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Sediments and nutrients input to a small reservoir in the tropical semi-arid region[1]

Sedimentos e nutrientes aportados a um reservatório de pequeno porte no Semiárido tropical

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ABSTRACT - The sediment and nutrients that are input to surface reservoirs compromise the quality and quantity of the stored water. The aim of this study was to investigate the dynamics of sediment and nutrient input along the drainage basin of a small reservoir in the semi-arid region. The reservoir under study was built in 1956 and has a storage capacity of 5.01 hm^3. Seven trenches were dug along the drainage basin of the reservoir following the river. Sediment samples were collected at increasing depths of 20 cm until reaching the original riverbed. An analysis of particle size, total organic carbon (TOC), total nitrogen (TN), available phosphorus (P), exchangeable aluminium (Al), total iron (TFe) and pH was carried out. Approximately 60% of the sediment in the reservoir is composed of clay and silt, and 40% of sand. The greatest thickness of the sediment layer, as well as the greatest concentration of fine sediment, was registered in the section nearest to the dam. The values for TOC ($2.47 < TOC < 34.47$ g kg^{-1}) and TN ($0.69 < T N < 3.97$ g kg^{-1}) showed a positive and significant correlation with each other ($r = 0.95$) and with the fine sediment ($r = 0.85$; $r = 0.77$). The P ($12.19 < P < 41.99$ mg kg^{-1}) showed an inverse relationship with the organic components, fine sediment, TFe and Al. The mean C/N ratio of 8.77 demonstrates the predominance of sources of anthropogenic pollution in the drainage basin of the reservoir. The fine sediment proved to a determinant factor in the retention and availability of TOC, TN and P, with the reservoir acting as a deposit for the input nutrients.

Key words: Silting. Toposequence. Water resources.

RESUMO - Os sedimentos e nutrientes aportados à reservatórios superficiais comprometem a qualidade e a quantidade da água armazenada. Desta forma, objetivou-se investigar a dinâmica do aporte de sedimentos e nutrientes ao logo da bacia hidráulica de um reservatório de pequeno porte no semiárido. O reservatório estudado foi construído no ano de 1956, com capacidade de armazenamento de 5,01 hm^3. Foram escavadas sete trincheiras seguindo o leito do rio ao longo da bacia hidráulica do reservatório. As amostras de sedimento foram coletadas a cada 20 cm de profundidade até atingir o leito original do rio. Foi realizada análise granulométrica, carbono orgânico total (COT), nitrogênio total (NT), fósforo disponível (P), alumínio trocável (Al), ferro total (FeT) e pH. Aproximadamente 60% do sedimento no reservatório é composto por argila e silte e 40% por areia. A maior espessura da camada de sedimentos, bem como a maior concentração de sedimentos finos, registrou-se no trecho próximo à barragem. Os valores de COT ($2,47 < COT < 34,47$ g kg^{-1}) e NT ($0,69 < NT < 3,97$ g kg^{-1}) apresentaram correlações positivas e significativas entre si ($r = 0,95$) e com sedimentos finos ($r = 0,85$; $r = 0,77$). O P ($12,19 < P < 41,99$ mg kg^{-1}) apresentou relação inversa com os componentes orgânicos, sedimentos finos, FeT e Al. A relação C/N média de 8,77 demonstra o predomínio de fontes de poluição antrópicas na bacia de contribuição do reservatório. Os sedimentos finos mostraram-se determinante na retenção e disponibilidade do COT, NT e P, atuando o reservatório como depósito dos nutrientes aportados.

Palavras-chave: Assoreamento. Topossequência. Recursos hídricos.

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INTRODUCTION

Surface reservoirs in the semi-arid region of Brazil are susceptible to eutrophication and silting. This is due to natural conditions, such as shallow soils, long periods with no rain followed by intense rainfall, high rates of evaporation, and little natural soil cover that is intensified by human exploitation (MALVEIRA; ARAÚJO; GÜTNNER, 2012). Such characteristics favour the deposition of high levels of sediment and nutrients in the waterbody during periods of flooding; whereas during times of little rainfall, reductions in the volume of water in the reservoir accelerate the deposition of dissolved nutrients on the sediment (ALMEIDA *et al*., 2017; CAVALCATNE *et al*., 2018). Monitoring silting in these reservoirs therefore becomes a fundamental tool for evaluating their useful life, and the quantitative and qualitative changes in the stored water, as well as understanding the impact on the reservoir of land use and occupation in the drainage basin on the reservoir (LOPES *et al*., 2014; MILLARES; MOÑINO, 2018).

The distribution of sediment in the reservoir and its granulometric characteristics are essential factors in understanding the retention of nutrients in the sediment or their availability to the water column (SANTOS *et al*., 2016). The transport of material carried via runoff depends on granulometry, the particle-size distribution of the underlying material, the intensity of the water flow and the width of the channel (EAST *et al*., 2015). Upon entering the reservoir the water flow loses part of its runoff energy, depositing the coarser material in the area upstream of the reservoir, forming the delta, while the fine sediment is carried by turbulent flow towards the dam, generating different deposition zones for the material throughout the length of the reservoir (NAVAS *et al*., 2009).

Due to its high adsorptive capacity, the fine sediment formed by clay and silt is closely related to the various substances present in the reservoir, such as organic matter, composed largely of carbon (ALMEIDA *et al*., 2016), nitrogen and phosphorus, in addition to various metals and pollutants. Because of this relationship, the distribution and composition of the sediment in the reservoir can alter the retention of these elements or their release to the water column, which tends to affect the water quality due to the proliferation of algae (LÓPEZ *et al*., 2015). In the semi-arid region of Brazil, for example, reductions in the water quality of the reservoir are directly related to sediment accumulation on the bottom of the reservoir (ARAÚJO; GÜNTNER; BRONSTERT, 2006).

Water quality in the reservoir can be assessed from the C/N ratio of the sediment. The presence of carbon and nitrogen in the sediment results from the decomposition of aquatic flora and fauna, in addition to sources of anthropogenic pollution (AVRAMIDIS; NIKOLAOU; BEKIARI, 2015). As such, high values for the C/N ratio indicate the predominance of sources external to the reservoir, with a prevalence of recalcitrant organic compounds (humic and fulvic acids); while low C/N values indicate a source of native organic matter, due to the predominance of non-vascularised photosynthetic organisms in the waterbody, as is the case of algae that cause eutrophication (DUC; CRILL; BASTVIKEN, 2010; LÓPEZ *et al*., 2015).

Due to questions raised by Malveira, Araújo and Güntner (2012), who associate small reservoirs in the semi-arid region of Brazil with the accumulation of sediment, thereby reducing downstream silting in strategic reservoirs, the aim of this study was to: 1) investigate the dynamics of sediment and nutrient input throughout the length of the drainage basin of a small reservoir; 2) determine the characteristics of decomposed material in the reservoir with regard to the carbon to nitrogen ratio (C/N); 3) to ascertain whether nutrients are retained or dispersed in the water column based on the relationship between particle size and the nutrients in the sediment; and 4) whether the reservoir acts as a deposit for sediment and nutrients.

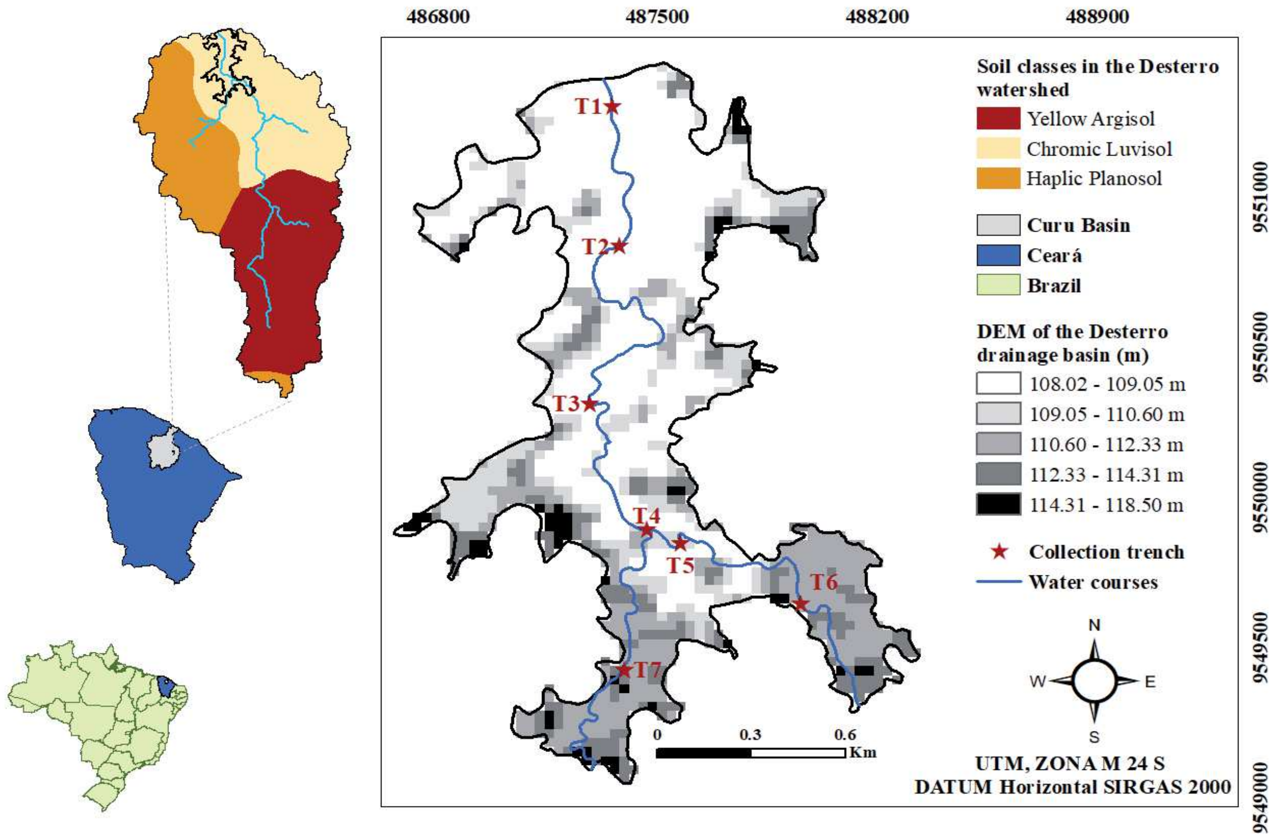
MATERIAL AND METHODS

The study was carried out in the Desterro Reservoir, located in the semi-arid region of north-eastern Brazil, in the district of Caridade, in state of Ceará (Figure 1). The reservoir was built in 1956 following damming of the Desterro River, and has a storage capacity of 5.01 hm^3 and a drainage basin of 170.91 ha (CEARÁ, 2018a). The reservoir has two tributaries: the Desterro River (main course), and the Riacho Lemos Stream.

Seventy-eight percent of the rainfall regime in the study area is concentrated between January and April, with a climate normal of 619.12 mm yr^{-1} (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2019). The soil classes in the watershed of the reservoir are: Yellow Argisol (39.35%), Chromic Luvisol (33.85%) and Haplic Planosol (26.80%), Figure 1 (CEARÁ, 2018b).

Sediment was collected in the drainage basin of the reservoir on 10 March 2018, with the reservoir at zero volume since 2013, a result of rainfall below the historical average between 2012 and 2018. Seven trenches were dug inside the drainage basin of the reservoir along the bed of the original river, easily identified by the lower terrain caused by passage of the runoff, and including areas of the reservoir from the principal entries of the water courses to the dam (Figure 1).

Figure 1 - Location of the drainage basin and watershed of the Desterro Reservoir, Ceará, Brazil



After opening the trenches, disturbed samples were taken at increasing intervals of 20 cm to the maximum sediment depth, identified by variations in the characteristic colour and texture of each material, where the material of the riverbed has a light colour and coarse texture, and the sediment presents concretions and aggregates of varying darker colour. The collected samples were packed in sealed plastic bags, then air dried, and sieved through a 2 mm mesh. The analysis was carried out at the Soil Management and Conservation Laboratory and the Soil Physics Laboratory, both belonging to the Department of Soil Sciences at the Federal University of Ceará.

Total organic carbon (TOC) was determined using the Walkley-Black method, modified by Yeomans and Bremner (1988). Total nitrogen (TN), assimilable phosphorus (P), pH, total iron (TFe), exchangeable aluminium (Al) and the granulometry of the sediment were determined using the methodologies described by the Brazilian Agricultural Research Corporation (EMBRAPA) (2011). Granulometry was classified according to the criteria of the Brazilian Society for Soil Sciences, which adopts the United States Department of Agriculture (USDA) standard. The results for TOC and TN were evaluated following the limits established by resolution 454 of the National Environment Council (CONAMA, 2012).

The correlations between the nutrients and granulometric fractions of the sediment were evaluated by the Pearson method. Cluster analysis employing the Ward method was used to verify similarity between the trenches and sampling depths. The mean values of the groups were then analysed by Tukey's test when the variables showed a normal distribution, and by the Kruskal-Wallis test when normality was not found, using the SPSS 16.0 software.

Satellite images were used to assess the evolution of land use and occupation. The images employed refer to path 217 and row 63 of the LANDSAT 5 satellite (7 April 2011) and the LANDSAT 8 satellite (26 June 2017), with image classification carried out by the supervised maximum-likelihood method using the ENVI 4.7 software. Due to the high incidence of clouds, it was not possible to obtain images for the same month; however, even with different dates, the values for rainfall up to the date of passage of the satellite were similar, at 678.3 mm and 613.8 mm for 2011 and 2017 respectively (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2019).

RESULTS AND DISCUSSION

The results for granulometry of the sediment retained in the Desterro Reservoir (Figure 2) showed an average distribution: 40.64% sand, 21.72% silt and 37.64% clay, giving a total of 59.36% fine sediment (clay and silt). The predominance of these smaller granulometric fractions reinforces Malveira, Araújo and Güntner (2012), who state that small reservoirs act by retaining sediment in the drainage basin, instead of allowing it to continue along the water course towards the larger strategic reservoirs and reduce their water storage capacity.

T6 and T7, which represent the trenches opened in the region of the reservoir delta, have a predominance of coarse material (sand) deposited at the expense of fine sediment, with a mean value for the sand fraction of 53% and 79% for the respective trenches. T4 and T5 present characteristics of the transition between the delta and fine-sediment deposition zone, where the fine material makes up 60.78% and 55.75% respectively.

From T3 to T1, fine sediment predominates in the profile, where T3 shows a prevalence of fine sediment over 65.26% of the deposition profile, T2 presents 58.43% fine sediment, and T1 presents the greatest concentration of fine sediment, 87.33% of the deposit. Millares and Moñino (2018), studying sediment in a reservoir in the semi-arid region of Spain, identified a predominance of 68% fine sediment in the fine-sediment deposition zone; while in the reservoir delta, there was a 66% predominance of sand.

It can be seen that at a depth of 20-40 cm T2 presented the lowest concentration of clay and silt among the trenches in the fine-sediment deposition zone (Figure 2b), where, due to its proximity to the dam, a higher concentration of these granulometric classes was expected than in T3. It is worth pointing out that the dynamics of sediment deposition does not necessarily follow a predefined pattern, and depends on a set of factors. For East *et al*. (2015), the dynamics of sediment transport and deposition along a river system has important implications for the geomorphological evolution of the river. The flow of sediment varies with the granulometry of the transported material, the size of the particles in the pre-existing material in the riverbed, the flow of the river and width of the channel. Therefore, the difference in the sediment deposited on the riverbed at a depth of 20-40 cm, and in trenches T2 and T3, results from waves of coarser sediment carried by floods with high runoff energy that deposit this material in T2.

Evaluating sampling depth in relation to particle size, it can be seen that at a depth of 0-20 cm the trenches showed an average of 62.98% fine sediment (Figure 2A), while at a depth of 20-40 cm, the average was 50.42% (Figure 2B). This difference is due to the samples from 20-40 cm having contact with the original material of the river, which is predominantly sandy, increasing the participation of sandy material in the samples taken at this depth. Sediment was identified at a depth of 40-60 cm only in T1, and consisted of 87.76% fine sediment (Figure 2C).

While the transport of coarser sediments, such as sand fractions, occurs as bottom drag in the runoff channel, fine sediment is transported by turbulent flow, the particles following the flow of the runoff. As the water course enters the reservoir, the capacity for transporting coarse material (such as gravel and sand) is reduced due to a reduction in runoff velocity, with the material being deposited near the inlet area, characterised by the reservoir delta. At the same time, the fine particles are transported towards the dam by turbulent flow, and are deposited by sedimentation when the incident flow ceases (NAVAS *et al*., 2009; SCHLEISS *et al*., 2016).

With regard to sediment depth in the longitudinal profile of the drainage basin (Table 1), a gradual increase can be seen from the tributaries towards the dam. The smallest values were seen in T6 and T7, with respective depths of 12 and 30 cm, followed by 33 cm for T5. Between T4, T3 and T2, it can be seen that sediment depth varies little, at 39, 38 and 40 cm respectively, culminating in the greatest depth in T1, of 51 cm. Such a deposition pattern is classified by Morris and Fan (1998) as decreasing deposition, where an increasing gradient of depth and fine-sediment can be seen from the entries of the water courses towards the dam.

Figure 2 – Particle-size distribution of the sediment at different depths in the trenches excavated in the Desterro Reservoir

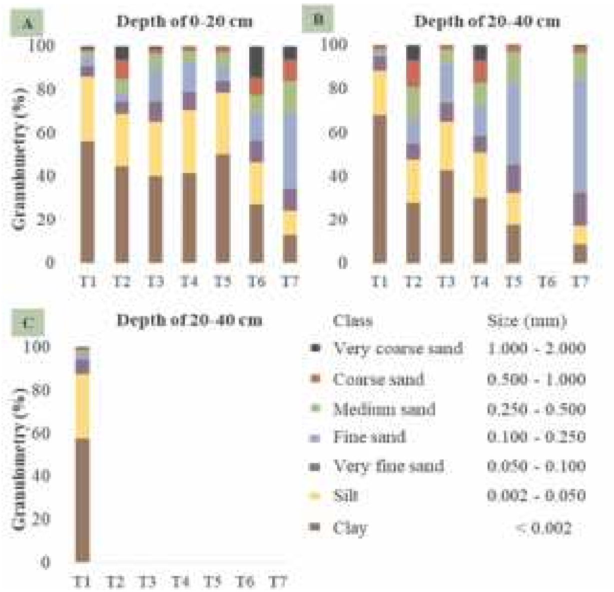


Table 1 - Sediment depth, sampling depths, total organic carbon (TOC), total nitrogen (TN), carbon to nitrogen ratio (C/N), available phosphorus (P), exchangeable aluminium (Al), total iron (TFe) and pH in the sediment of the seven trenches excavated in the Desterro Reservoir in 2018

Trench	Sediment depth (cm)	Sampling depth (cm)	TOC (g kg^{-1})	TN (g kg^{-1})	C/N	P (mg kg^{-1})	Al (g kg^{-1})	TFe (g kg^{-1})	pH
T1	51	0-20	32.35	3.97	8.16	24.99	9.00	382.90	4,88
		20-40	29.60	3.56	8.32	27.82	9.00	411.00	4,81
		40-60	23.38	1.84	12.73	23.74	6.75	183.60	6,45
T1	51	0-20	22.61	1.86	12.18	20.68	15.75	525.60	4,99
		20-40	12.47	1.02	12.19	27.38	13.50	499.70	5,05
T3	38	0-20	34.47	3.66	9.41	32.83	9.00	389.50	5,18
		20-40	22.35	2.71	8.25	36.65	58.50	328.70	4,73
T4	39	0-20	20.39	2.53	8.06	29.96	4.50	157.30	5,48
		20-40	9.62	1.35	7.15	31.50	4.50	176.50	5,14
T5	33	0-20	18.17	2.00	9.08	12.19	40.50	314.60	4,75
		20-40	4.20	0.69	6.05	19.95	22.50	528.70	5,05
T6	12	0-20	17.34	2.20	7.87	25.95	4.50	79.50	5,21
T7	30	0-20	7.45	1.03	7.23	41.99	4.50	227.60	5,41
		20-40	2.47	0.41	6.07	40.63	9.00	232.80	5,08
Minimum			2.47	0.41	6.05	12.19	4.50	79.50	4,73
Maximum			34.47	3.97	12.7	41.99	58.50	528.70	6,45
Mean			18.35	2.06	8.77	28.3	15.11	317.00	5,16
Standard Deviation			10,11	1.13	2.17	8.17	15.82	145.39	0.43

TOC values in the sediment, shown in Table 1, (2.47 < TOC < 34.47 g kg^{-1}) proved to be below the critical limit established by CONAMA, of 100 g kg^{-1} (CONSELHO NACIONAL DO MEIO AMBIENTE, 2012). In each of the trenches, the surface layer (0-20 cm) presented the highest concentration of TOC in the toposequence. This predominance stems from the organic material and nutrients, together with fine sediment, deposited on the top layer of the material at the bottom of the reservoir during periods of runoff (ALMEIDA *et al*., 2016). Another factor is the mineralisation of aquatic organisms (macro- and microbiota) during periods of drought, and the reduction in water volume common in reservoirs in the semi-arid region of Brazil, which favours the accumulation of decomposed nutrients on this top layer (BALDWIN; MITCHELL, 2000; LIU *et al*., 2019).

For the individual sample profiles, the highest TOC concentrations were seen in T1 and T3, with mean values of 28.44 and 28.41 g kg^{-1} respectively (Table 1). T2 presented an average for this nutrient of 17.54 g kg^{-1}. T7, which is representative of the secondary river, had lower TOC values (7.45 and 2.47 g kg^{-1}) than seen for the principal river, represented by T6 (17.34 g kg^{-1}), which indicates that the principal river is the main source of TOC for the reservoir. It is important to note that the area of influence of the principal river up to the entrance of the reservoir is 29.92 km^2, around three times greater than the area of influence of the secondary river, 9.07 km^2, favouring a greater input of sediment and nutrients that originate in the principal river.

In the trenches that intersect with the water courses, represented by T4 and T5, TOC values are higher in the 0-20 cm layer than those seen for the trenches in the incident water courses (T6 and T7), due to the nutrients and sediment from both water courses, less prevalent in these higher trenches, converging at this point.

The results seen for TN in the sediment (0.69 < TN < 3.97 g kg^{-1}) did not reach the critical value of CONAMA resolution 357, of 4.8 g kg^{-1}. The mean value for TN in the sediment was 2.06 g kg^{-1}, with the highest concentrations seen in T1 and T3, with an average of 3.12 and 3.19 g kg^{-1} respectively, and the lowest values seen in T7, with an average in the profile of 0.72 g kg^{-1}.

It can be seen that, maintaining the scales for each variable, the TN values in the sediment of the Desterro Reservoir are similar to those seen for TOC, which is reflected in the high positive correlation between the two nutrients (r = 0.95) (Table 2). For Avramidis, Nikolaou and Bekiari (2015), the intimate relationship between TOC and TN is the result of the high concentration of both nutrients in the make-up of animals and plants that decompose in the waterbody, as well as constituting a large part of anthropogenic organic pollutants.

Table 2 - Correlation between the variables under evaluation in the sediment of the Desterro Reservoir

Variable	COT	NT	P	Al	Fe	pH	Fine Sediment	Sand
TOC	1.00							
TN	0.95**	1.00						
P	-0.22	-0.15	1.00					
Al	0.04	0.06	-0.19	1.00				
Fe	0.15	0.07	-0.33	0.29	1.00			
PH	-0.03	-0.18	0.07	-0.48	-0.46	1.00		
Fine Sediment	0.85**	0.77**	-0.52	0.14	0.10	0.07	1.00	
Sand	-0.85**	-0.77**	0.52	-0.14	-0.10	-0.07	-1.00**	1.00

** Significant correlation at 0.01, * Significant correlation at 0.05

TOC and TN showed a high correlation with fine sediment (r_{toc} = 0.85 and r_{tn} = 0.77) (Table 2), a relationship expressed by the higher values for both nutrients in profiles containing a higher concentration of fine sediment. For López *et al.* (2015), the ratio between the fine particles of the sediment and the organic matter is due to the high specific surface of both, which favours the adsorption of organic matter on the sediment that is largely composed of TOC and TN.

The C/N ratio for the sediment under study had a mean value of 8.77 (Table 1). According to Duc, Crill and Bastviken (2010), C/N values of around 10 in the sediment of water bodies indicate the predominance of native organic matter, characterised by the proliferation of decomposed algae in the sediment, which indicates the prevalence of sources of anthropogenic pollution. According to López *et al*. (2015), this is due to non-vascularised organisms having a low concentration of lignin, which constitutes the conducting vessels in plants, thereby generating, after decomposition, low-recalcitrant organic compounds.

The assimilable P in the sediment showed a mean value of 28.30 mg kg^{-1} (12.19 < P < 41.99 mg kg^{-1}) (Table 1). The highest values are seen for T7, with a mean for the profile of 41.31 mg kg^{-1}. As the assimilable P refers to the P fraction not retained in colloids in the sediment, represented by the organic matter and fine sediment, negative correlations, albeit low, can be seen with TOC (r = -0.22) and TN (r = -0.15), due to the organic matter retaining a considerable concentration of P from metabolic processes (CAVALCANTE *et al*., 2018).

Assimilable P showed a stronger and negative correlation with the fine sediment (r = -0.52) and TFe (r = -0.33), in addition to a low correlation with exchangeable Al (r = -0.19). Higher concentrations of exchangeable Al and TFe are seen at acidic pH, demonstrated by the negative correlations of r = -0.48 and r = -0.46 between the pH and each element respectively. According to Almeida *et al*. (2017), under acidic conditions there is greater P adsorption by TFe and Al, which reduces the concentration of the available P fraction in the sediment.

According to Santos *et al*. (2016), the main phosphorus regulators at the interface between the deposited material and the water depth in the reservoir are the fine-sediment fraction, the organic matter, and the Fe and Al oxides/hydroxides. As such, the negative correlation of available P with TOC and TN (representative of organic matter), as well as with the fine sediment, TFe and Al, demonstrates the principal components of the sediment which retain the phosphorus fractions, thereby reducing detection of available P in the sediment.

From the results of Table 2, there is a clear association between the fine sediment and the nutrients input to the reservoir. This accumulated sediment acts as a diffuse polluter, since, depending on the dynamics of each reservoir, the nutrients associated with the sediment may return to the water column. For Araújo, Güntner and Bronstert (2006), there is a clear reduction in the quality of the water stored in the reservoirs of the Brazilian semi-arid region caused by sediment accumulation. This is corroborated by the data available in Ceará (2019), which show that between 2008 and 2018 the Desterro Reservoir was classified as predominantly eutrophic, with different stored volumes.

Figure 3 shows the cluster analysis for the sediment in the reservoir under study, with the formation of three groups (G1, G2 and G3). It can be seen that G1 is composed of sediment samples with a higher proportion of sand (average of 75.16%) (Table 3). As a result, a statistical difference was found between this group and the other groups with regard to fine sediment, due to the low concentration of these particles in the composition of G1 (Table 3). This resulted in low concentrations of TOC and TN on account of the inverse relationship between these nutrients and the sand, with mean values of 0.71 g kg^{-1} and 4.71 g kg^{-1}, leading to statistical differences for these variables between G1 and the other groups.

G2 presented intermediate values between the sand and fine sediment that can be confirmed by the statistical similarity of G2 and G1, which represents the group with the highest concentration of sand among the three groups under analysis, as well as by a statistical similarity with the group with the highest concentration of fine sediment (G3).

G3 represents the samples with the highest concentration of fine sediment and TOC among the groups, and does not differ statistically from G2 for these variables; G3, however, does differ statistically from the other groups for TN, with an average of 2.96 g kg^{-1}. P showed no statistical difference between groups, a behaviour shared by Al and TFe, demonstrating a balance between the available P and the other two variables. The low variation in P value in the three groups is related to the predominance of fine sediment and organic matter in the waterbody, which reduces the availability of this P fraction in the sediment.

Satellite images (Google Earth) show the presence of three pig farms in the Desterro River basin, several homes with no basic sanitation, areas of rainfed agriculture and others irrigated with water from the river and reservoir. Animals of various sizes were seen in the drainage basin of the reservoir, feeding on the vegetation that arose in the absence of accumulated water.

Figure 4, together with the results shown in Table 4, present the evolution of land use and occupation between 2011 and 2017. It is important to emphasise that for a

Figure 3 - Cluster analysis of the depths of sediment samples in relation to the variables under analysis in the seven trenches excavated in the Desterro Reservoir

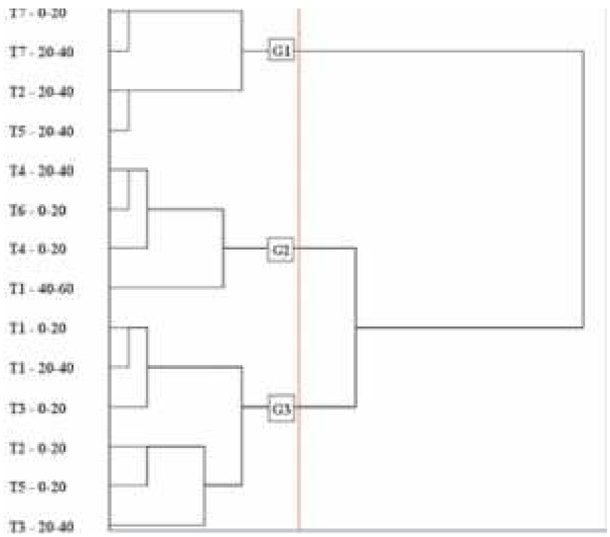


Table 3 - Mean, minimum and maximum values, and standard deviation (SD) for the groups formed for similarity in the samples in relation to the variables under study in the Desterro Reservoir

Variable	Descriptive Statistic	Group 1	Group 2	Group 3
TOC (g kg^{-1})	Mean ± SD	4.71 ± 2.53 a	23.38 ± 5.91 b	26.59 ± 6.47 b
	Min. - Max.	2.47 - 7.45	9.62 - 23.38	18.17 - 34.47
TN (g kg^{-1})	Mean ± SD	0.71 ± 0.31 a	1.98 ± 0.51 b	2.96 ± 0.90 c
	Min. - Max.	0.41 - 1.03	1.35 - 2.53	1.86 - 3.97
P (mg kg^{-1})	Mean ± SD	34.19 ± 12.35 a	27.79 ± 3.57 a	25.86 ± 8.76 a
	Min. - Max.	19.95 - 41.99	23.74 - 31.50	12.19 - 36.65
AL (g kg^{-1})	Mean ± SD	12.00 ± 9.37 a	5.06 ± 1.13 a	23.63 ± 21.00 a
	Min. - Max.	4.50 - 22.50	4.50 - 6.75	9.00 - 58.5
TFe (g kg^{-1})	Mean ± SD	329.70 ± 172.36 a	149.23 ± 47.79 a	392.10 ± 75.23 a
	Min. - Max.	227.60 - 528.70 a	79.50 - 183.60 a	314.6 - 525.6 a
pH	Mean ± SD	5.18 ± 0.20 a	5.57 ± 0.60 a	4.89 ± 0.17 b
	Min. - Max.	5.05 - 5.41	5.14 - 6.45	4.73 - 5.18
Sand (%)	Mean ± SD	75.16 ± 7.77 a	35.90 ± 18.90 a	24.61 ± 10.35 b
	Min. - Max.	67.18 - 82.69	12.20 - 53.00	11.59 - 34.95
Fine Sediment (%)	Mean ± SD	30.61 ± 13.17 a	64.08 ± 18.86 b	75.39 ± 10.35 b
	Min. - Max.	17.31 - 47.93	46.98 – 87.76	65.05 - 88.40

Mean values followed by different letters differ statistically by Tukey's HSD test (parametric variables) and the Kruskal-Wallis test (non-parametric variables) at $p>0.05$

valid comparison, the area covered by cloud and cloud shadow in 2017 (1.45 km^2), was ignored in the image from 2011.

The impact of human action on the environment increases during periods of drought in the semi-arid region of Brazil. This was confirmed by a reduction of 10.76 km^2 in the dense vegetation, which became thin vegetation, increasing by 10.04 km^2 between 2011 and 2017 (Table 4). It is worth noting that the rainfall between 2012 and 2017 was 467 mm yr^{-1}, around 25% less than the climate normal for the area under study (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2019), which may have caused the death of several of the larger plants. For Lopes *et al*. (2014) and Chaves *et al*. (2019), water quality in surface reservoirs is directly affected by degradation of the watershed and by the temporal variability of the rainfall.

The above-mentioned drought caused a reduction of 1.19 km^2 in the waterbodies, which represents more than 95% of the accumulated water in 2011 (Table 4). This cover became exposed soil, with an increase of 0.41 km^2, and agricultural land, whose contribution to the area increased by 1.50 km^2. This more-recent use of the land (classification, 2017, Figure 4B), together with the high erodibility of the soil classes found in the study area (PEREIRA *et al*., 2017), tend to intensify

Figure 4 - Land use and occupation for 2011 and 2017 in the watershed of the Desterro Reservoir: (A) - Classification for 2011; (B) - Classification for 2017

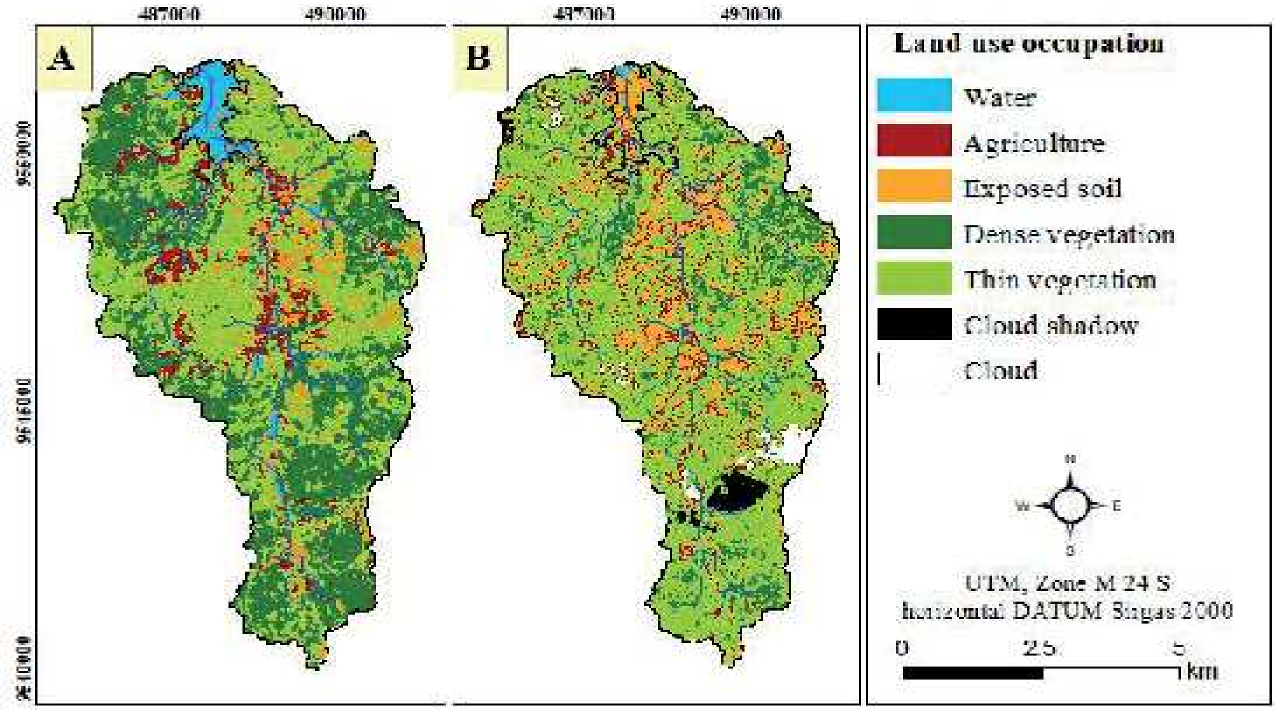


Table 4 - Variation in land use and occupation between 2011 and 2017 in the Desterro Basin

Land use and occupation	Year of Classification		Change 2011 to 2017 (km^2)	Change 2011 a 2017 (%)
	2011	2017		
Waterbodies (km^2)	1.25	0.06	-1.19	-95.43
Dense vegetation (km^2)	15.33	4.57	-10.76	-70.17
Thin vegetation (km^2)	18.87	28.91	10.04	53.22
Exposed soil (km^2)	4.47	4.88	0.41	9.17
Agriculture (km^2)	3.05	4.55	1.50	49.07

the rate of silting and the increase in nutrients in the Desterro Reservoir, with a negative effect on the volume of accumulated water, as well as its quality, which is already eutrophic (CEARÁ, 2019).

CONCLUSIONS

1. The material deposited along the drainage basin of the reservoir showed a gradual increase in depth and the concentration of fine sediment, from the entry of the water courses towards the dam;
2. The C/N ratio demonstrates a predominance of decomposed, non-vascularised photosynthetic organisms in the sediment, which implies a predominance of sources of anthropogenic pollution in the drainage basin of the reservoir;
3. The fine sediment proved to be a determinant factor in the retention and availability of TOC, TN and P;
4. The predominance of fine sediment in the drainage basin of the reservoir shows that it acts as a deposit for sediment and, consequently, for nutrients, and does not allow the sediment to continue downstream of the dam.

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