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Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region

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SUMMARY

A novel Quality Indicator (QI) and Water Quality Index (WQI) were constructed in the present study for the evaluation of the water quality of a Hydroelectric Plant reservoir in the Amazon area, Brazil, taking into account the specific characteristics of the Amazon area. Factor analyses were applied in order to select the relevant parameters to be included in the construction of both indices. Quality curves for each selected parameter were then created and the constructed QI and WQI were then applied to investigate the water quality at the reservoir. The hydrological cycle was shown by the indices to directly affect reservoir water quality, and the WQI was further useful in identifying anthropogenic impacts in the area, since water sampling stations suffering different anthropogenic impacts were categorized differently, with poorer water quality, than stations near the dam and the environmental preservation area, which suffer significantly less anthropogenic impacts, and were categorized as presenting better water quality. The constructed indices are thus helpful in investigating environmental conditions in areas that show well-defined hydrological cycles, in addition to being valuable tools in the detection of anthropogenic impacts. The statistical techniques applied in the construction of these indices may also be used to construct other indices in different geographical areas, taking into account the specificities for each area.

1. Introduction

Water quality is largely determined by natural processes, such as weathering and soil erosion, but also by anthropogenic inputs (Kazi et al., 2009; Singh et al., 2004). To assess human impacts on water quality, variations in space and time and in the biological, physical and chemical processes of natural systems should be considered. One important factor in this context is the hydrological cycle, which directly affects the drainage network of water bodies and may causes surface runoff along riverbanks. This, in turn, may lead to contamination by sediments and several types of pollutants, besides directly affecting the local vegetation and biota (Aubert et al., 2013; Lai et al., 2013; Merten and Minella, 2002). By evaluating these hydrological variations and their effects, it is possible to create management actions that can intervene in the recovery and/or preservation of ecosystems (Abaurrea et al., 2011; Braga et al., 2006; Lucas et al., 2010; Shah et al., 2007; Tundisi and Tundisi, 2008). Water quality assessments also allow for decision-making policies to be made regarding water potability and use.

Several water quality assessment studies have been conducted by applying statistical techniques, such as the principal component analysis, which can aid in identifying natural or anthropogenic factors that can cause alterations in water quality (Andrade et al., 2007; Boyacioglu, 2006; Brito et al., 2006; El-Iskandarani et al., 2004; Guedes et al., 2012; Laureano and Navar, 2002; Petersen et al., 2001; Selle et al., 2013; Vialle et al., 2011; Vonberg et al., 2014). Some studies have applied this statistical technique to specifically propose a Water Quality Index (WQI), by using the weighted scores of each analyzed water quality parameter (Haase et al., 2003; Toledo and Nicolella, 2002). WQIs usually take into account general water parameters, such as dissolved oxygen, pH, temperature, turbidity, and NH_3 concentrations, among others.

UNESCO defines the Amazon region and adjacent areas like the Pantanal as world interest areas due to their unique flora and fauna and great biodiversity. These regions have, however, been increasingly under anthropogenic pressure (Sucksdorff, 1984). One of the

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main impacts in these areas has been the construction of Hydroelectric Power Plants reservoirs, which have become the predominant lake type in many regions throughout the world (Lewis, 2000). These tropical areas go though well-defined defined hydrological cycles each year, and this feature has, increasingly, been studied to obtain environmental information which may help in the monitoring of environmental impacts caused by anthropogenic pressures and may lead to decision-making in this regard. However, to the best of our knowledge, no WQI data in the literature has been constructed taking into account the water transparency or hydrological cycle of the Amazon area.

In this context, the aims of the present study were to create a new Water Quality Index (WQI) by applying multivariate statistical techniques, taking into account the water transparency and specific hydrological cycle of the Amazon, besides other selected parameters. Another objective was the creation of a Quality Indicator (QI), by constructing water quality index curves, and the subsequent application of the constructed QI to the investigation of the water quality of a Hydroelectric Power Plant reservoir in the Amazon region, in order to verify the impact of this construction on the reservoir's water quality throughout the well-defined hydrological cycles of the area.

2. Material and methods

2.1. Study area and sampling stations

The Tucuruí Hydroelectric Plant is located in the state of Pará, Brazil, at latitude 03°43′–05°15′, longitude 49°12′–50°00′W (Fig. 1). The plant was constructed in September 1984 on the river Tocantins, at approximately 7 km from the town of Tucuruí and 300 km from the city of Belém, the state capital. It is the first large-scale (25 units) hydroelectric project in the Brazilian Amazon rainforest, with an installed capacity of 8370 MW. The main purpose of the dam is hydroelectric power production to the Brazilian states of Maranhão and Pará and navigation between the upper and lower Tocantins river.

The reservoir has a total flooded area of approximately 2850 m^2, with approximately 50.8 million m^3 of water and water residence time of 46 days (WCD, 2000). The area is characterized by rainy (December to May) and dry (June to November) seasons, with annual precipitations between 2250 and 2500 mm. The rainiest month is March and the driest is September (Fisch et al., 1990). The local hydrological cycle in the reservoir is reflected in the local water levels, and, consequently, the reservoir goes through a cycle constituted by a full stage, during March, April and May, an emptying stage, during June, July and August, an empty stage during September, October and November, and a filling stage during December, January and February. Eleven water sampling stations (C1, C2, M1, M3, MR, MBB, MBL, MP, MIP, ML and MJV) are present at the Tucuruí Hydroelectric Plant reservoir also displayed in Fig. 1. All are located upstream and represent the specific characteristics of each area within the reservoir.

The large influx of people to this area has also led to deforestation and negative impacts from increased cattle-raising activities. Population increases have also strained the existing infrastructure, or lack thereof (Rebouças et al., 2002; WCD, 2000), leading to concerns regarding anthropogenic influences in the area.

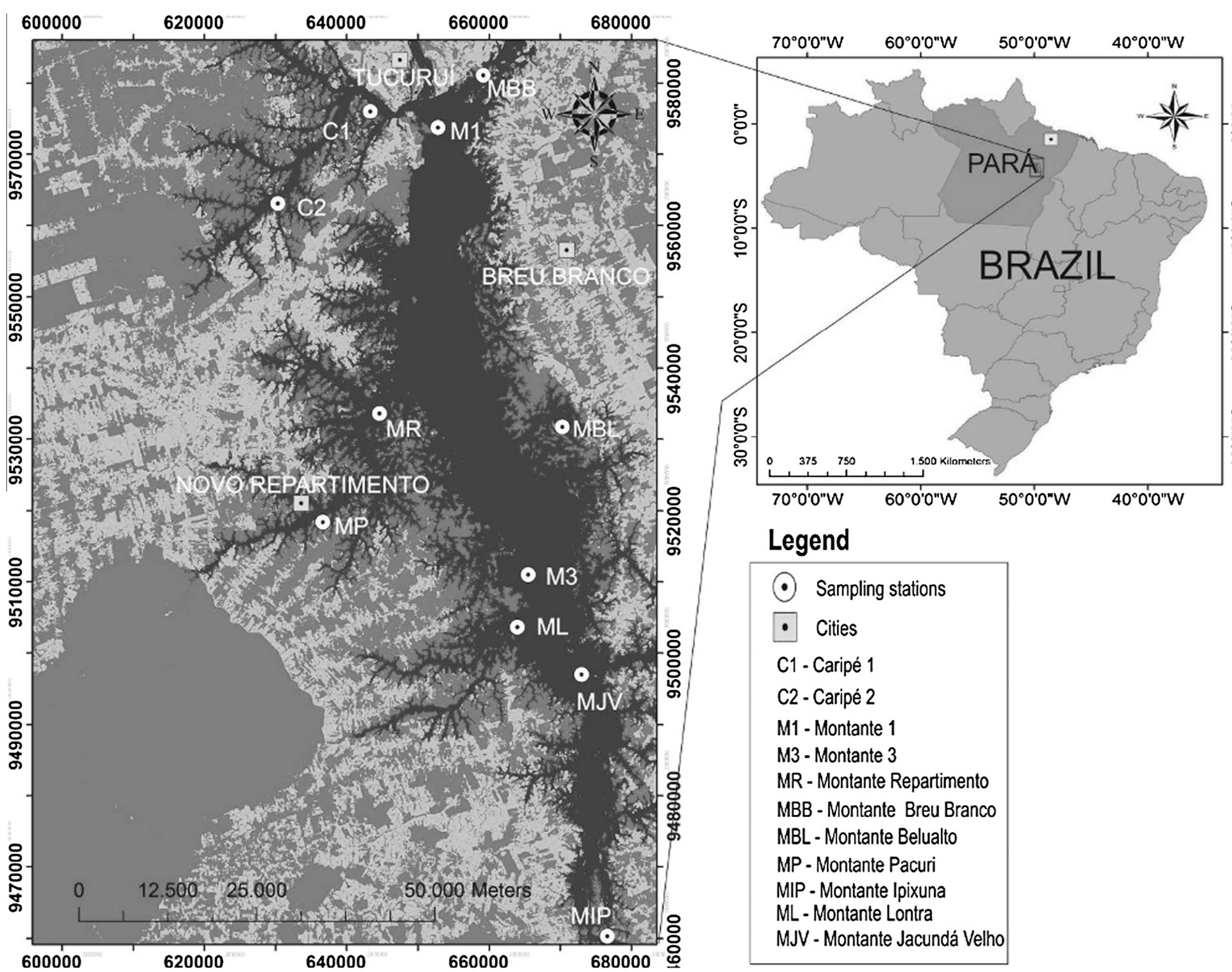

Fig. 1. Location of the Tucuruí Hydroelectric Power Plant reservoir, indicating the water sampling stations.