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Guarapiranga Dam (São Paulo-SP/Brazil) Nitrogen Distribution

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ABSTRACT

Nowadays Guarapiranga Dam is responsible for about 20% of Metropolitan Region of São Paulo (RMSP) water supply. However, since the 60s an irregular and disordered occupation appears in the area. From the 70's, the reservoir was reported eutrophic due to untreated urban sewage. Cyanobacteria blooms were frequent since 1990. Nitrogen species are a significant part of this eutrophication problem. In this scenario, the present work presents the distributions of nitrogen species in the Guarapiranga Dam, to compare with other lakes and reservoirs status in the world and to find options to this nutrient management in Guarapiranga Reservoir.

Keywords: Nitrogen species; Guarapiranga Dam; eutrophication.

INTRODUCTION

Nitrogen is a key nutrient, required to support primary production of high plants and algae. However high nutrient levels (N and P) could lead to loss of biodiversity, fish kills, dominance of N fixing cyanobacteria and shifts in food web. In addition this events disrupt drinking water condition affecting directly water treatment systems. In urban reservoirs, like Guarapiranga reservoir, point sources are most frequent related to industrial activities, sewage treatment systems or releases and septic tanks overflow. Thus nitrogen distribution could help to locate hot spots from these undesirable point sources

Nitrogen cycling is more complex than phosphorous due to occurrence of several species (NO_3^- , NO_2^- , NH_4^+ , NH_3 , DIN, etc.) and to several source (atmospheric, agricultural, urban, etc.) possibilities. The Nitrogen species oxidation state gives a good indication from the source proximity. Usually, ammonium NH_4^+ -N is considered the beginning of organic nitrogenous residues decomposition by oxidation that slowly converts to nitrate and at the end favors algae blooms. Often high ammonium concentrations in freshwater indicate sewage overflow proximity, that later will be converted to Nitrate. As a more oxidized form, Nitrate high concentrations are found far from the point source when not consumed from algae and plants. In more oxygenated waters, ammonium is not frequent, increasing slowly with the increase of the trophic state.

Since the 60's, Guarapiranga Reservoir was reported eutrophic (Mozeto et al., 2001) due to untreated urban sewage releases, that increases both nitrogen and phosphorus loads. However Guarapiranga Dam presents so far a high intern phosphorous load released from anoxic sediments (Silva et al., 2013). Also Guarapiranga has a high external nitrogen load from urban low income households that needs to be tracked. So by using nitrogen species distribution, this work aim to locate point sources and to estimate nitrogen external load in order to systematize water reservoir management to improve water conditions.

METHODOLOGY

Study site

Guarapiranga Dam (Figure 1) was built in 1909 for energy production, and the dam construction flooded a large portion of Atlantic forest. In 1928 the city of São Paulo began to use the reservoir as a public water supply (Whately et al., 2006). Today, the reservoir is the second major water source in one of the most populated cities in the world. Guarapiranga water catchment station (Alto da Boa Vista station) supplies water to approximately 4 million inhabitants. Guarapiranga is located in the Metropolitan area of São Paulo city, São Paulo State, Brazil (23° 41' S and 46° 43' W) (Mozeto et al., 1998). Some of Guarapiranga Dam hydraulic parameters are presented in Table 1.

Table 1. Guarapiranga Dam characterization.

Hydraulic Parameter	Guarapiranga Dam
Average depth (m)	7
Maximum depth(m)	13
Catchment area (km ²)	640
Urban area (km ²)	106
Volume (m ³)	2.53x10 ⁸
Surface area (m ²)	36.18
Average Residence time in 2013(days)	115
Water supply (m ³ .s ⁻¹)	13.63

Source: adapted CETESB, 2014

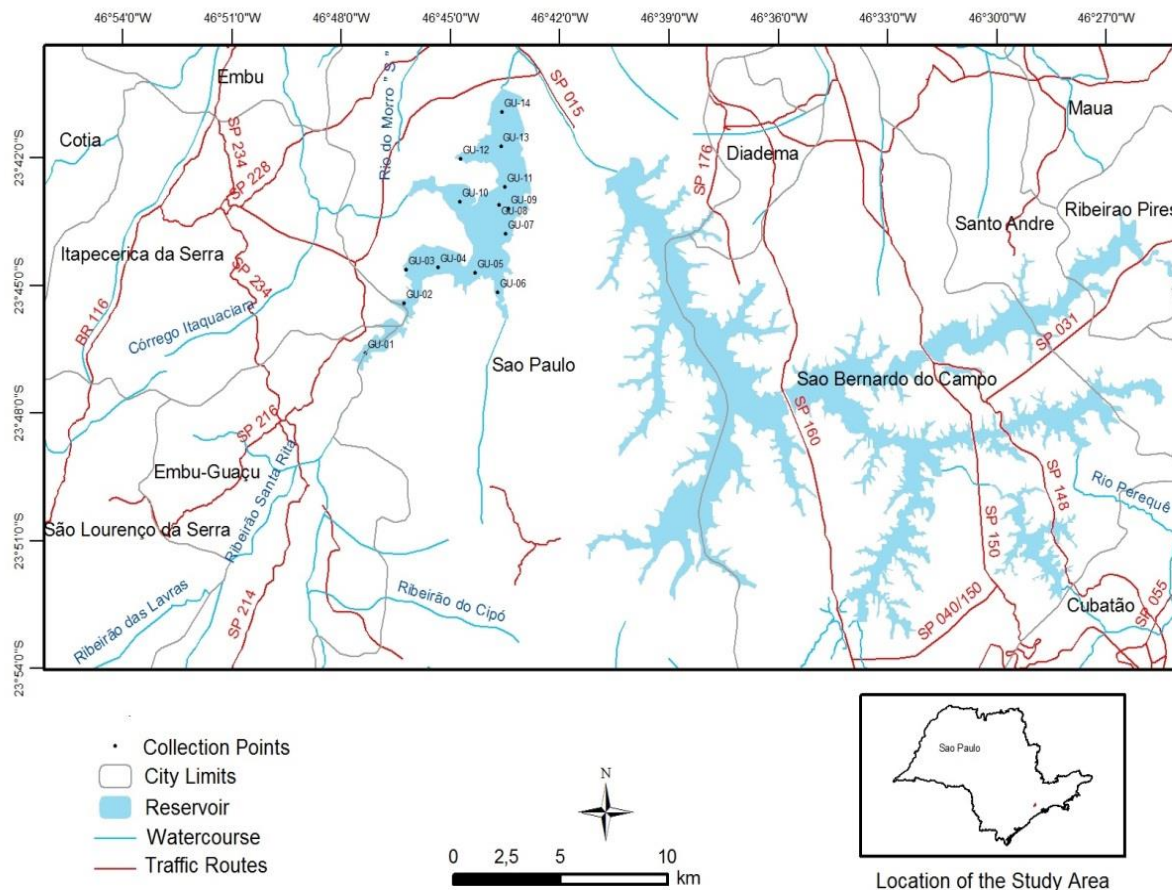


Figure 1. Location of 14 water collection points at Guarapiranga Dam.

Sample collection

Four collections were carried out in dry (August/2011 and September/2012) and rainy seasons (March/2011 and April/2013) in three water column depths (surface, middle and bottom). All collected samples were filtered with a 0.45 µm cellulose acetate filter, maintained at 4°C, and analyzed up to 24 hours after collection (ANA et al., 2011; APHA AWWA WPCF, 2005). NO₂⁻-N, NO₃⁻-N and NH₄⁺-N were measured by ion chromatography - DX-120 (Dionex Corporation) at IPEN/CNEN-SP. Thematic maps were obtained by ArcGIS 10.2 program and statistical analysis performed through Principal Component Analysis (PCA) using the program Statistic version 7.0. Figure 1 presents Guarapiranga Dam with the 14 collection point's distribution.

RESULTS

The summary of four collections campaign, from March 2011 to April 2013, in 14 collection points, regarding NH₄⁺-N, NO₃⁻-N, TN and NO₃⁻-N/NH₄⁺-N ratios results are presented in Table 2. Generally TN and NO₃⁻-N concentrations were larger (0.01 to 0.2 mg.L⁻¹) at highest depth, as expected due to N absorption by algae and plant at shallow depths with light. The difference was larger into deepest points (13 and 14) closed to catchment site.

Table 2. Summary of NH₄⁺-N, NO₃⁻-N, TN and NO₃⁻-N/NH₄⁺-N ratios in 4 sample collection campaigns.

		March 11	August 11	September 12	April 13
NH ₄ ⁺ -N	Average	-	0.77	0.38	0.06
	Std.dev	-	0.60	0.64	0.12
	RSD	-	77%	171%	197%
	Max	-	2.37	2.83	0.51
NO ₃ ⁻ -N	Average	0.34	0.80	0.36	0.61
	Std.dev	0.14	0.34	0.12	0.27
	RSD	40%	43%	32%	45%
	Max	0.52	1.49	0.53	1.05
Total N	Average	0.35	1.33	0.67	0.74
	Std.dev	0.17	0.82	0.62	0.36
	RSD	49%	62%	93%	48%
	Max	0.62	3.06	2.96	1.37
NO ₃ ⁻ -N/NH ₄ ⁺ -N	Average	-	1.47	0.99	3.86
	Std.dev	-	1.17	0.49	1.71
	RSD	-	80%	49%	44%
	Max	-	5.32	1.62	6.31

Figures 2 and 3 presents surface average concentration distribution of nitrogen species in Guarapiranga Dam water collected in four collections. In the Figure 2, NH₄⁺-N high concentrations were observed in an area influenced by Embu-Mirim River (point 10), by Itupu and Guavirutuba streams (point 12) and from the Taquaquacetuba transposition of Billings Dam (point 6). These regions are known to receive large amounts of untreated sewage, due to irregular occupation around the basin. The reductive lake characteristic is expected to increase with the increase of its trophic state (Quiros, 2003). Regarding NH₄⁺-N a decrease was observed on time from August 2011 to April 2013 that could be associated with a faster oxidation to NO₃⁻-N.

A Nitrate longitudinal gradient was identified in Guarapiranga Dam (see Figure 3). The highest NO_3^- -N concentrations were observed closed to water abduction sites from SABESP, São Paulo's public water supplier (points 13 and 14), in these area, algae blooms are often observed. The water flow towards the uptake area is associated with longest retention times and allows NH_4^+ -N biological oxidation (Richter et al., 2007).

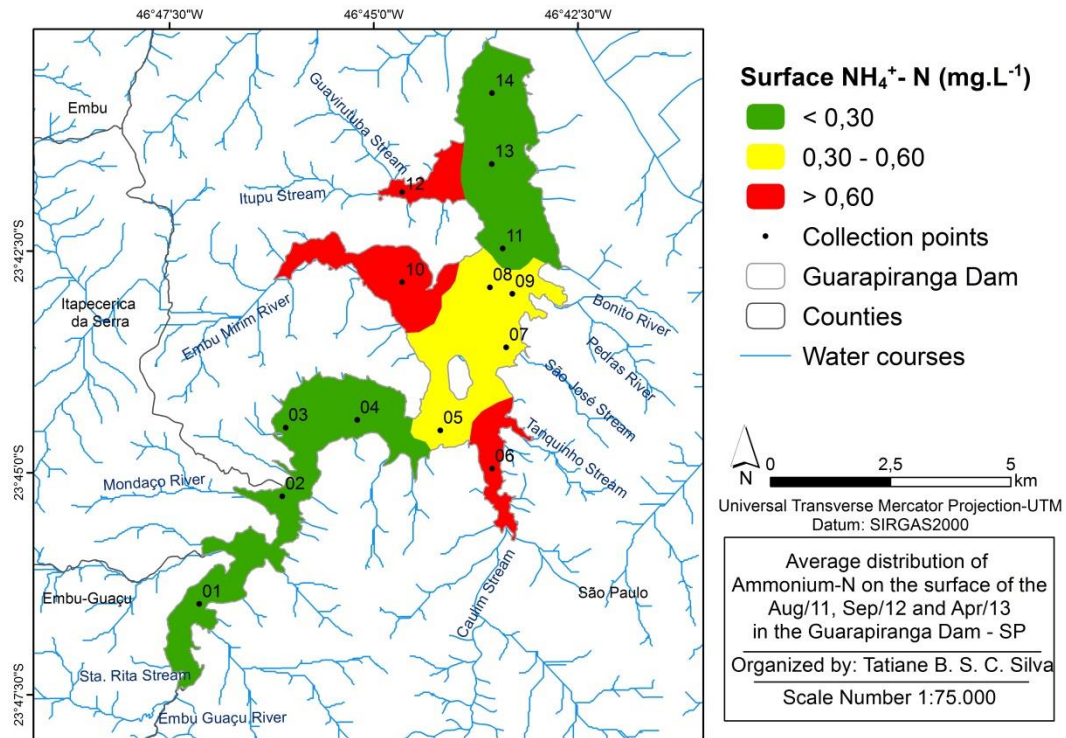


Figure 2. Average surface NH_4^+ -N distribution in Guarapiranga Dam water in collections.

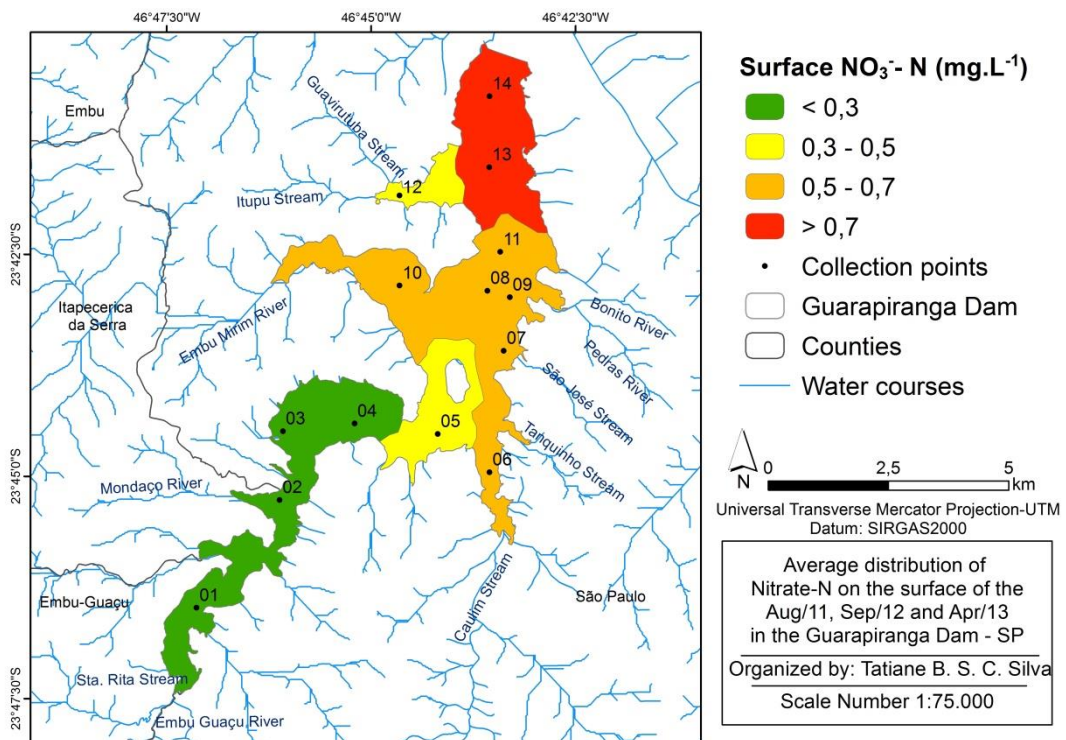


Figure 3. Average surface NO_3^- -N distribution in Guarapiranga Dam water in all collections.

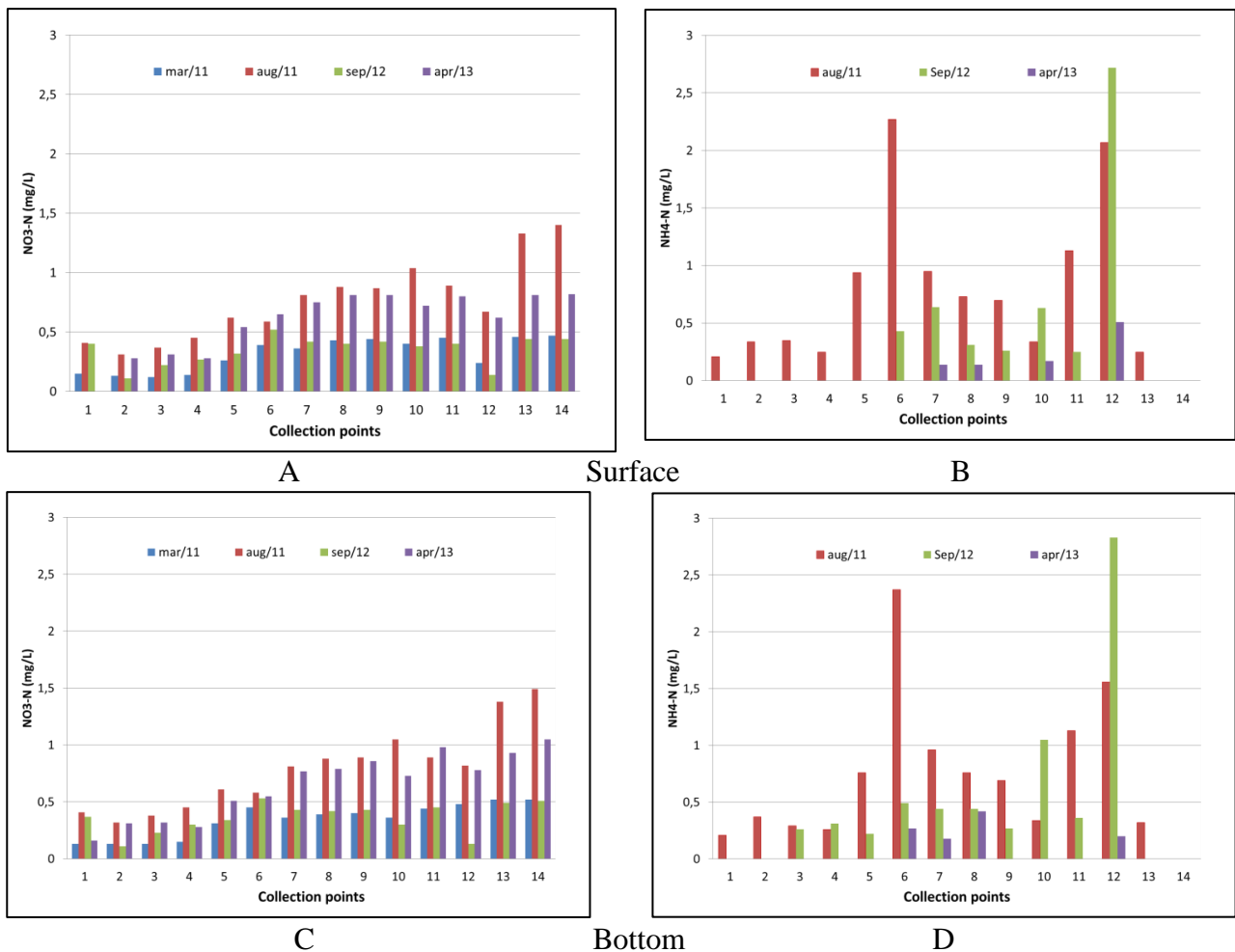


Figure 4: Nitrate and ammonia concentrations on surface and bottom water column from Guarapiranga Dam.

The maps presented in Figure 2 and Figure 3 are an average representation of reactive nitrogen species, therefore a much attenuated scale in concentration is showed. The seasonal values at water column surface and bottom are presented in Figure 4. Therefore, the values present at Figure 4 exhibit higher values. In March 2011, due to a dilution effect, NO₃⁻-N presented lower values that coincide with the rainy season that is also the highest nutrient-loading period for the basin. In August 2011, NO₃⁻-N concentrations were the highest, and NO₃⁻-N in three collection points reached values over 1 mg.L⁻¹. September 2012 was a period of intense drought with smaller water input and high light incidence over water that reduced once again NO₃⁻-N concentration. At all times, most of Guarapiranga Dam area presented nitrogen concentrations away over 20 µg.L⁻¹ a biological limit to algae blooms. Nitrate was uniformly distributed (Figure 4A and 4C) increasing with depth and presenting a transversal gradient trough Guarapiranga Dam. Due its chemical properties, nitrate comes from the oxidation of other nitrogen forms, to be consumed depending on phosphorus and light availability

Ammonia on water column surface and bottom was not uniformly distributed (Figure 4B and 4D), and presented two hotspots over 1 mg.L⁻¹ (collection point 6 and 12) on two different occasions (Aug/11 and Set/12). The expected high ammonia value with water depth did not present a clear trend over these data. Also at several points and occasions ammonia exceeded 0.2 mg.L⁻¹ drinking water limit where water starts to presents taste and odor, and to indicate fecal pollution.

Sources of nutrients in lakes and reservoirs include bedrock, atmospheric deposition, vegetation, animal life and input from human activities (Walker et al., 2007). Guarapiranga reservoir receives most of its water income from continuous source of some tributaries such as Embu-Guaçu e Embu Mirim, Itupu-Guavarituba streams and Caulim-Tanquinho streams. Due to irregular and clandestine untreated sewage releases, the water at Guarapiranga Dam presents a eutrophic to hypereutrophic condition. The frequent algae blooms lead to several impairments at water treatment station, causing blocking filters, undesired odor and taste and increasing water treatment costs. To locate the high ammonia areas could help the sanitation department to increase its control actions and to prevent undesired sewage releases near critical areas such as Embu-mirim River, Itupu, Guavarituba, Caulim and Tanquinho streams.

Nitrogen in other Lakes

Cultural eutrophication is one of the major lake problems around the world, such problem was reported to a series of other lakes such as North America Great Lakes, Lake Biwa in Japan and Lake Fure in Denmark (UNEP, 2017). However in lakes such Lake Victoria which is the largest fresh water in Africa and the second largest in the world, the eutrophication is associated mainly with atmospheric deposition (natural and biomass burning) and land run-off (e.g. agriculture), and these together account for about 90% of phosphorus and 94% of nitrogen input to the Lake (UNEP, 2006). No significant untreated sewage is released in Lake Victoria waters.

In other lakes such as Lake Udaisagar of Udaipur in Rajasthan - India, a hypereutrophic lake that suffers frequent untreated sewage releases and algae blooms and that presents foul odor blue-green color and recreational decrease of water use (Vijayvergia, 2008), nitrate levels are very similar to those found at Guarapiranga Dam.

CONCLUSION

The necessity of nutrient (N and P) removal from lake waters to a safe water environmental is constant in lakes around the world. The first layer of action is a proper sewage collection and treatment that in main lake management systems is absolutely essential. Point sources are the most affecting pollution source with high nutrient loads. In this work, through reactive and soluble nitrogen species in the Guarapiranga Dam, the main nitrogen source area was identified where remediation and sanitation actions must be increased. Embu-Mirim River, Tanquinho, Caulim, Guavarituba and Itupu streams were the critical release points.

Nitrogen species impacted water treatment costs at Alto da Boa Vista Water Supply Station at Guarapiranga Dam, not only due to algacide increasing amounts, but also due to active carbon, polymer and oxidizing agents requested to remove taste and odor from water derived from algae grown and decomposition. Although necessary, Guarapiranga corrective actions are not properly taken, these costs should only increase over time.

These remediation actions closer to nutrient sources would be more cost-effective in the long run. Guarapiranga land use and nutrient input should be properly managed in order to improve water quality and decrease water treatment costs.

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