

Original Research Article

NUTRIENT DYNAMICS IN BOTTOM SEDIMENT OF A RESERVOIR IN THE SEMI-ARID REGION

ABSTRACT:

Aims: This research was developed to quantify the dynamics of the stocks of organic carbon, phosphorus and nitrogen in sediments, as well as the retention or release of nutrients in the water column of a reservoir in the tropical semi-arid region.

Place and Duration of Study: To achieve these goals, trenches were opened in the two tributaries (the Canindé and Capitão Mor Rivers) of the Pereira de Miranda reservoir. The trenches were located 500 m upstream from the waterbody. Samples were collected from each sediment deposition profile. After collection, the total organic carbon, labile carbon, granulometry, and total and assimilable phosphorus were analysed.

Results: The Canindé and Capitão Mor display different dynamics for the contribution of carbon, phosphorus and nitrogen, and it is evident that the Canindé River contributes more nutrient to the sediments, a fact that is mainly related to the greater deposition of fine sediment found in the Canindé.

Conclusion: Sediment granulometry has a strong influence on the retention or release of TOC, P and N, and reservoirs with a predominance of fine sediments display greater fixation of these elements, and become a nutrient sink within the ecosystem.

Keywords: *erosion, soil loss, nutrients, eutrophication.*

1. INTRODUCTION

The increasing demand for the production of fibre and food and for urban expansion has significantly altered land use and occupation in recent years, and has had a negative impact on the environment, society and the economy (1). The inadequate management of watersheds, together with a lack of soil and water conservation practices, has favoured the degradation of ecosystems (2), as the soil is exposed to erosive processes, significantly increasing the production and deposition of sediment in surface waterbodies and the impoverishment of agricultural land (3).

In regions of arid and semi-arid climate, the process of environmental degradation has intensified, mainly due to the simultaneous combination of soil and climate factors with the use and occupation of the land (4, 5). Among the main environmental factors characteristic of regions of semi-arid climate are the high rate of evapotranspiration, little-weathered soils and rainfall irregularity (6).

In view of irregularities in the rainfall regime and the increase in water demand during recent years in these regions, artificial reservoirs for multiple uses have been constructed, be it for agriculture, livestock or human supply (7). Nevertheless, the usefulness of these reservoirs depends mainly on the use and occupation of the land in their basins.

The absence of conservation practices has accelerated sediment production and deposition in waterbodies, compromising water availability (8) and causing nutrient enrichment (eutrophication) as well as the enrichment of other substances that pollute the water (9).

The process of eutrophication in the reservoirs is usually triggered by the input of sediments that carry nutrients such as phosphorus and nitrogen, which alter the chemical, physical and biological characteristics of the water in the reservoirs. According to (10) 43% of the phosphorus contained in spring water originates from agricultural activity, which intensifies the erosive process. The sediment carried and deposited in large quantities in waterbodies promote changes in turbidity, light penetration, water temperature and available oxygen (11).

Study of the nutrient supply in the bottom sediment of reservoirs can provide information about conditions for the release (Source) or retention (Sink) of these nutrients in waterbodies. The physical and chemical characteristics of the sediments and the conditions for oxyreduction at the

water-sediment interface are the main factors involved in the process of nutrient retention and release in the water column of a reservoir (12).

The (13) report that sediment behaviour, transport and deposition in reservoirs are important issues to be considered and studied in the management and impounding of these environments, as the deposition and accumulation of bottom sediment in the reservoirs decreases the useful life and quality of the water for multiple uses. The aim of this study therefore, was to evaluate the stocks of organic carbon, phosphorus and nitrogen in sediments of the Canindé and Capitão Mor Rivers, the principal tributaries of the Pereira de Miranda reservoir, and to analyse the correlation of their potential for retaining or releasing these nutrients in the water column with particle-size fractions in the sediments.

2. MATERIAL AND METHODS

The study was carried out at the Pereira de Miranda reservoir, which is inserted in the Curu river basin between 3°20' and 4°36' S and 38°55' and 39°50' W, in the district of Pentecoste in the State of Ceará, Brazil (Fig. 1). The reservoir was built in 1950-1957 on the bed of the Canindé River, and has a storage capacity of 395 hm³ (14).

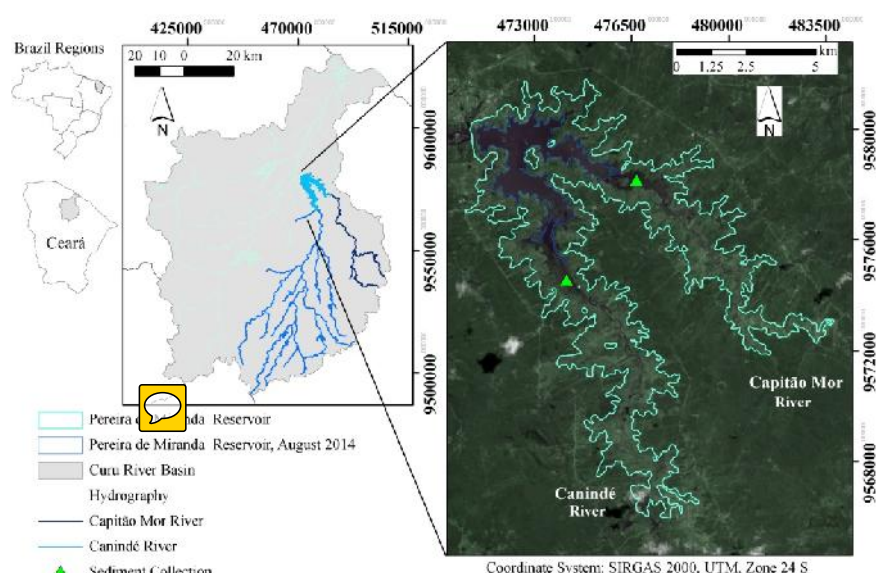


Fig. 1. Basin of the Pereira de Miranda reservoir, with emphasis on the area covered at maximum capacity and the area covered in August 2014 - collection points on the Canindé and Capitão Mor tributaries.

The rainfall regime in the region is characterised by temporal and spatial irregularity, with an average annual rainfall of 782 mm (1974-2015), of which 75% of the total precipitation is concentrated over four months (January-April). The dominant soils in the basin of the reservoir are shallow and young, with crystalline outcrops on the surface due to the low-intensity action of soil-formation factors, a consequence of the climate irregularities of semi-arid region. The predominant soils in the basin under study are Luvisols (71%), Argisols (22%), Planosols (4%) and Neosols (2%) (15). It should be noted that most of these soil classes are highly susceptible to erosion, especially when used with no soil or water conservation practices.

The sediment were collected in June 2015 in the two main tributaries of the Pereira de Miranda reservoir, the Canindé and Capitão Mor (Fig. 1); the water stored in the reservoir was at 13% of its capacity. The choice of where to open the trenches to sample the bottom sediment was the preferred path of the water when entering the reservoir, which is easily observed from the topography of the terrain. The trenches were placed 500 m upstream from the waterbody (16).

The sediments were sampled in distinct layers, delimited by the external morphological characteristics (colour and texture) of the profiles, the depth limit being the original riverbed, generally

characterised by a layer of coarse sand. After collecting the samples, the sediments were air dried, packed into plastic bags and sent to the Soil Management and Conservation Laboratory of the Department of Soil Sciences at the Federal University of Ceará for quantification of the total organic carbon, labile carbon, total nitrogen, total and assimilable phosphorus, and the granulometry.

The total organic carbon (TOC) was quantified using the Walkley-Black method modified by Yeomans and Bremner (17). The method consists in the oxidation of soil organic carbon by dichromate (Cr^{6+}) in the presence of concentrated sulphuric acid (H_2SO_4) under strong external heat, in which the excess Cr^{6+} is titrated with (iron) Fe^{2+} . The labile carbon content (C_{lab}) of the sediment was determined as per the methodology adapted by (described by 18).

The total nitrogen, total phosphorus (P_{total}), assimilable phosphorus and particle-size fractions were determined according to the methodology described by Embrapa (18). As the sediment layers are of different thicknesses, a comparative analysis between the tributaries was performed considering each variable per cm of sediment in the profiles. Correlation analysis was carried out by relating the contents of the analysed variables in each layer to their respective particle-size fractions.

The data were first submitted to the Shapiro-Wilk test of normality ($p \leq 0.05$); when the variables presented a parametric distribution, the T-test was used, and when they presented a non-parametric distribution, they were submitted to the Mann-Whitney U test to evaluate the differences between the two tributaries, the Canindé and Capitão Mor, as to the values per layer for nitrogen, phosphorus and total organic carbon, and for the carbon/nitrogen ratio. The potential for the retention or release of nutrients in the water column of the reservoir was determined by means of the correlation between these nutrients and the total organic carbon content and granulometry of the sediment layers under analysis. A descriptive analysis of the data was also made. All statistical analyses were carried out using the SPSS 16.0 software.

3. RESULTS AND DISCUSSION

The stock of TOC per cm of sediment in the Canindé River is 50% more than that stored in the Capitão Mor (Table 1). The stock of P_{total} per cm of sediment was on average 62% greater in the Canindé than found in the Capitão Mor. The greatest difference was seen for TN, where the content per cm of sediment in the Canindé was four times higher than seen in the Capitão Mor (Table 1).

Table 1. Mean value and standard deviation for total organic carbon (TOC), labile carbon (C_{lab}), carbon/nitrogen ratio (C/N), organic matter (OM), total phosphorus (P_{total}), assimilable phosphorus P_{asm} and nitrogen (TN) per cm of sediment in the two main tributaries (the Canindé and Capitão Mor Rivers) of the Pereira de Miranda reservoir in 2015.

RIVER		TOC	C_{lab}	OM	TN	C/N	P_{total}	P_{asm}
		g/kg			mg/kg			
Canindé	N	6	6	6	6	6	6	6
	Mean	13.0a	1.4a	22.5a	1.3a	47.4a	832.9a	64.2 ^a
	Median	13.2	1.4	22.8	1.3	46.7	837.3	62.7
	CV (%)	13.8	20.6	13.8	18.6	89.6	2.5	71.6
Capitão Mor	N	6	6	6	6	6	6	6
	Mean	7.7b	0.4b	13.4b	0.3b	81.0b	513.4b	52.4 ^a
	Median	4.6	0.4	8.0	0.3	34.9	541.5	52.4
	CV (%)	92.1	48.2	92.1	9.3	122.1	18.1	14.5

* Mean values followed by the same letter do not differ at 5% significance by Tukey's test when presenting a normal distribution, or by the Mann-Whitney U test when presenting a non-normal distribution, between the Canindé and Capitão Mor rivers. CV = coefficient of variation.

The highest recorded values for TOC, P_{total} and TN in sediments from the Canindé River are due to their finer texture, as the smaller particle size has a higher specific surface area (19), which favours the retention of carbon, phosphorus and nitrogen. However, the content of these variables was below the value suggested by Resolution 454/2012 (20) for sediment.

The greatest contribution of TOC to the sediments of the Canindé River is related to the presence of fine sediments carried along the basin during flood events, since according to (21), nutrients that are deposited in reservoirs during periods of flood are adsorbed onto the sediment and accumulate at the bottom of springs. Also relevant is that the fine fractions (clay + silt) have a large surface area and high cation exchange capacity, thereby favouring greater nutrient adsorption in their layers (22). According to (23), fine-particle fractions retain around four times more organic material on the surface than does the coarse material (sand).

The percentage of labile carbon present in the TOC showed no difference between the two rivers, with a median close to 10% (Fig. 2B). Since both rivers have the same mean percentage of labile fraction and a different TOC content (13 g kg^{-1} TOC for the Canindé, and 7.7 g kg^{-1} TOC for the Capitão Mor), the greatest contribution of available carbon in the water column occurs in the Canindé River.

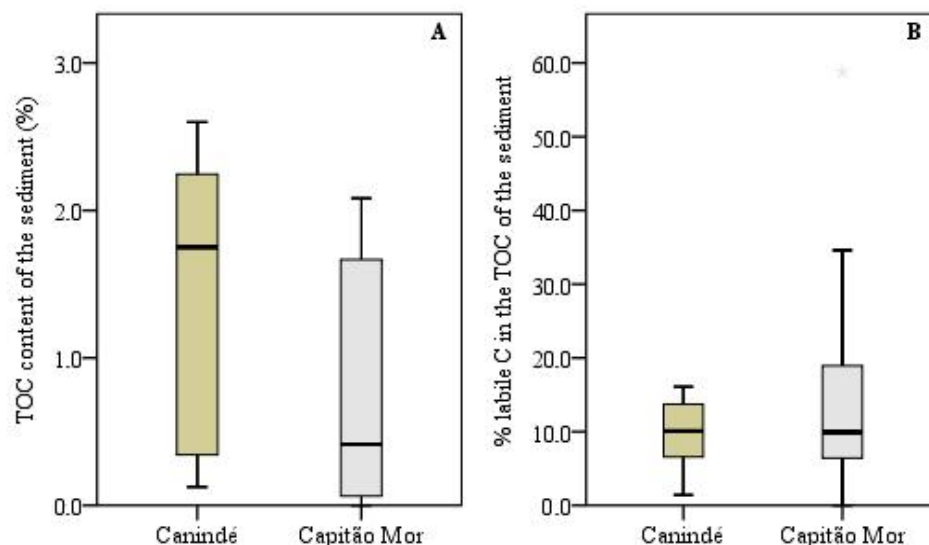
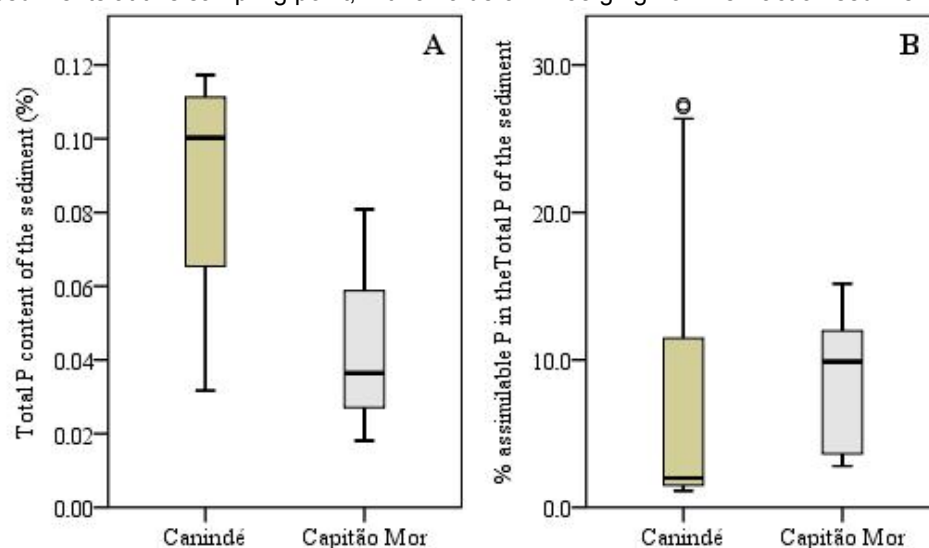


Fig. 2. Distribution of total organic carbon content - TOC (2A) and percentage of labile Carbon contained in the TOC (2B) in the two main tributaries (the Canindé and Capitão Mor Rivers) of the Pereira de Miranda reservoir in 2015.

Despite the greater contribution of P_{total} in the sediments of the Canindé River (Fig. 3A), only 2% of this phosphorus is in assimilable form (Fig. 3B), while in the Capitão Mor, the figure is 10%. This result shows that phosphorus availability to the water column in the reservoir is influenced by the granulometric characteristics of the sediments, since the Canindé River shows a deposition of fine sediments at this sampling point, with a value of 4.488 g kg^{-1} of fine-fraction sediments.



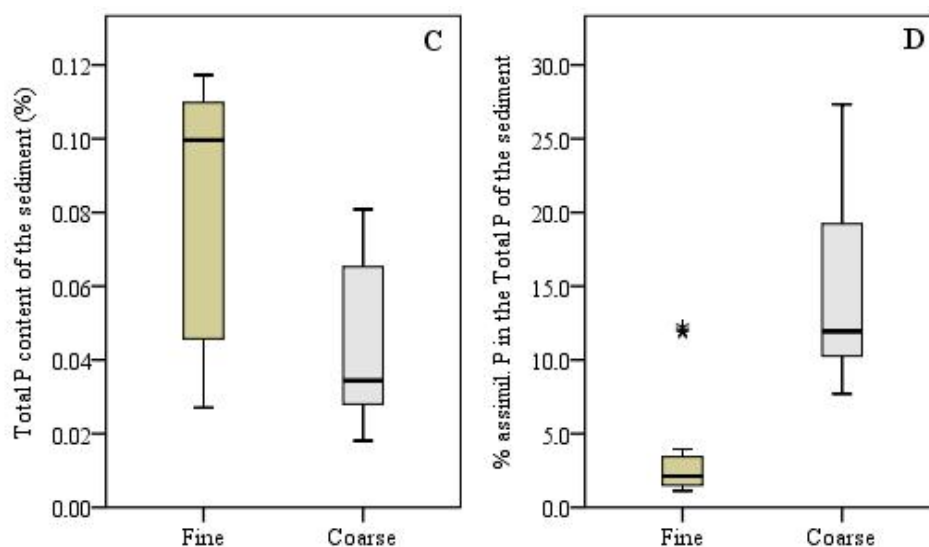


Fig. 3. Distribution of total phosphorus (P) (3A) and percentage of assimilable P contained in the P_{total} (3B) of the fine and coarse sediment fractions in the Canindé and Capitão Mor Rivers in 2015.

The lower percentage of assimilable P (Fig. 3B) in the P_{total} of the Canindé River is possibly associated with the predominance of fine sediment (silt + clay) in the profile, since fine particles retain a greater amount of phosphorus, a fact evidenced by Figure 3D.

This adsorption of P onto the fine sediment is mainly related to the presence of clay minerals and iron oxides (24);(25). The pH values in the sediments may also have had an influence, since the high adsorption of phosphate by the sediments is favoured at a pH range of between 5 and 6.5 (26), the range found for the sediments under analysis.

On average, the fine sediments contribute more P_{total} to the reservoir compared to the coarse fraction (Fig. 3C), however only 0.05% of P_{total} in the fine sediments is in the form of assimilable P (Fig. 3D). The sediments are an important source of phosphorus in the reservoirs, but its availability in the water column is affected by chemical, physical and biological parameters, which interfere in the immobility or mobility of the phosphorus (27) in the waterbody, with emphasis on the fine fractions, the concentrations of iron, aluminium, calcium and magnesium ions, the pH and organic compounds, as well as the biological processes of decomposition of the organic matter present in the environment. The fine materials are typically composed of clays with a large surface area and a moderate to high cation exchange capacity, as a function of (28) their negative surface charge. (29) found a strong adsorption of nutrient phosphorus onto fine-fraction particles, due to the intrinsic characteristics of this fine material.

The low values for nitrogen contribution of the Capitão Mor River to the sediments tend to increase the C/N ratio (Fig. 4). At this point, there may be a considerable input of organic material from plant residue coming from areas under deforestation around the reservoir.

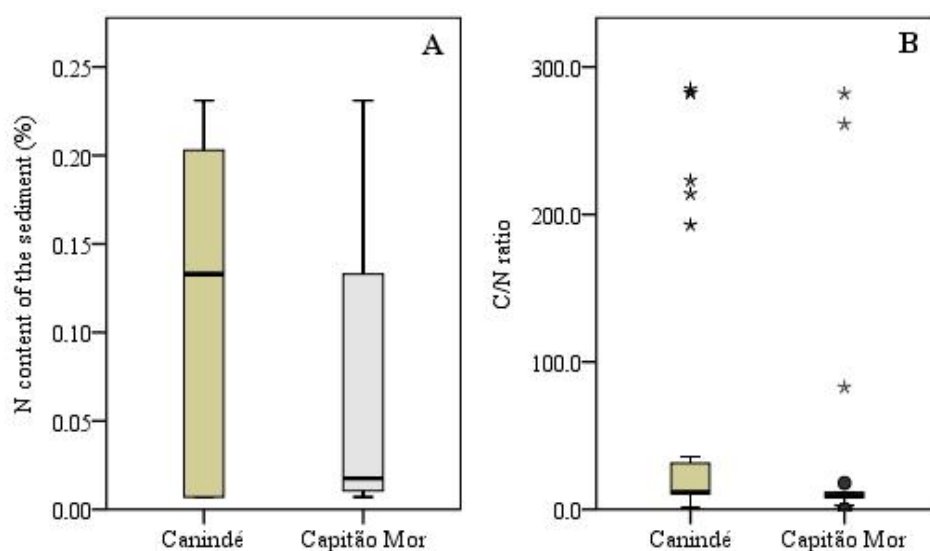


Fig. 4. Distribution of total Nitrogen content (4A) and the carbon/nitrogen ratio (4B) in the sediments of the two main tributaries of the Pereira de Miranda reservoir (the Canindé and Capitão Mor Rivers) in 2015.

According to (30), high levels of plant organic matter contain a low percentage of nitrogen, which increases the C/N ratio of bottom sediment.

The sand and clay content of the sediment layers displayed the best correlation with the TOC ($R = 0.93$, $p < 0.001$, $n = 51$) and TP ($R = 0.64$, $p < 0.001$, $n = 51$) respectively. A reduction in the levels of total organic carbon can be seen as the amount of coarse sediment increases (Figure 5A); this is due to the low reactivity of the sand surface with the nutrients, since sand is an inert material, with little or no reactive power. Despite the regression coefficient being classified as moderate (31), it was highly significant, together with its elements in the regression equation ($P \leq 0.01$) (Fig. 5B). This demonstrates the effect of the clay content on phosphorus retention in the sediment, and that there are other factors involved in the process.

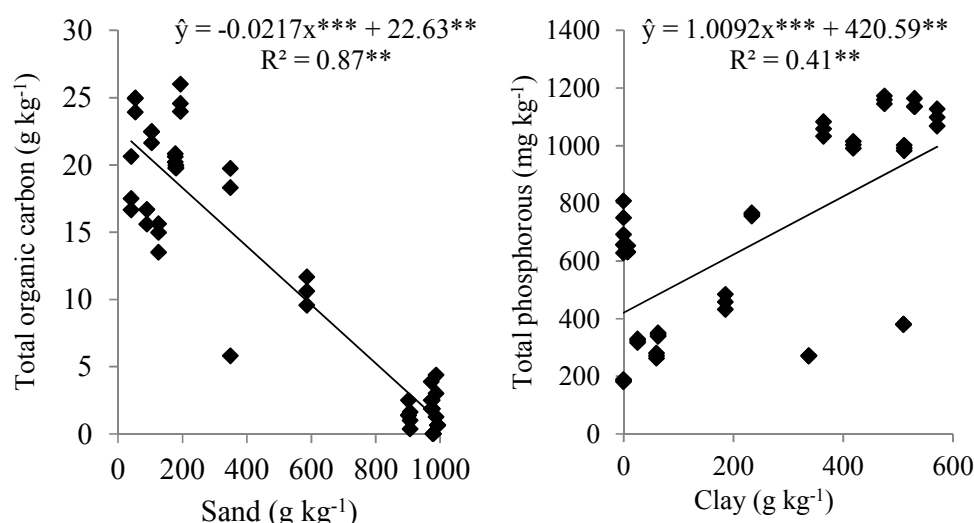


Fig. 5. Relationship between the levels of organic carbon and total phosphorus with the sand and clay respectively, in sediments from the Canindé and Capitão Mor tributaries of the Pereira de Miranda reservoir in 2015. ** 1% significance; *** 0.1% significance.

According to (32) and (33), strong correlations have been found between total phosphorus content and fine sediments (clay + silt). This high correlation is related to the strong affinity of these elements for adsorption onto clay minerals, which have a large specific surface. (34) found an

increase in P with increases in the fine-sediment content (< 0.062 mm); they report that the variation in phosphorus availability in reservoir sediments is influenced by the granulometry and the depth of the water column.

4. CONCLUSIONS

The Canindé and Capitão Mor Rivers display different dynamics for the contribution of carbon, phosphorus and nitrogen, and it is evident that the Canindé contributes more nutrient to the sediments, a fact that is mainly related to the greater deposition of fine sediments found in the Canindé.

Sediment granulometry has a strong influence on the retention or release of TOC, P and N, and reservoirs with a predominance of fine sediments display greater fixation of these elements, and become a nutrient sink within the ecosystem.

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