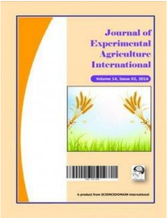

Journal of Experimental Agriculture International

25(1): 1-9, 2018; Article no.JEAI.42944
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Nutrient Dynamics in Bottom Sediment of a Reservoir in the Semi-Arid Region

Aldênia Mendes Mascena de Almeida[1*], Fernando Bezerra Lopes[1], Eunice Maia de Andrade[1], Cicero Lima de Almeida[2] and Leilson Carvalho de Oliveira[1]

[1]Departamento de Engenharia Agrícola, Universidade Federal do Ceará, Campus do PICI Bloco 804, Fortaleza – CE, Caixa Postal 12.168 CEP.: 60450-760, Brasil.
[2]Instituto Federal do Ceará, Campus Sobral Av. Dr. Guarani, 317 - Derby Clube, Sobral/CE, 62040-730, Brasil.

Authors' contributions

This work was carried out in collaboration between all authors. Author AMMA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors FBL and EMA managed the analyses of the study. Authors CLA and LCO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/42944
Editor(s):
(1) Mariusz Cycon, Professor, Department and Institute of Microbiology and Virology, School of Pharmacy, Division of Laboratory Medicine, Medical University of Silesia, Poland.
Reviewers:
(1) Jesús Rodrigo-Comino, University of Málaga, Spain.
(2) Kabi Prasad Pokhrel, Tribhuvan University, Nepal.
Complete Peer review History: http://www.sciencedomain.org/review-history/25656

Original Research Article

Received 7th May 2018
Accepted 15th July 2018
Published 24th July 2018

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, Pentecoste, in the State of Ceará (CE), Brazil. 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

---

**Corresponding author: E-mail: ald_m_m@hotmail.com;*

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 favored 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 [4] with the use and occupation of the land by man [5]. Among the main environmental factors, the characteristics of regions of brazilian semi-arid climate are the high rate of evapotranspiration, little-weathered soils and rainfall irregularity [6].

Given irregularities in the rainfall regime and the increase in water demand during recent years in these regions semi-arid, artificial reservoirs for multiple uses have been constructed, be it for agriculture, livestock or human supply [7]. Nevertheless, the useful life (water storage capacity)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 [10]. According to [11] 43% of the phosphorus contained in spring water originates from agricultural activity, which intensifies the erosive process [11]. The sediment carried and deposited in large quantities in waterbodies promote changes in turbidity, light penetration, water temperature and available oxygen [12].

Therfore, study of the nutrient supply in the bottom sediment of reservoirs could 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 [13].

Report that [5] sediment behavior, transport and deposition in reservoirs are important issues to be considered and studied in the management and impounding of these environments, because 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. MATERIALS AND METHODS

2.1 Study Area

The study was carried out at the Pereira de Miranda reservoir, which is inserted in the Cururiver 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 hm^3 [14]. During the time collection, the reservoir contained only 1% of their storage capacity.

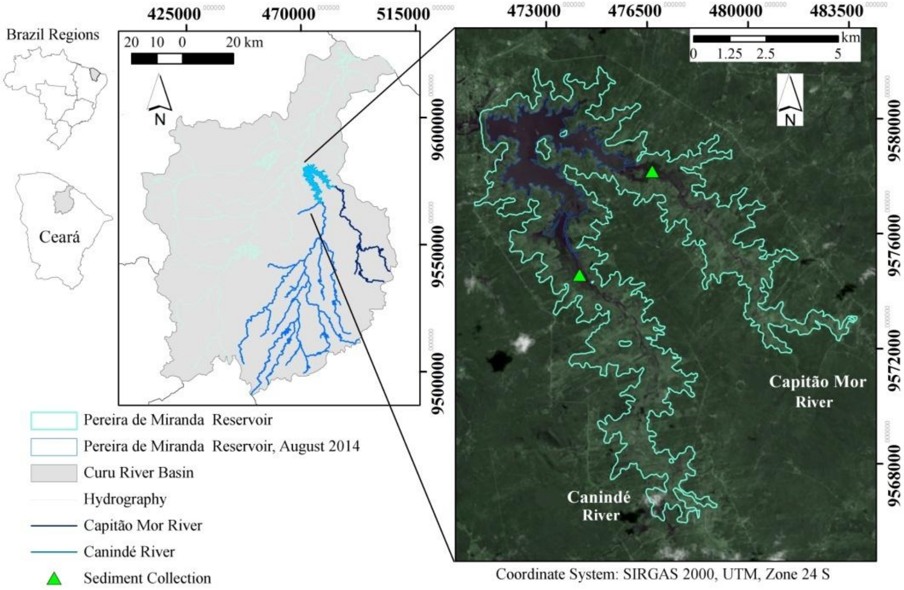

Fig. 1. Basin of the Pereira de Miranda reservoir, with emphasis on the area covered at maximum capacity and the area covered in August 2015

The rainfall regime in the region is characterized 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 regions (15).According to the Brazilian Soil Classification System– SiBCS (2013) the predominant soils in the basin under study are Luvisols (71%), Argisols (22%), Planosols (4%) and Neosols (2%) [15] [16]. 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.

2.2 Collection and Analysis of Data

The sediment was 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 1% 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 [17].

The sediments were sampled in distinct layers, delimited by the external morphological characteristics (color and texture) of the profiles, the depth limit being the original riverbed, generally characterized 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 granulometric fractions (coarse and fine – silt + clay).

The total organic carbon (TOC) was quantified using the Walkley-Black method modified by Yeomans and Bremner [18]. 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 Embrapa [19].

The total nitrogen, total phosphorus (P_total), assimilable phosphorus and particle-size fractions were determined according to the methodology described by Embrapa [19]. 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, and two granulometric fractions, coarse and fine, 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).

The higher recorded values for TOC, P_total and TN in sediments from the Canindé River are due to their finer texture, in which 52% of the sampled sediments were classified as fine whilst in the profile obtained in the Capitão Mor River, this type of sediment represented 36% of the total. The smaller particle size has a higher specific surface [20], which favors the retention of carbon, phosphorus and nitrogen. However, the content of these variables was below the value suggested by Resolution 454/2012 [21] 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 [22], nutrients that are deposited in reservoirs during periods of a 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 favoring greater nutrient adsorption in their layers [23]. According to [24], fine-particle fractions retain around four times more organic material on the surface than does the course 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.

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	64.2a
	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	52.4a
	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*

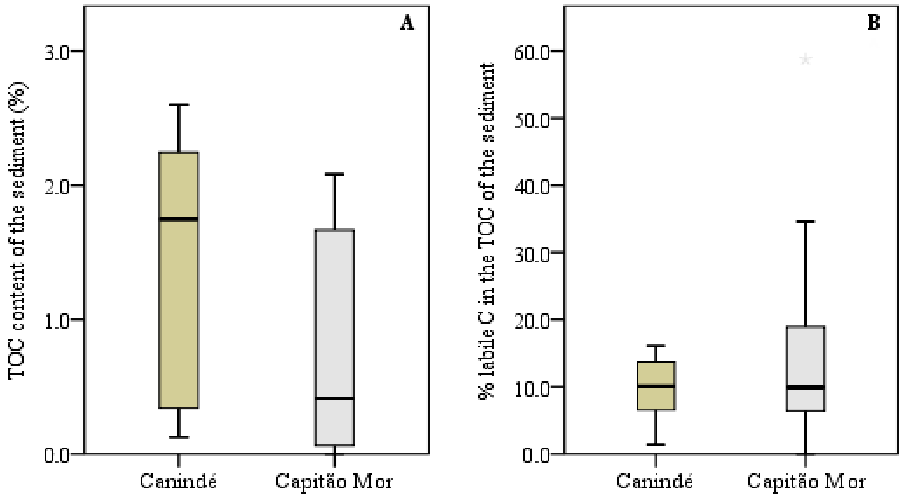

Fig. 2. Distribution of total organic carbon content - TOC (2A) and percentage of labile Carbon contained in the TOC (2B) in the two main tributaries (the Canindé and Capitão Mor Rivers) of the Pereira de Miranda reservoir in 2015

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 52% of fine sediments (clay + loam) in the profile.

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 in the profile since fine particles retain a greater amount of phosphorus, a fact evidenced by Fig. 3D. The fine particles present in the sediments can be considered as phosphorus sinks.

This adsorption of P onto the fine sediment is mainly related to the presence of clay minerals and iron oxides [25];[26]. The pH values in the sediments may also have had an influence since the high adsorption of phosphate by the sediments is favored at a pH range of between 5 and 6.5 [27], 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, about 1.0% of P_total in the fine sediments is in the form of assimilable P (Fig. 3D). Although the coarse fraction presented a smaller percentage of P_total in the sediment total (Fig. 3C), part of this phosphorus is available in the water column, about 10 to 15 times more available than in the fine fraction of the sediments (Fig. 3D). This high availability is explained by the low retention capacity of the coarse fraction (sand) of the phosphorus since said fraction has a low specific surface.

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 [28] 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 [29] their negative surface charge. [30] 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.

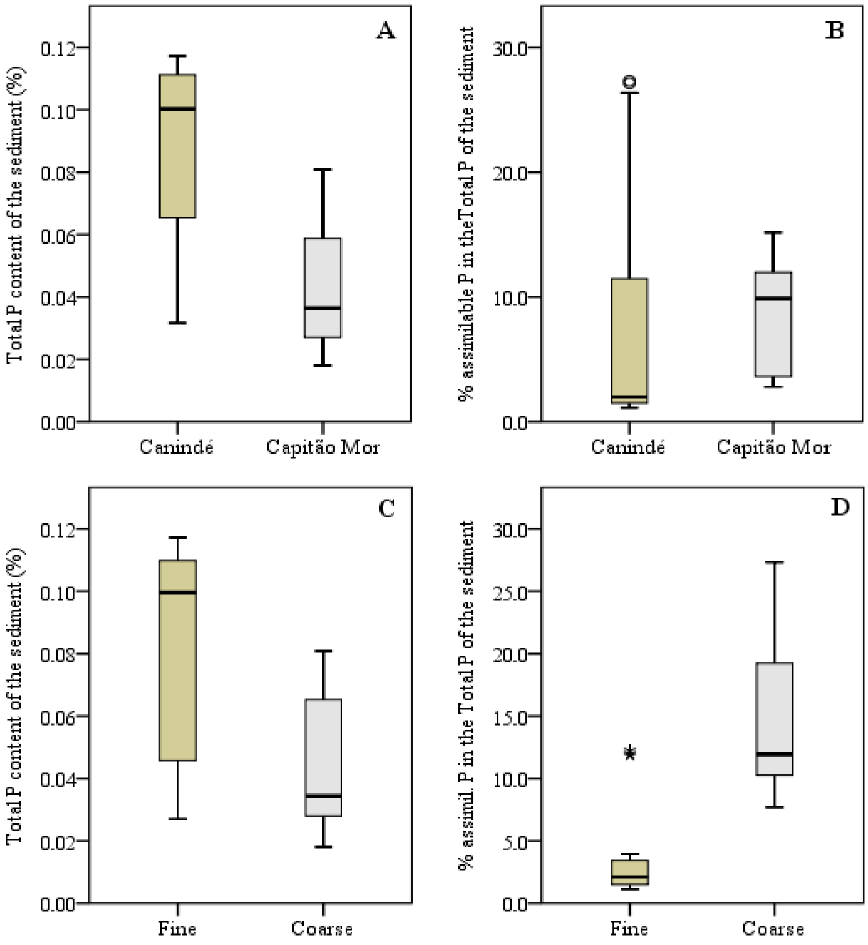

Fig. 3. Distribution of total phosphorus (P) (3A) and percentage of assimilable P contained in the P_total (3B) of the fine and coarse sediment fractions in the Canindé and Capitão Mor Rivers in 2015

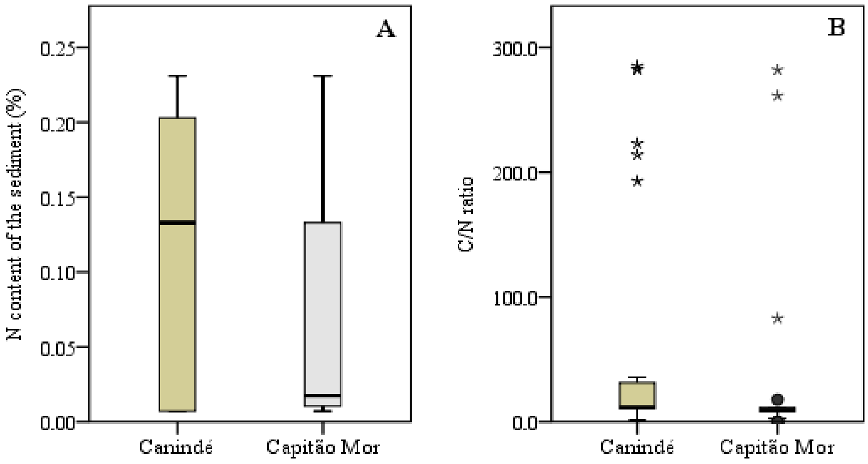

Fig. 4. Distribution of total Nitrogen content (4A) and the carbon/nitrogen ratio (4B) in the sediments of the two main tributaries of the Pereira de Miranda reservoir (the Canindé and Capitão Mor Rivers) in 2015

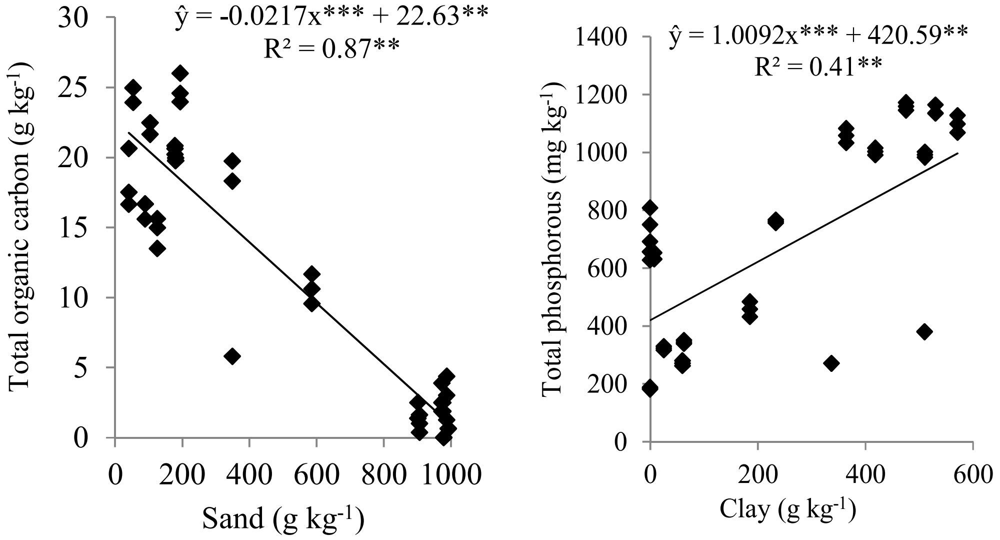

Fig. 5. Relationship between the levels of organic carbon and total phosphorus with the sand and clay respectively, in sediments from the Canindé and Capitão Mor tributaries of the Pereira de Miranda reservoir in 2015

*** 1% significance; *** 0.1% significance*

According to [31], 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, $p \leq 0.001$, n = 51) and TP (R = 0.64, $p \leq 0.001$, n = 51) respectively. A reduction in the levels of total organic carbon can be seen as the amount of coarse sediment increases (Fig. 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.

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.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Brazilian National Council for Scientific and Technological Development (CNPq); Coordination for the Improvement of Higher Education Personnel (CAPES) e a Cearense Foundation for Scientific and Technological Development (FUNCAP) for their financial support of this research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pellegrini JBR, Santos DR, Gonçalves CS, Copetti A, Carlos C, Bortoluzzi EC. Phosphorus fractions and adsorption in sediments in relation to anthropogenic activity. Brazilian Journal of Soil Science. 2008;32:2639-2646.
2. Medeiros PHA, Güntner A, Til F, Mamede GL, Araújo JC. Modellingspatio-temporal patterns of sediment yield and connectivity in a semi-arid catchment with the WASA-SED model. Hydrological, Sciences Journal. 2010;55:636-648.
3. Thomaz EL. The influence of traditional steep land agricultural practices on runoff and soil loss. Agricultural, Ecosystem and Environment. 2009;130:23-30.
4. Santos JÁ, Oliveira KF, Araújo ICS, Avelino IIF, Cajuí KNS, Lacerda LD, Marins RV. Phosphorus partitioning in sediment from a tropical reservoir during a strong period of drought. Environmental Science and Pollution Research. 2016A; 23:24237-24247.
5. Bronstert A, Araújo JC, Batalla RJ, Costa AC, Delgado JM, Franck T. Process-based modelling of erosion, sediment transport and reservoir siltation in mesoscale semi-arid catchments. Journal Soils Sediments. 2014;14:2001-2018.
6. Guerrero LM, Montalvo M, Romeo J, Guijarro. Suport Vector machine for crops/weeds identification in maize fields. Experts Systems with Aplications. 2012; 63:59-271.
7. Peter S, Araújo JC, Araújo N, Herrmann HJ. Flood avalanches in a semiarid basin with a dense reservoir network. Journal of Hydrology. 2014; 512:408-420.
8. Siyue L, Richard TB, Rong M, Lihua X, Chen Y. Extreme drought causes distinct water acidification and eutrophication in the Lower Lakes (Lakes Alexandrina and Albert), Australia. Journal of Hydrology. 2017;544:133-146.
9. Santos JCN, Andrade EM, Guerreiro MJS, Medeiros PHA, Palácio HAQ, Araújo Neto JR. Effect of dry spells and soil cracking on runoff generation in a semiarid micro watershed under land use change. Journal of Hydrology. 2016B;541:1057-1066.
10. Zhaokui N, Shengrui W. Historical accumulation and environmental risk of nitrogen and phosphorus in sediments of Erhai Lake, Southwest China. Ecological Engineering. 2015;79:42-53.
11. Pretty JN, Brett C, Geec D, Hinea RE, Morison JIL, Raven H, Rayment MD, Van der Bijl G. An assessment of the total external costs of UK agriculture. Agricultural Systems. 2000;65:113-36.
12. Bilotta RE, Brazier A. Understanding the influence of suspended solids on water quality and aquatic biota. Water Research. 2008;42:2849-2861.
13. Bostic EM, White JR. Soil phosphorus and vegetation influence on wetland phosphorus release after simulated drought. Soil Science Society of America Journal. 2007;71:238-244.
14. SRH - Secretaria de Recursos Hídricos do Estado do Ceará. Atlas Eletrônico dos Recursos Hídricos e Meteorológicos do Ceará “Electronic Atlas of Waterand Meteorological Resourcesof Ceará”; 2013. Available:http://atlas.srh.ce.gov.br/obras/index.asp
(Acessado em:17março2014)
15. Funceme - Fundação De Meteorologia E Recursos Hídricos. Levantamento de reconhecimento de média intensidade dos solos “*Recognitionofmediumintensityofsoils*”. Mesorregião do Sul Cearense; 2012.
16. Brazilian Soil Classification System – SiBCS, EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária; 2013.
17. Lima NIE, Wiegand LMC, Araújo JC. Sediment redistribution due to a dense reservoir network in a large semi-arid Brazilian basin. Hydrological Sciences Journal. 2011;56:319-333.
18. Yeomans JC, Bremner JM. A rapid and precise method for routine determination of organic carbon insoil. Commun. Soil Science. Plant Anal. 1988;19:1467-1476.
19. EMBRAPA- Empresa Brasileira de Pesquisa Agropecuária. Manual de métodos de análises de solo “*Manual of methods of soi lanalysis*”; 2011.
20. Manning AJ, Langston WJ, Jonas PJ. A review of sediment dynamics in the Severn Estuary: Influence of flocculation. Marine Pollution Bulletin. 2010;61:37-51.
21. CONAMA - Conselho Nacional do Meio Ambiente. Resolução n° 454 novembro de 2017; 2012.
22. Zhaokui N, Shengrui W. Historical accumulation and environmental risk of nitrogen an phosphorus in sediments Of Erhai Lake, Southwest China Zhaokui. Ecological Engineering. 2015; 79:42-53.

23. Cruz MAS, Santos LTSO, Lima LGLM, Jesus TB. Granulometric and mineralogical characterization of sedimentsas support for analysis of environmental contamination in Subaériver springs, Feira de Santana (BA). Geochimica Brasiliensis. 2013;27:49-62.
24. Oliveira TS, Barcellos RL, Schettini CAF, Camargo PB. Processo sedimentar atual e distribuição da matéria orgânica em complexo estuarino tropical, Recife, PE, Brasil. Revista de Gestão Costeira Integrada. 2014;14:399-411.
25. Shao X, Liang X, Wu M, Gu B, LI W, Sheng X, Wang S. Influences of sediment properties and macrophytes on phosphorous speciation in the intertidal marsh. Environmental Science and Pollution Research. 2014;21:10432-10441.
26. Gérard, F. Clay minerals, iron/aluminum oxides, and their contribution to phosphate sorption in soils - a myth revisited. Geoderma. 2016;262:213-226.
27. Wetzel RG. Limnology: lake and River Ecosystems. 3 ed. San Diego, California: Academic Press/Elsevier; 2001.
28. Luo Z, Ma JM, Zheng SL, Nan CZ, Nie LM. Different hydrodynamic conditions on the deposition of organic carbon in sediment of two reservoirs. Hydrobiologia. 2016; 765:15-26.
29. Fonseca R, Canário T, Morais M, Barriga FJAS. Phosphorus sequestration in Fe-rich sediment from two Brazilian tropical reservoirs. Applied Geochemistry. 2011; 26:1607-1622.
30. Siqueira WG, Aprile F. Evaluation of environmental risk by metallic contamination and organic compounds in sediments of the Aurá River basin, Belém, Pará - Brazil. Acta Amazonica. 2013; 43:51-62.
31. Milton JS. Statistical methods in the biological and health sciences. 2.ed. New York: McGrow-Hill; 1992.
32. Zinn YL, Lal R, Resck DVS. Changes in soil organic carbon stock under agriculture in Brasil. Soi Till. 2005;84:28-40.
33. Yuan X, Zhang L, Liab J, Wangc C, Junfeng J. Sediment properties and heavy metal pollution assessment in the river, estuary and lake environments of a fluvial plain, China. Catena. 2014;119:52-60.
34. Wu Y, Wang X, Zhou J, Bing H, Sun H, Wang J. The fate of phosphorus in sediment after the full operation of the Three Gorges Reservoir, China. Environmental Pollution. 2016;214:282-289.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/25656