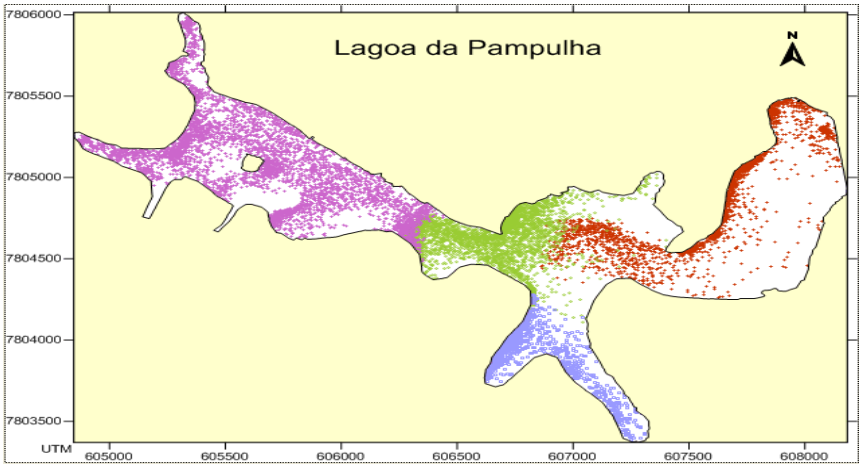

Figure 2. Lagrangean particles distributed in the surface of Lake Pampulha (simulation in 15/09/09)

Hydrodynamic studies have been carried out due to the limnological importance of transport processes in lakes, which influence on the water retention time and consequently on the magnitude of algal blooms. The hydrodynamic tridimensional model SisBaHia^{R} (www.sisbahia.coppe.ufrj.br), which calculates velocities profiles along the depth has been used in Lake Pampulha. Hydrodymanic models are very useful for water bodies where wind action is relevant, as is the case of Lake Pampulha (wind velocities till 7 m/s). Model application allows the calculation of velocities distribution at the surface of the lake. Higher values were obtained close to the dam. i.e.,at the outlet of the lake, what indicates that longer retention times are registered at the opposite direction (entrance of the lake). These results confirm the trend in the onset of the most severe algal blooms exactly in this riverine region of the lake, where hydrodynamic is limited and consequently water retention times are higher. Also a Lagrangean transport model was used for simulation of cyanobacteria distribution in the lake (Figure 2). These organisms may be considered as passive contaminants, whose dispersion plume is represented by an amount of small particles launched in the lake. The simulation shows a trend of cyanobacteria accumulation at the entrance and in the shorelines of the lake.

Conclusions

Belo Horizonte has been selected as one of the cities for the soccer games in the next World Cup, which will be held in Brazil in July 2014. Due to this increased touristic potential the local municipality started already a new restoration program for the lake with the collaboration of experts from the Federal University of Minas Gerais and the awareness, understanding and commitment of public. The implementation of advanced restoration techniques such as hypolimnetic aeration, bioremediation and long distance dredging will take place in 2011. These actions will surely bring an enhanced ecological value and a sounder landscape harmony to the most relevant touristic attraction of Belo Horizonte. The restoration program should be finished in its first phase before 2014. The second phase of the restoration program will encompass the appropriate maintenance of the water quality according to the established levels.

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