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Influence of rainfall on the trophic status of a Brazilian semiarid reservoir

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ABSTRACT. This study evaluated the trophic conditions of the reservoir located in the urban perimeter of the town General Sampaio, semiarid region of the Ceará State, Brazil and its relationship with seasonal variation in rainfall between 2010 and 2011. It was obtained data for Secchi disk transparency, total phosphorus, and chlorophyll *a* to calculate the Trophic State Index (TSI), as well as rainfall data. The Trophic State Index (TSI) proposed by Carlson (1977) and modified by Toledo Junior (1990) was used to test the influence of the seasonal variation in rainfall on hydrological variables and on trophic conditions of the reservoir in 2010 and 2011. There was seasonal variability in variables analyzed between climatic periods (rainy and dry) and trophic conditions determined through the trophic index indicated conditions ranging from oligotrophic to eutrophic during the two years analyzed in this reservoir. Under these circumstances, one may conclude that the trophic status is related to seasonal fluctuations in the hydrology of the system controlled by rainfall, which is a common feature of semiarid regions.

Keywords: Brazilian semiarid, reservoir, trophic state index.

Influência da chuva no estado trófico de um reservatório do semiárido brasileiro

RESUMO. Este estudo buscou avaliar as condições tróficas do reservatório situado no perímetro urbano da cidade de General Sampaio, semiárido do Estado do Ceará, Brasil e sua relação com a variação sazonal das chuvas nos anos 2010 e 2011. Foram obtidos dados de transparência do disco de Secchi, fósforo total e clorofila a para calcular o Índice de Estado Trófico (IET), em paralelo com os dados pluviométricos. Foi utilizado o Índice de Estado Trófico (IET), proposto por Carlson (1977), modificado por Toledo Junior (1990), para testar se a variação sazonal de chuva alterou significativamente as variáveis hidrológicas e as condições tróficas das águas do reservatório nos anos 2010 e 2011. Houve variabilidade sazonal nas variáveis analisadas entre os períodos climáticos (chuvoso e seco) e as condições tróficas determinadas por meio do índice trófico indicaram a presença de condições oligotróficas variando as condições eutróficas durante os anos analisados neste reservatório. Conclui-se que o estado trófico deste reservatório está relacionado com as flutuações sazonais na hidrologia do sistema controlado pela chuva, que é uma característica comum de regiões semiáridas.

Palavras-chave: semiárido brasileiro, reservatório, índice de estado trófico.

Introduction

Large reservoirs have a horizontal spatial distribution and temporal fluctuations, with their own dynamics, balancing the input/output (TUNDISI et al., 2004). These authors have reported a temporary compartmentalization depending on the horizontal flow in the surface. It is influenced by the distribution of water masses with different densities and wind action. According to Blenckner (2005), the seasonal distribution of limnological variables in a reservoir is related to the following factors: i) advection flows generated by the entrance of rivers caused by rainfall; ii) streams due to the horizontal flow, consequence of water masses outflow at several depths and iii) surface flows due to seasonal wind action.

Temporal fluctuations generated by seasonal variations in rainfall lead chemical, physical and biological modifications in the reservoir water (TUNDISI et al., 2004).

Chellappa et al. (2009) theorized that rainfall regimes may act as a variation factor in semiarid reservoirs, since these regions present well-defined seasonal climates, with cycles of rain in the first half (rainy period) of the year and drought in the second half (dry period). Consequently, physical, chemical, and biological variables face up to significant change-over related to alterations in the water level

and the input of allochthonous material (PAGIORO et al., 2005).

In semiarid regions some studies demonstrated changes in the trophic state of water sources, through human practices and occupation of watersheds which may raise nitrogen and phosphorus levels, which in turn can lead to the eutrophication and poor quality of the water of lakes, rivers and reservoirs (CHELLAPPA et al., 2009; MOLISANI et al., 2010).

In reservoirs of semiarid regions of Brazil, the eutrophication is a usual problem because many of these reservoirs were constructed near or within urban areas. Therefore, it is important to conduct researches to understand how the seasonal variation in rainfall can change the water level, allochthonous material input, and its influence on trophic conditions of water in reservoirs located in the northeastern Brazilian region (PAGIORO et al., 2005).

Accordingly, the hypothesis of this study is that seasonal variation in rainfall promotes significant fluctuations in hydrological variables, and hence modifies the trophic conditions in the water of General Sampaio Reservoir, Ceará State, Brazil. In this study, we used the Trophic State Index (TSI) proposed by Carlson (1977) modified by Toledo Junior (1990) to assess trophic conditions of the reservoir in relation to rainfall variations in 2010 and 2011.

Material and methods

Study area

The General Sampaio reservoir (39°27'16"W, 4°3'52"S) is situated inside the urban perimeter of the municipality of General Sampaio, Curu River Basin, which is located in the middle of the northern state of Ceará, Brazil (Figure 1).

This region is characterized by irregular rainfall, variable natural water flows, high temperatures, and severe heat stroke (FUNCEME, 2011; IPECE, 2011). According to the classification of Köppen (1948), the climate is characterized as BSw'h', i.e., it is semiarid and warm with rain in summer and autumn, and dry in winter and spring. There are 2 distinct climatic periods, in this region: (1) a rainy season from January to June and (2) a dry season from July to December, with a historical rainfall average (1980 to 2011) of 818.7 mm (FUNCEME, 2011).

The water storage capacity of the General Sampaio Reservoir is 322,200,000 m^3. The basin has an average depth of 15.1 m and covers a hydraulic area of 3,300 ha, with a drainage system of 1,720 km^2 (ARAÚJO, 1990). The water from this reservoir is used to supply the local population, to irrigate small crops and fish farming in cages. Although the reservoir is located in an urban area, it has little population along its banks. The vegetation in the abstraction area of this reservoir is dominated by dense shrub named 'Caatinga' (IPECE, 2011).

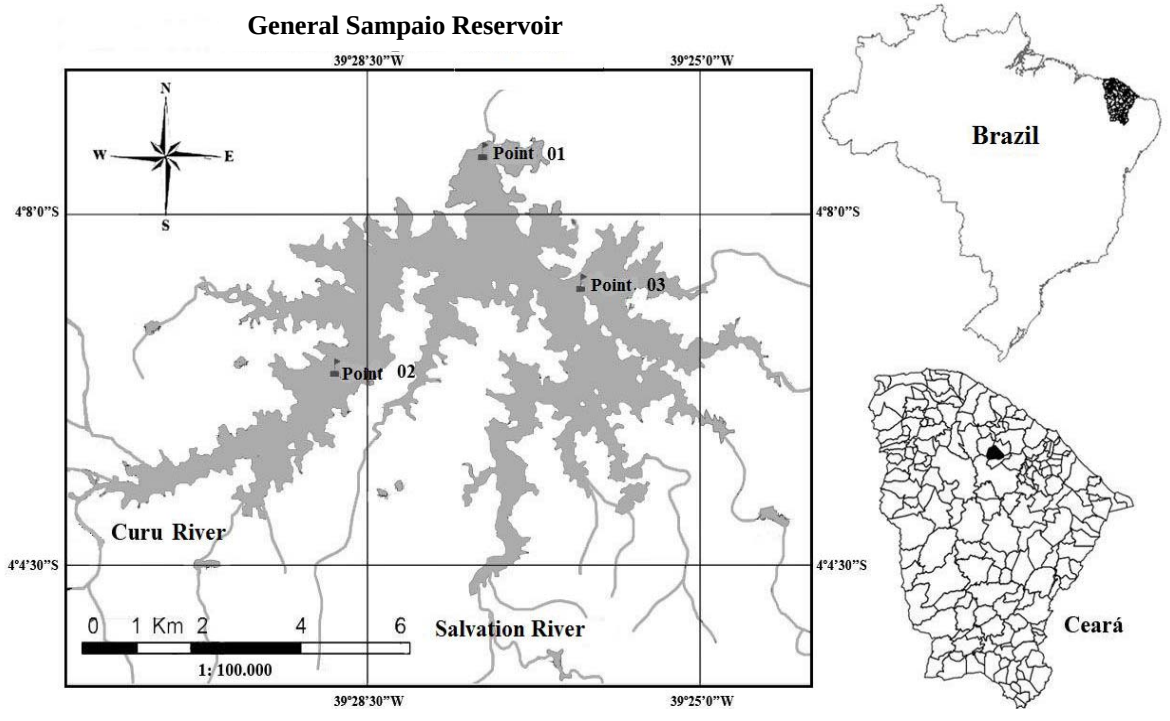

Figure 1. General Sampaio reservoir, Ceará State, Brazil.

In the State of Ceará, the reservoir limnology is still at early stages. The location at the North end of the country and in a semiarid region assigns great importance to comparative studies on the ecosystem variability as a result of geographical location.

Climatic and hydrological variables

The rainfall data were collected daily and monthly *in situ* by the Ceará Foundation for Meteorology - Funceme. This organization reveals data obtained from monitoring conducted at the General Sampaio Weather Station in the last 31 years (1980 to 2011), which is located in the watershed of the reservoir. The values of hydraulic retention time and cumulative volume of the General Sampaio Reservoir were made available for the years 2010 and 2011 by the Company of Water Resources of the State of Ceara - COGERH-CE.

Collection methods and laboratory assessment

Every two months, water samples were collected from January (the beginning of the rainy season) to November (dry season), in 2010 and 2011. Samples were always collected between 9:00 a.m. and 3:00 p.m. on the same day at 3 sampling stations (sites 1, 2 and 3) in the General Sampaio Reservoir (Figure 1), and were located using a Global Positioning System (GPS). Sampling stations were selected using the significance criteria: Near the reservoir water outflow (site 1) and at the two main tributaries of the reservoir basin (sites 2 and 3).

The water for analysis was collected using a Van Dorn bottle at the surface. Variables selected to calculate the trophic state were water transparency, estimated by the Secchi disk (30 cm in diameter), total phosphorus (ammonium persulfate and ascorbic acid method), and chlorophyll *a* (acetone extraction). These parameters were determined according to the methods described in Standard Methods for the Examination of Water and Wastewater (CLESCERI et al., 2005).

Trophic State Index

Trophic conditions of the General Sampaio Reservoir were derived from Trophic State Index (TSI) proposed by Carlson (1977) modified by Toledo Junior (1990), which incorporates Secchi disk transparency, total phosphorus and chlorophyll *a* as indicators (or variables) of trophic state, based on equations 1, 2 and 3:

$$IET\ (DS) = 10\left[6 - \left(\frac{0.64 + \ln DS}{\ln 2}\right)\right] \quad (1)$$

$$IET\ (PT) = 10\left[6 - \left(\frac{\ln\left(80.32 / PT\right)}{\ln 2}\right)\right] \quad (2)$$

$$IET\ (Cl"a") = 10\left[6 - \left(\frac{2.04 - 0.695 * \ln Cl"a"}{\ln 2}\right)\right] \quad (3)$$

where:

Cl "a" = chlorophyll *a* (μg L^{-1}), DS = Secchi disk (m), PT = total phosphorus (mg L^{-1}), and ln = natural logarithm.

For determining the mean TSI, the calculation of this index was carried out using the weighted mean (equation 4), attributing a lesser weight to the water Secchi disk transparency, as suggested by Toledo Junior (1990).

$$TSI\ (mean) = \frac{TSI\ (DS) + 2\left[TSI\ (PT) + TSI\ (Cl"a")\right]}{5} \quad (4)$$

The criteria adopted for the classification of trophic typology were ultraoligotrophic (TSI ≤ 24), oligotrophic (24 < TSI ≤ 44), mesotrophic (44 < TSI ≤ 54), eutrophic (54 < TSI ≤ 74), and hypereutrophic (TSI > 74).

Statistical analysis

Possible differences between the 3 sampling stations (sites 1, 2 and 3) of the Reservoir, in the 4 climatic periods (rainy and dry seasons of 2010 and 2011) and were checked through ANOVAs ($p < 0.05$) applied for the trophic state index.

Results and discussion

Climatic and hydrological variables

During 2010, rainfall at the General Sampaio Reservoir was well below the historical monthly average of the preceding 30 years. The year of 2010 was considered a year with atypical rainfall, and the fourth driest year since 1980. The total rainfall of 2010 was 479.7 mm, concentrated in January (78 mm) and April (175.2 mm), while rainfall during the other months was below 60 mm. In contrast, rainfall in 2011 was close to the expected annual average (788.2 mm) ensuring a normal volume for the current year (COGERH-CE, 2011) (Figure 2).

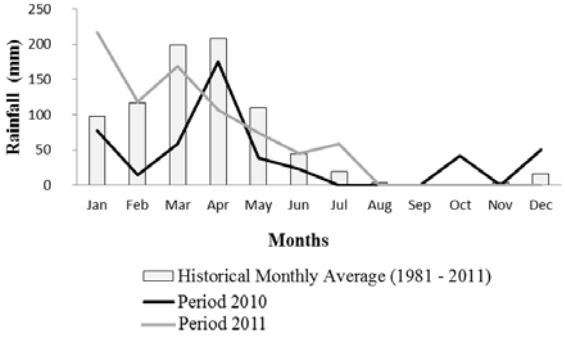

Figure 2. Historical monthly average (1980-2011) and annual rainfall regime during 2010 and 2011 at the General Sampaio Reservoir, Ceará State, Brazil. Source: Funceme (2011).

At the beginning of 2010, the volumetric capacity of the General Sampaio Reservoir was 83.4% of the total, corresponding to 274.6 hm^3 (Figure 3).

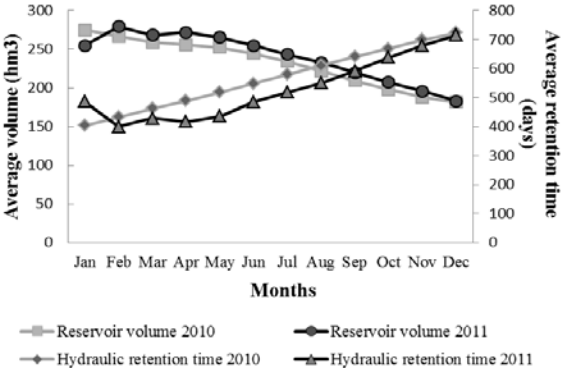

Figure 3. Variation in the volume and hydraulic retention time during 2010 and 2011 at the General Sampaio Reservoir, Ceará State, Brazil. Source: COGERH-CE (2011).

This volume showed an annual strong linear decline, with lower values recorded in December, reaching 51.7% of total volume. This amount further declined 35.2% of total volume during the 2010 study period. But in 2011, the volume of rainfall during the rainy season was enough to raise the water level of the reservoir to a normal volume (86.9% of the total volume), with just a slower decline during the year. Despite the release of water from the reservoir to help supplying the neighbor cities of the region, their local consumption and natural evaporation, losses were not caused to the local population around the reservoir and the water supply was normally maintained in both of the research years.

In contrast, the hydraulic retention time increased linearly during both years, increasing from 403.1 to 723.3 days between January and December 2010 and from 486.5 to 715.3 days between January and December 2011. These values were inversely proportional to the water volume of the reservoir.

According to Molisani et al. (2010) the relationship among horizontal spatial distribution suggest that the seasonal variability is explained by the hydrodynamic process, that is the different variations in reservoir hydraulic area and through transport of particles and deposition influence its water and biological process. In this study, the irregular dynamics of limnological variables may be explained by this process and by discharges of the Curu river in the rainy period.

Atypical rainfall events below the average in 2009 (1267.8 mm) have been caused by the El Niño phenomenon (FUNCEME, 2011), so hydrological and climatic conditions are considered as causal factors of changes in limnological variables of the reservoirs of semiarid regions (CHELLAPPA et al., 2009). During the first half of 2010, the maintenance of high average depth and water volume in the reservoir favored the maintenance of nutrient concentrations able to keep the oligotrophic state. Otherwise, during 2011, the initial low water volume favored the sustenance of eutrophic conditions and the inflow of the rainwater promoted the decrease in the eutrophication level.

Henry et al. (2006) pointed out that the rain is an important dilution factor in relation to variables such as phosphorus and chlorophyll *a* in reservoirs, with a negative correlation between rainfall and these limnological variables, highlighting the importance of measuring these factors to estimate the productivity of aquatic systems.

Trophic State Index

Figure 4 depicts the mean TSI values for 2010.

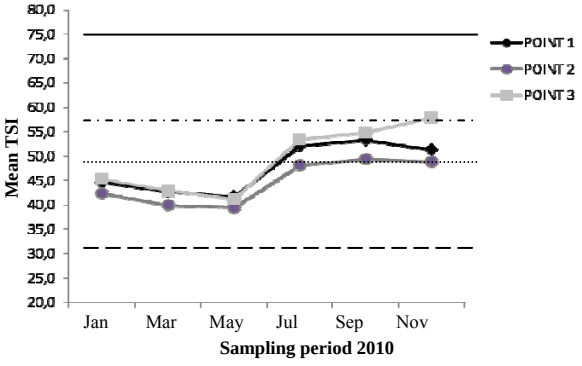

Figure 4. Mean Trophic State Index (TSI) proposed by Carlson (1977) modified by Toledo Junior (1990) at the 3 sampling sites in the General Sampaio Reservoir during 2010. Ultraoligotrophic limit (— — —), oligotrophic limit (·····), mesotrophic limit (- · - ·), eutrophic limit (——).

The results of the mean TSI during 2010 showed a gradual increase in the eutrophication level, which was classified between oligotrophic to eutrophic state.

The data generated by the mean TSI during 2010 showed that the site 3 presented eutrophic status with the highest value registered in November/2010 (57.9). The site 2 presented the lowest value in May/2010 (39.4). The mean TSI for the entire reservoir was 47.2 (n = 18; SD = 5.6) which classified it as mesotrophic. This value, however, was close to the upper limit of oligotrophy (<45). When considered the two climatic seasons (rainy and dry) separately, the reservoir may be considered oligotrophic in rainy season as its mean value was 42.2 (n = 9; SD = 1.7). On the one hand, the reservoir may be considered mesotrophic in dry season as its mean value was 52.1 (n = 9; SD = 1.3), close to the limit value classified as eutrophic (>54). Statistical analysis corroborated these results: the sampling sites in the reservoir have not been different, but climatic seasons were different ($p < 0.05$).

On the other hand, the results of the mean TSI during 2011 had a gradual decrease in eutrophication, which was classified between eutrophic to oligotrophic state (Figure 5).

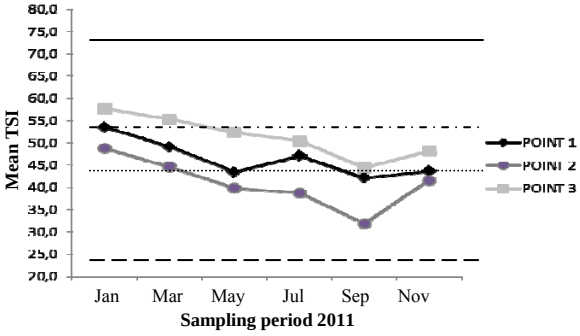

Figure 5. Mean Trophic State Index (TSI) proposed by Carlson (1977) modified by Toledo Junior (1990) at the 3 sampling sites in the General Sampaio Reservoir during 2011. Ultraoligotrophic limit (— —), oligotrophic limit (·····), mesotrophic limit (- · - · -), eutrophic limit (——).

The data generated by the mean TSI during 2011 indicated that the site 3 presented the highest value in January/2011 (57.7). The site 2 presented the lowest value in September/2011 (31.9). The mean TSI for the entire reservoir was 46.3 (n = 18; SD = 5.3) classifying it as mesotrophic. This value, however, was close to the upper limit value classified as oligotrophic (TSI < 45). When considered the two climatic seasons (rainy and dry) separately, the reservoir may be considered mesotrophic in rainy season as its mean value was 49.4 (n = 9; SD = 4.1). In contrast to 2010, the reservoir may be considered oligotrophic in dry season as its mean value was 43.1 (n = 9; SD = 4.2). Statistical analysis corroborated these results: the sampling sites in the reservoir and the climatic seasons have not been different to each other ($p < 0.05$).

Furthermore the water entering in the reservoir potentiated by the rainfall allows the input of suspended material which strongly changes the water transparency and influences the trophic status of aquatic habitats, and the light penetration determines the development of phytoplankton and as a consequence, habitat enrichment by nutrients (ESTEVES, 2011).

Nitrogen and phosphorus are the major nutrients for primary producers in aquatic habitats (ESTEVES, 2011). Chellappa et al. (2009) demonstrated that in a semiarid reservoir; phosphorus was the nutrient that presented the best significant and linear relationship with chlorophyll *a* concentrations, and a significant and positive relationship with the water transparency.

When poorly managed, human occupation of watersheds and large nutrient loads for water systems are factors that contribute to the eutrophication process of water in tropical reservoirs (ELSER, 2007). The level of eutrophication in the General Sampaio Reservoir based on the Trophic State Index (TSI) proposed by Carlson (1977) modified by Toledo Junior (1990), indicated that the water quality of the drainage basin has deteriorated during the dry period of 2010, year with low level of rainfall. However, high levels of phosphorus during the first half of 2010 may be associated with the input of organic matter from the watershed by heavy rains in 2009, particularly as the reservoir is situated in an area under the influence of the urban perimeter of the city of General Sampaio.

Amancio et al. (2005) conducted a study on reservoirs located in the same watershed of the General Sampaio Reservoir, and noticed the importance of the drainage on the reservoir trophic conditions, with organic matter from the watershed comprising the main source of phosphorus and nitrogen. A classification system exists to distinguish between different trophic limnological variables, describing the dynamics of the system and the limitations of the medium (MOLISANI et al., 2010).

The variability detected in the trophic classification of the General Sampaio Reservoir (based on each indicator) was explained by the degree of constraint exerted by the medium. Therefore, during 2010 and 2011, the inconsistency of the trophic classification along with the higher variation in phosphorus levels, may have facilitated the maintenance and gradual increase of chlorophyll *a*, which subsequently allowed the development of microalgal biomass.

Some studies in semiarid Brazilian reservoirs (ESKINAZI-SANT'ANNA et al., 2007; VON

SPERLING et al., 2008) have shown that advanced stages of eutrophication (between eutrophic or hypereutrophic categories) are associated with climatic and hydrological factors, which when combined with inappropriate human use and occupation of river basins, may result in the dominance and abundance of cyanobacteria that can be harmful to human health.

Several studies (COSTA et al., 2009; ESKINAZI-SANT'ANNA et al., 2007) have reported that the Cyanophyceae class has physiological features that maximize the use of nutrients from the water, even when in minute concentrations, which prevents other species to reach dominance, including Chlorophyceae. Some characteristics of semiarid reservoirs provide favorable conditions necessary for the occurrence and blooms of the Cyanophyceae class. Such characteristics included water level reduction and increased hydraulic retention time during the dry season, in addition to water column stability, high average depth, sunlight, and high temperatures (COSTA et al., 2006; DELLAMANO-OLIVEIRA et al., 2003).

Therefore, the intensity and frequency of rainfall events in the General Sampaio Reservoir during 2010 and 2011 cannot be classified as a high-intensity disturbance, but that might promote gradual changes in the trophic level. These results confirm the hypothesis of Scheffer (2003) who stated that in the absence of disturbances (such as very low annual rainfall), limnological variables are minimally changed over the year. This observation also supports the findings of Chellappa et al. (2009) in others Brazilian semiarid reservoirs, and provides additional evidence for positive correlation between these two variables and the level of rainfall in these aquatic ecosystems.

Conclusion

This study verified the temporal variation in the trophic status of the General Sampaio reservoir, in 2010, with lower values during the rainy season, which have gradually increased over the dry period, and inversely in 2011, with higher values in the rainy season that have gradually reduced over the dry period. Despite the evidence already obtained, further studies on semiarid reservoirs should be performed, in order to confirm this hypothesis and to detect significant changes in the trophic conditions and in the phytoplankton assemblage in these reservoirs and their effects on the water quality and on the supply for the population of the region.

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