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Impact of floating platforms on the limnological aspects of hydropower plant reservoirs

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ABSTRACT

Floating platforms at the hydropower plant reservoirs are attractive sites for aquaculture, fishing and other recreational activities. However, the unregulated construction of these platforms may negatively affect the fauna, flora and water quality of reservoirs. Thus, this study aimed to evaluate the impact of floating platforms on the limnological aspects of Nova Ponte hydropower plant reservoirs at the Center-West of Minas Gerais State of Brazil. The obtained data were analyzed using the correlation and regression analysis. Dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total coliforms and thermotolerant bacteria were plotted against the density of floating platforms. The density of platforms significantly (p-value > 0.05) impacted the analyzed limnological aspects of reservoirs. Based on the present results, 4 floating platforms/km2 (1 platform per 25 hectares) of surface water should be the maximum density in order to avoid the deterioration of water quality of reservoirs. With 4 platforms/km^2, the expected values in fishing period were estimated to be 5.4 mg/L for biochemical oxygen demand, 375 most probable number per 100 mL of sample for thermotolerant bacteria and 6.1 mg/L for chemical oxygen demand. In fishing-ban period, the expected values were estimated to be 4.1 mg/L for dissolved oxygen, 3.4 mg/L for biochemical oxygen demand, 379 most probable number per 100 mL of sample for thermotolerant bacteria and 4.2 mg/L for chemical oxygen demand. This finding provides important base-line information which could help policy makers to take effective measurements for the appropriate management of surface water resources.

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INTRODUCTION

Brazil has large surface water resources (8,500 km marine coast and 12% of total global freshwater) (BMPA, 2014). These water resources are utilized for different purposes including the construction of hydropower plants (Dias *et al.,* 2018), which are the main source of electricity generation (Chen *et al.,* 2016; IPCC, 2014). Hydropower plant reservoirs are attractive locations for aquaculture, fishing and other recreational activities. These activities provide healthy food and income to the public and play an important role in the socioeconomic growth (Lasage *et al.,* 2015; FAO, 2013). According to BMPA, (2011), Brazil is the 19th largest fish producing country, with about 1,260,000 tons in 2010 being 0.75% of world's total production. The establishment of hydropower plants at the Southeast Region of Brazil has significantly expanded the surface water resources (Dias *et al.,* 2018). These plants have a positive impact on the surrounding environments as well as provide large areas and infrastructure for the above mentioned activities (Dessu *et al.,* 2014; ANA, 2013; Patil *et al.,* 2012). Floating platforms at the reservoirs are usually composed of wooden parapets under floats with a maximum size of 15 m^2 (DOEMGS, 2012). These platforms have been gradually increased over time, allowing fisherman to stay longer on surface waters. The attractant materials used for fishing such as "cevas", a fish food and the discharge of untreated sanitary waste from platforms into the surrounding water are continuously deteriorating the aquatic life of reservoirs (Nnji *et al.,* 2010). The increased density of floating platforms followed by fishing and other recreational activities during spring season is the potential source of pollution production in these reservoirs (Henry-Silva and Camargo, 2008). The increasing organic waste loads are causing unhealthy changes to water quality variables including eutrophication (Bora and Goswami 2017; Haritash *et al.,* 2016; FAO, 2013) and reduction in the diversity and quantity of aquatic flora and fauna (Poff *et al.,* 2017; Binet *et al.,* 1995; Scudder and Conelly, 1985). These unhealthy changes in aquatic environments intimidate the aquatic life and serve as a source of several waterborne diseases, which adversely affect the public health, such as Weil's disease, Hepatitis A, gastroenteritis by *Escherichia coli* and *Samonelas spp.*, and allergies caused by cyanobacteria (FAO, 2013). Therefore, getting right information about the limnological aspects of hydropower plant reservoirs and the establishment of appropriate water quality assessment models (Kükrer and Mutlu, 2019; Jiang *et al.,* 2015) could help policy makers to make effective plans for the conservation of aquatic environments sustainability (Abd-Elrahman *et al.,* 2011; Nóbrega *et al.,* 2011; Hubbard, 2009). This study aimed to evaluate the impact of floating platforms on the limnological aspects of Nova Ponte hydropower plant reservoirs at the Santa Juliana City of Minas Gerais State, Brazil during 2015 - 2016.

MATERIALS AND METHODS

Nova Ponte Hydropower Plant reservoirs are located at the Santa Juliana City in Minas Gerais State of Brazil, between latitude of 19°17'01,69" South and longitude of 47°37'39,71" West (Fig. 1). According to Köppen (1901), the climate of this region is tropical of high altitude, with a dry winter and has the hottest month over 22°C (Humid subtropical climate). The region is characterized by annual average rainfall of 1,574 mm, with annual average temperature of 20.4°C (Sentelhas *et al.*, 2003).

The limnological variables were plotted against the density of floating platforms and the correlation and regression analysis was performed. The density of platforms was calculated by the quotient between numbers of platforms per hectare of the sampled fields distributed along the margins of the reservoirs. These values were then transformed into platform per square kilometer (Km^2). A total of 8 sampling fields were selected, covering 100 by 100 meter (m), with the establishment of 3 sampling (for water samples collection) points (Fig. 2A). Water quality variables were evaluated at the 3 central points (15, 30 and 45 m from the margins) and at the depth (3, 4 and 5 m from the water surface) of each point within each sampled field, respectively (Fig. 2B).

Overall, 2 sampling campaigns were carried out and 3 samples were collected per sampled field, totaling 24 samples in fishing (F) (April to September, the dry winter season of Brazil) and fishing-ban period (FB) (October to March, the rainy summer season of Brazil), respectively. Dissolved oxygen (DO, mg/L), biochemical oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), total coliforms bacteria (TCB, Most Probable Number - MPN/100 mL) and thermotolerant bacteria (TB, MPN/ 100 mL) were evaluated according to the standard methods of

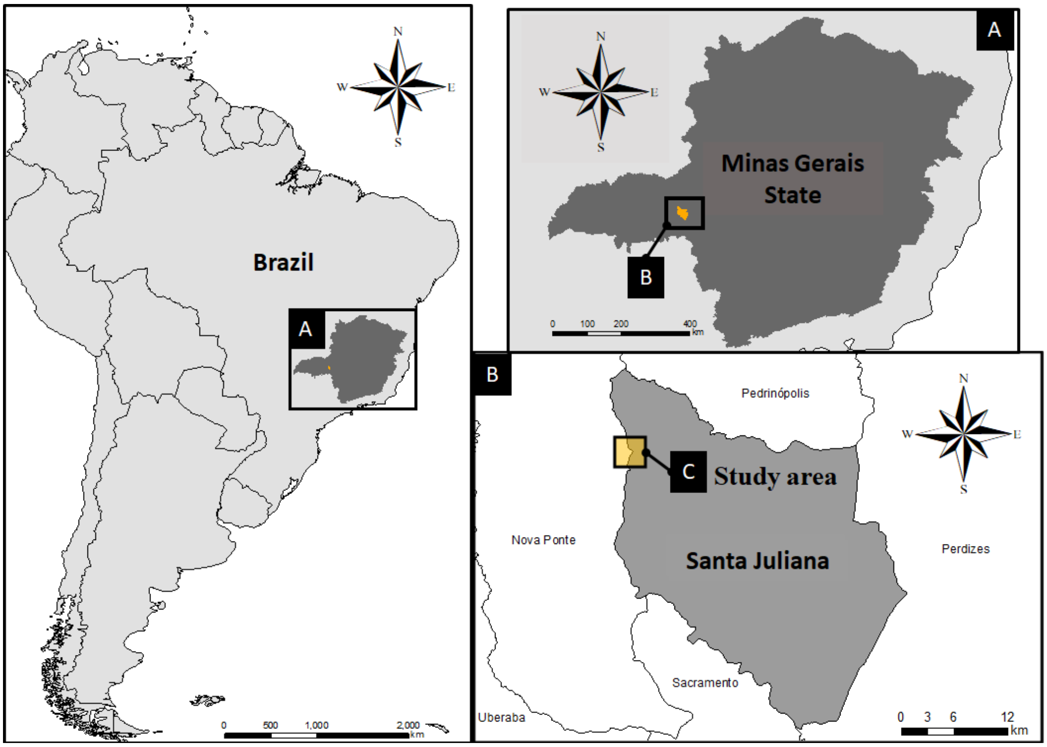

Fig. 1: Geographic location of the study area in Nova Ponte Hydropower Plant reservoirs (C) at the Santa Juliana City (B) in Minas Gerais State of Brazil (A)

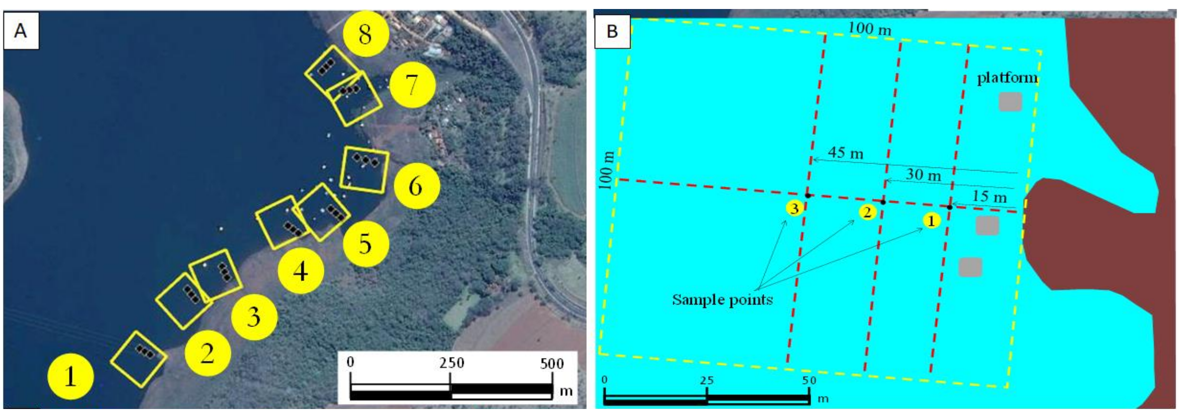

Fig. 2: Location of sampled fields (A) and layout of sampling points within the fields (B)

APHA (2005). The obtained results were the average of the 3 points within each sampled field. For the calculation of averages to water quality variables at each sampled field and respective densities of the platforms (Table 1), Person's cross correlation analysis was performed.

The statistical method used consisted of Person's correlation test with 5% significance level (p-value < 0.05) between water quality variables (dependent variables) and calculated platform density (independent variable). For significant correlations, the analysis proceeded with statistical regression in

Table 1: Observed platform numbers (OPN) and calculated platform densities (CPD) at one-hectare sampled fields

Sampled field	OPN (Platforms/ha)	CPD (Platforms/km^2)
1	0	0
2	0	0
3	1	100
4	4	400
5	7	700
6	6	600
7	4	400
8	3	300

which different models were tested including linear, quadratic, power, exponential and logarithmic. The selection of model fitted to dependent variables as a function of the independent variable was made by considering the level of significance (p-value) and coefficient of determination (r^2). Statistical analysis was performed using SPSS for Windows software (SPSS, 2008).

RESULTS AND DISCUSSION

In fishing (F) (Fig. 3a) and fishing-ban period (FB) (Fig. 3b), BOD, COD, TCB and TB presented a significant (p-value < 0.05) positive correlation with the CPD while DO showed a significant (p-value < 0.05) negative correlation with the density of platforms.

Aquaculture, fishing and other recreational activities at the platforms produce large amounts of organic waste loads which are negatively affecting the water quality of hydropower plant reservoirs. The main causes are probably the use of green maize, cherry, feed, rice and food remains (Tarcitani and Barrella, 2009), dumping of sanitary waste into water without any proper treatment (Chapman et al., 2016; Spirelle and Beaumord, 2006), erosion and deforestation of the slopes as well as sediments transport (Luz *et al.*, 2016; Scudder and Connelly, 1985). Another fact that must be considered is that this study was carried out in a lentic aquatic environment of hydropower plant reservoirs which have stable water levels. Floating

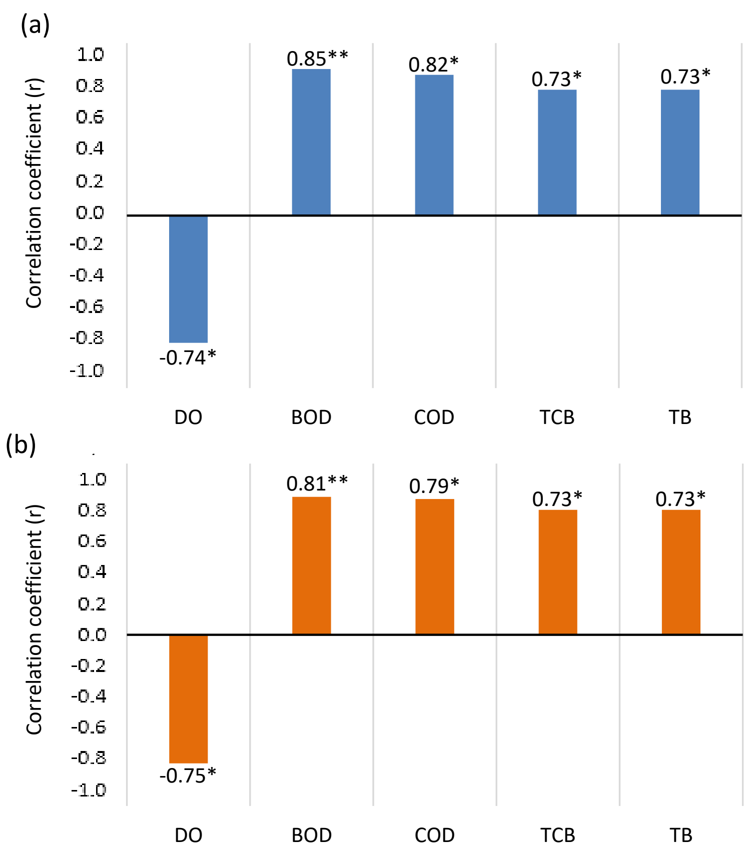

Fig. 3: Cross-correlation between water quality variables and platforms density in fishing (a) and fishing-ban periods (b)

Fig. 4: Typical floating platforms of the Nova Ponte Hydropower Plant reservoirs at the Santa Juliana County in Minas Gerais State of Brazil

platforms (Fig. 4) at the Nova Ponte Plant reservoirs are more robust structures which efficiently work up to 5-10 years. Therefore, considering the long-life span of these platforms and the stable environmental conditions of the studied site, the results obtained during the under-study period could be attributed to current situations.

As shown in Fig. 5, minimum DO (1.7 mg/L) was observed at the CPD of 480 platforms/km^2 in fishing and fishing-ban periods. In the case of BOD, maximum concentrations at the CPDs of 498 and 504 platforms/km^2 were observed as 11.2 and 10.0 mg/L in fishing and fishing-ban periods, respectively. Maximum expected COD concentrations were observed at the CPDs of 490 and 503 platforms/km^2 in fishing and fishing-ban periods (Fig. 5), respectively. Similarly, in the two periods and at the indicated CPDs, maximum COD concentrations were observed as 16.6 and 15.2 mg/L, respectively. DO is usually influenced by the amount of organic waste load (due to the consumption by microorganisms) in water and the local altitude and temperature (solubility of gases in liquid) (Eiger, 2003). In the present study, DO was influenced by the organic waste load produced as a result of the excessive use of bait and dumping of sanitary waste without any proper treatment into water in the regions with high CPD. This phenomenon explains that DO dependent variables would show a significant response in the case of limiting DO concentrations in reservoirs.

Maximum TCB was determined at the CPD of 472 platforms/km^2 in fishing and fishing-ban periods which exceeded beyond 5,000 MPN/100 mL (Fig. 5). Maximum TB was expected at the CPD of 472 platforms/km^2 in fishing and at the 468 platforms/km^2 in fishing-ban period (Fig. 5). At the same CPDs and in the indicated periods, maximum TB exceeded 1,000 MPN/100 mL. The high correlation found between CPD and TB can be explained by the disposal of untreated sanitary waste into aquatic environment, as these bacteria are present in the feces of warm-blooded animals (Edberg *et al.,* 2000). According to the obtained results, beside increase in CPD, intensification of fish in fishing period also influenced the water quality variables (Fig. 6). In both periods, the density of 500 platforms/km^2 resulted in worsened water quality variables as compared to the platforms-free areas. This density further deteriorated the water quality in fishing-ban period (280% increase in COD and 199% in BOD, respectively) than fishing period (179% increase in COD and 110% in COD, respectively). Similar results were obtained for DO, TCB and TB in both periods. These results clearly show that there was greater amplitude between platform-concentrated and platforms-free areas in fishing-ban period. This may happen because the end of the rainy summer season coincides with the beginning of fishing period (dry winter season), where the contribution of diffused organic load (Vanzela *et al.,* 2012; Larentis *et al.,* 2008) results in higher BOD and COD even in the platforms-free areas, and thus the difference between BOD and

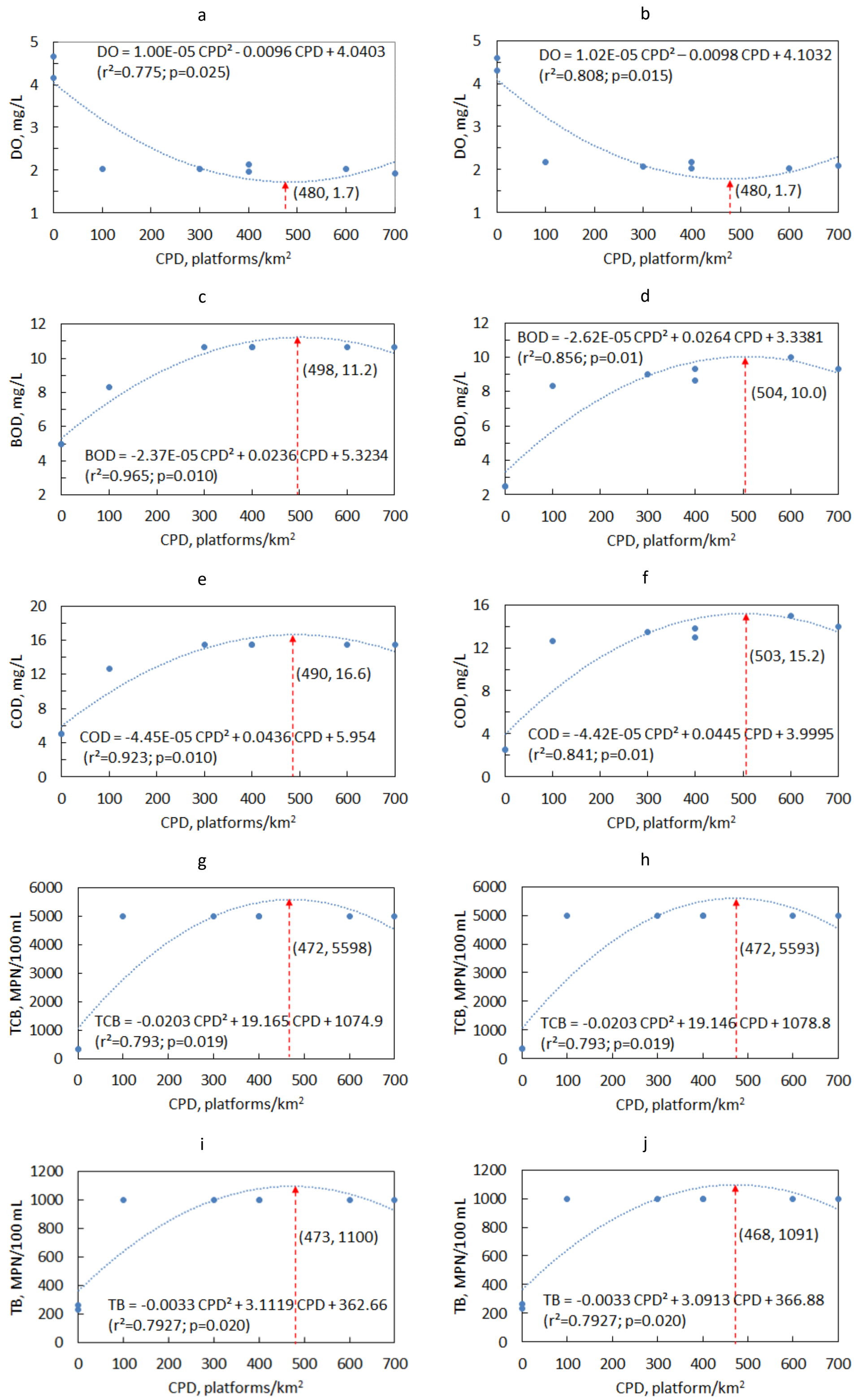

Fig. 5: Adjusted curves of DO, BOD, COD, TCB and TB in response to the CPD in fishing (a, c, e, g, i) and fishing-ban period (b, d, f, h, j)

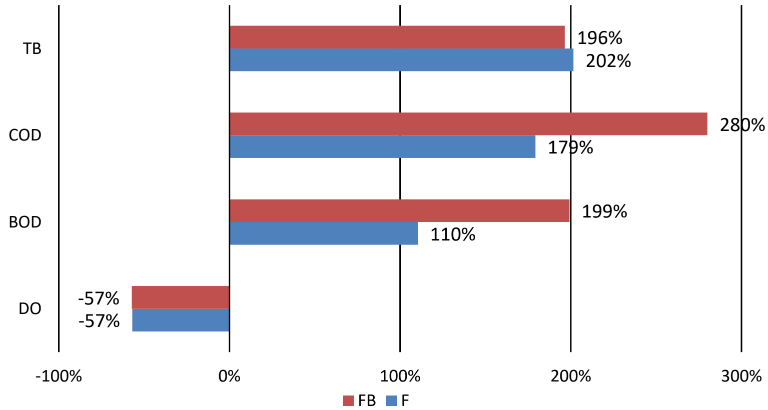

Fig. 6: Percentage variation in water quality variables at platforms-free areas in relation to the areas with 500 platforms/km^2 in fishing (F) and fishing-ban period (FB)

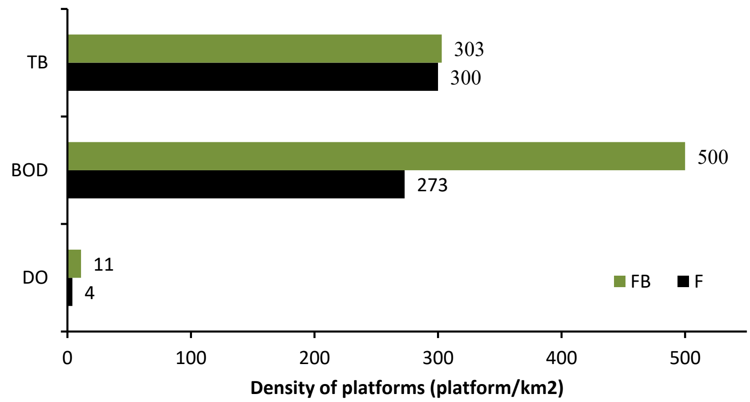

Fig. 7: Maximum number of platforms allowed by the CONAMA Resolution 357/2005 (DORFB, 2005) in fishing (F) and fishing-ban period (FB)

COD reduce in the two areas. Each year, fishing-ban period usually begins in October which continues up to March of the subsequent year (Porcher *et al.,* 2010) and coincides with the end of dry winter season (April to September). Thus, the disposal of untreated organic waste loads from platforms into the surrounding water may cause greater differences between the two areas.

Based on the models fitted and keeping in view the most limiting variable (DO in the present study), following the standards (DO of 4.0 mg/L) of Class 3 (DORFB, 2005), maximum number of allowed CPD was estimated as 4 platforms/km^2 (approximately 1 platform per 25 hectares of water mirror, equivalent to a square of 158 by 158 m) (Fig. 7). At the CPD of 4 platforms/km^2, the expected values in fishing period were estimated to be 5.4 mg/L for BOD, 375 NMP/100 mL for TB and 6.1 mg/L for COD. In fishing-ban period, the expected values were estimated to be 4.1 mg/L for DO, 3.4 mg/L for BOD, 379 MPN/100 mL for TB and 4.2 mg/L for COD. In the case of 4 platforms/km^2, it is expected that all the analyzed water quality variables would remain within the established range.

In fishing period followed by the excessive agglomeration of platforms, maximum 1 platform in an area of 158 by 158 m has considerable impacts on the water quality variables and making them worse as compared to the water quality variables of Class 3 standards (DORFB, 2005). The consequences may be negative even alone for the fishing activity due to reduction in the quantity of fish species as described by Scudder and Conelly (1985) and Binet *et al.* (1995). These authors reported that the dumping of increased salt and organic waste loads into the surrounding aquatic environments causes significant reductions in the number of fish species. Thus, appropriate and regular assessment of water quality variables at floating platforms is very necessary in order to guarantee the sustainability of reservoirs ecosystems (Poff *et al.,* 2017; Behmel *et al.,* 2016; Khalil and Ouarda, 2009).

CONCLUSION

Hydropower plants create reservoirs which play an important role in flood control, irrigation, water supply and rearing of aquaculture species as well as offer a variety of recreational activities, particularly fishing, swimming and boating. For the execution of these activities, reservoirs are usually provided with a large infrastructure including floating platforms. The density of platforms has a significant impact on the water quality of reservoirs. This study assessed the impact of floating platforms density on the limnological acpects of Nova Ponte Hydropower Plant reservoirs located at the Santa Juliana City in Minas Gerais State of Brazil. Samples collection campaigns were carried out in fishing and fishing-ban periods for the analysis of dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total coliforms and thermotolerant bacteria concentrations in hydropower reservoirs. Hence, these data (dependent variables) plotted against the independent variable (platforms density) were fitted to the polynomial regression model to define the maximum feasible density of platforms/km^2. Statistical analysis done revealed that the density of platforms significantly affected the water quality variables in the two periods. The dissolved oxygen concentration was greatly affected by the fishing activity at platforms, with the limiting concentrations being observed at the density of 4 platforms/km^2 (1 platform per 25 ha). In fishing period, the excessive agglomeration of platforms, such as maximum 1 platform in an area of 158 by 158 m, adversely influenced the water quality variables. In the platforms-concentrated areas, the reductions in DO concentrations observed were 45 and 57% in fishing and fishing-ban periods, respectively. The increase in BOD and COD concentrations observed was 92 and 146% in fishing and 169 and 237% in fishing-ban period, respectively. In the two evaluated periods, the density of 500 platforms/Km^2 resulted in worsened water quality as compared to the platforms-free areas, which in fishing-ban period further declined the concentrations of COD and BOD. The concentration of microorganisms increased with the density of platforms. Total coliforms exceeded above 4,500 MPN/100 mL while thermotolerant bacteria exceeded 900 MPN/100 mL at the maximum density of platforms (700 platforms/km^2) in the two periods. The high correlation between number of platforms and quantity of the total and thermotolerant coliforms in water was found directly associated to the disposal of untreated organic waste loads from platforms. This finding provides important base-line information on the reliable assessment of water quality variables at floating platforms which could help policy makers to understand, interpret and make effective plans and legislations for the conservation of hydropower-plant-reservoirs ecosystems.

AUTHOR CONTRIBUTIONS

L.S. Vanzela, D.C. Pereira, and L.D.S.C. Lima developed the study, conducted the experiment, collected and analyzed the data and wrote the manuscript. K.U. Khan helped in literature review and manuscript writing and editing. C.F.M. Mansano helped in data collection and analysis and manuscript writing.

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CONFLICT OF INTEREST

The authors declare that there are no potential conflicts of interests regarding the publication of this work. The ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

°C	Degree Celsius
%	Percentage
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CPD	Calculated platform density

CPDs	Calculated platform densities
DO	Dissolved oxygen
F	Fishing
FB	Fishing-ban
Fig.	Figure
ha	Hectare
km	Kilometre
km^2	Square kilometre
m	Meter
m^2	Square meter
mg/L	Milligrams per litre
MPN	Most probable number
NPN/ 100 mL	Most Probable Number per 100 ml of sample
OPN	Observed platform number
platforms/ km^2	Platforms per square kilometre
P-value	Probability value
r^2	Determination of coefficient
TCB	Total coliform
TB	Thermotolerant bacteria

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