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Limnological dynamics in an artificial reservoir and intermittent river in the semi-arid region as a function of land use and occupation[1]

Dinâmica limnológica em reservatório artificial e rio intermitente na região semiárida em função do uso e ocupação do solo

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ABSTRACT - Remote sensing coupled with the measurement of physical, chemical and biological variables is an important tool in water resource management. The aim of this study, therefore, was to evaluate the dynamics of the physical, chemical and biological variables of the waters of an intermittent river and an artificial surface reservoir using multivariate analysis and in response to land use and occupation in the hydrographic basin. The study was carried out in the hydrographic basin of the River Cruxati in four study areas (three river areas and one artificial reservoir), with images obtained from the OLI sensor of the Landsat-8 satellite. The limnological variables measured were pH, electrical conductivity, dissolved oxygen, turbidity, nutrients (total nitrogen and total phosphorus) and chlorophyll *a*. The limnological variables were analysed using Principal Component Analysis - PCA, Tukey's test and Cluster Analysis. Eutrophication of the areas under study was calculated using the Trophic State Index. The PCA allowed three components to be selected that indicated the quality of the surface water, river and artificial reservoir, explaining 88.57% of the total variance. The limnological variables responsible for the grouping were electrical conductivity, dissolved oxygen and turbidity. Land use and occupation has influenced water quality in the stretches of river. Anthropisation has had an influence on the levels of dissolved oxygen, and the presence of agricultural areas has caused an increase in turbidity. However, the most conserved landscape (artificial reservoir) had the highest degree of eutrophication due to the difference in water dynamics between the lentic and lotic environments.

Key words: Water quality. Eutrophication. Remote sensing. Multivariate statistical analysis.

RESUMO - O sensoriamento remoto atrelado a mensuração de variáveis físicas, químicas e biológicas são importantes ferramentas para a gestão de recursos hídricos. Portanto, objetivou-se avaliar a dinâmica das variáveis físicas, químicas e biológicas das águas de rio intermitente e de reservatório superficial artificial por meio da análise multivariada e em resposta ao uso e ocupação dos solos de sua bacia hidrográfica. O estudo foi realizado na bacia hidrográfica do rio Cruxati em quatro áreas de estudo (três áreas de rio e um reservatório artificial) e as imagens foram obtidas do sensor OLI do satélite Landsat-8. As variáveis limnológicas mensuradas foram: pH, condutividade elétrica, oxigênio dissolvido, turbidez, nutrientes (nitrogênio total e fósforo total) e clorofila *a*. As variáveis limnológicas foram analisadas através da Análise de Componentes Principais - ACP, teste de Tukey e Análise de Agrupamento. A eutrofização das áreas estudadas foi calculada através do Índice do Estado Trófico. A ACP permitiu a seleção de três componentes indicadoras da qualidade das águas superficiais, rio e reservatório artificial, explicando 88,57% da variância total. As variáveis limnológicas responsáveis pelo agrupamento foram: condutividade elétrica; oxigênio dissolvido e a turbidez. O uso e ocupação do solo influenciou na qualidade da água dos trechos de rio. A antropização teve influência sobre o teor de oxigênio dissolvido e a presença de áreas agriculturáveis causou o aumento da turbidez. Porém, a paisagem mais conservada (reservatório artificial) foi a que apresentou maior grau de eutrofização devido a diferença na dinâmica hidrológica entre ambientes lênticos e lóticos.

Palavras-chave: Qualidade da água. Eutrofização. Sensoriamento remoto. Análise estatística multivariada.

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INTRODUCTION

The study of water quality in waterbodies is of fundamental importance to determine the health of the environment and consequently public health (MEDEIROS *et al*., 2016). In the semi-arid region of Brazil, such studies play a crucial role in guaranteeing economic and social development, since in this region water is a limiting resource due to its scarcity and intermittency throughout almost the entire hydrographic area (ARAÚJO NETO *et al*., 2017). It is therefore essential to monitor water quality, in order to prevent the scarce water sources of this region from becoming unusable.

Water quality can be measured using physical, chemical and biological variables. These variables are constantly subjected to the natural interference of the ecosystem itself, and anthropogenic interference caused by the activities of land use and occupation (MEDEIROS *et al*., 2016). In the northeast of Brazil, the main changes to land use and occupation have been caused by agriculture and livestock farming, which, when carried out inappropriately, generate a loss of biodiversity and a drop in soil fertility, and intensify the processes of erosion (VANZELA; HERNANDEZ; FRANCO, 2010). In addition, patterns of land use and occupation modify watercourses and affect the quality of the environment, as well as the quality and quantity of surface and groundwater, even in the long term (SÁLY *et al*., 2011).

In aquatic ecosystems, the health of the environment can be inferred based on a characterisation of its structure (biological elements and their interaction with physical and chemical variables) and function (processes fundamental to maintaining biodiversity, such as the production, consumption and decomposition of organic matter) (ARAÚJO *et al*., 2011). As such, various studies have used remote sensing to quantify the effects that different land uses and temporal changes in the structure of the landscape have caused to the health of waterbodies (ARAÚJO NETO *et al*., 2017; CHAVES *et al*., 2019; MENEZES *et al*., 2016; VANZELA; HERNANDEZ; FRANCO, 2010).

Remote sensing coupled with the measurement of physical, chemical and biological variables is an important tool in improving water resource management (LOPES *et al*., 2014b). In the semi-arid region of Brazil, changes in the water quality of artificial surface reservoirs in the face of anthropogenic impacts have been studied with the aid of remote sensing (CHAVES *et al*., 2019). However, studies in semi-arid regions of Brazil that use this tool to understand how changes in land use and occupation are interfering in the water quality of artificial and natural waterbodies remain scarce.

The aim of this study, therefore, was to evaluate the dynamics of the physical, chemical and biological variables of the waters of an intermittent river and an artificial surface reservoir in the semi-arid region using multivariate statistics and in response to land use and occupation in the hydrographic basin.

MATERIAL AND METHODS

The study was carried out in the hydrographic basin of the River Cruxati, Ceará, Brazil. Two areas were selected in the district of Amontada, Ceará, along the channel of the intermittent river (River Cruxati): Area 1 (-3.406505; -39.740857), covering a total area of 381 km^2; and Area 2 (-3.348007; -39.735144), covering an area of 504 km^2. Area 3 is located in the district of Itapipoca, Ceará (-3.30029; -39.670841), also corresponding to the intermittent river, covering an area of 884 km^2, and the Poço Verde reservoir (-3.439212; -39.6316720), with an area of 60 km^2, as shown in Figure 1.

The local climate is semi-arid with an average annual rainfall of 1,110.6 mm and evaporation of 1,914.7 mm; the average annual temperatures are between 26 ºC and 28 ºC, with higher rainfall from January to June (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2019). There is also a difference in the rainfall indices between the upper, middle-third and lower part of the hydrographic basin, with the rainfall tending to be higher in the lower part of the basin due to the increase in relative humidity and proximity to the coast.

The main classes of soil present in the hydrographic basin of the River Cruxati are Argisols, Gleisols, Neosols, Planosols and Plintosols (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2018). The Gleisols show low erodibility due to their sodic character down to 100 cm - flood area (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2018). According to Pereira *et al*. (2017), the Argisols and Planosols show average susceptibility to erosive processes, due to the layer of clay accumulation being located in the subsurface (Bt) and the planic B horizon. The Neosols are classified as highly erodible due to the low aggregation of soil particles (PEREIRA *et al*., 2017). According to Raimo *et al*. (2019), the presence of the plinthic or petroplinthic subsurface horizon leads to reduced water infiltration capacity in the profile, which favours high erodibility.

In this region, the rainfall is fairly characteristic of semi-arid regions, with the highest rainfall indices during the first semester, between February and May (Figure 2).

Multispectral images from the Landsat-8 satellite (13 June 2019, path 217, row 62, spatial resolution 30 m), available from the Earth Explorer website (http://earthexplorer.usgs.gov/), were used to analyse land use and occupation in the study areas.

Figure 1 - Location of the three areas of the river and of the Poço Verde reservoir inserted in the hydrographic basin of the River Cruxati, Ceará, Brazil

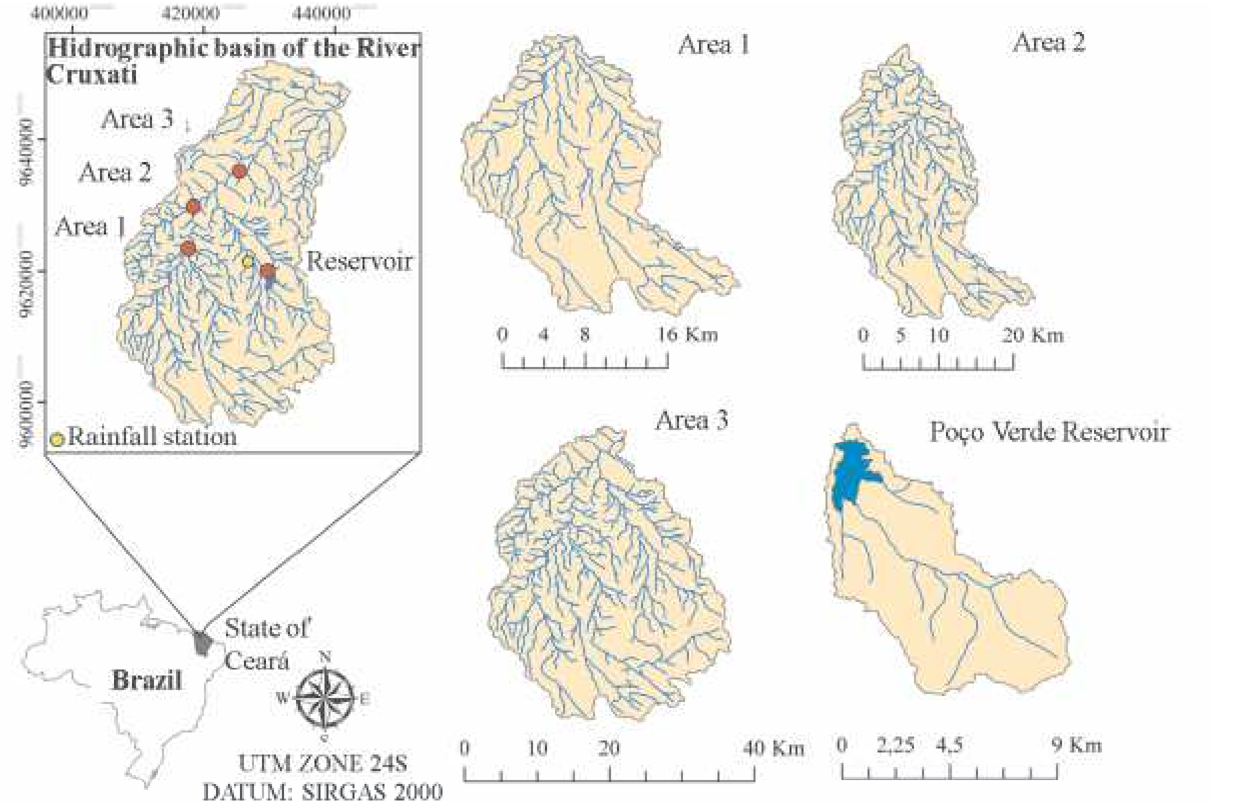
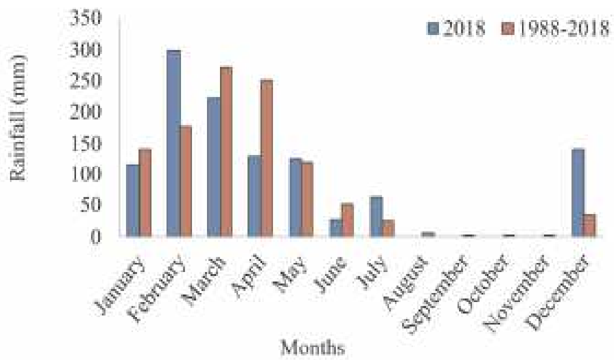


Figure 2 - Monthly rainfall in 2018, and the monthly average between 1988 and 2018, in the district of Itapipoca, Ceará, Brazil



Source: Fundação Cearence de Meteorologia e Recursos Hídricos (2019)

Radiometric calibration was carried out by converting the digital Number to the radiance of the spectral bands using equation 1.

$$L_{\lambda} = M_L Q_{cal} + A_L \quad (1)$$

where: L - spectral radiance at the sensor aperture in Watts/(m^2 * sr * μm); M_L - multiplicative band rescaling factor; Q_{cal} - band-specific additive rescaling factor; A_l - DN value quantised by a level 1 pixel.

The FLAASH algorithm (Fast Line-of-sight Atmospheric Analysis of Hypercubes) was applied for atmospheric correction of the images; this algorithm is based on the Radiative Transfer Model (MODTRAN). Atmospheric correction was carried out with the aid of the ENVI 5.3 software, receiving the radiance data as input, and using a scale factor of 10 (single scale factor), aerosol scale height of 1.08 km, and CO_2 rate of 400 ppm. The tropical atmospheric model was selected. Visibility can be estimated from the image itself, from the detection of dark pixels.

The images were classified with the ENVI 5.3 software using the Maximum Likelihood algorithm. Bands 5, 4 and 3 were used, as they configure the images in true colour, and this, together with the use of the near infrared band, helps to indicate areas of greater or lesser vegetative activity. The images were classified according to the percentage of dense vegetation, riparian vegetation, water, agriculture and anthropogenic areas (exposed soil and urban).

During June 2018, in each area of the river, 20 measurements of the physical and chemical variables of the water were taken. The data for pH, electrical conductivity (EC) (µS/cm) and dissolved oxygen (DO) (mg L^{-1}) were obtained using a multiparameter probe (Yes Professional plus), while the turbidity values (NTU) were determined with the aid of a turbidimeter (Ap, 200).

During June and September, three water samples were collected each month from each area of the river. The samples were collected with a Van Dorn bottle and placed in 2.0 L polyethylene bottles, which were wrapped in aluminium foil to restrict photosynthetic activity. From the water samples, the levels of total nitrogen (mg L^{-1}), total phosphorus (mg L^{-1}) and chlorophyll *a* (µg L^{-1}) were determined.

The samples were kept under refrigeration below 4 °C until time for the analytical procedure. Analytical determinations of the total phosphorus, total nitrogen and chlorophyll *a* were carried out as per the methods described by Eaton *et al*. (2005): total phosphorus - persulfate digestion followed by the ascorbic acid method; total nitrogen - persulfate digestion followed by cadmium column reduction; and chlorophyll *a* - spectrophotometric method with acetone extraction. The procedures were conducted at the Environmental Health Laboratory (LABOSAM) of the Federal Institute of Education, Science and Technology of Ceará.

The same levels were determined for the Poço Verde reservoir during January, April, July and October 2018; however, the data were obtained from the Ceará Hydrological website (COMPANHIA DE GESTÃO DE RECURSOS HÍDRICOS, 2019).

Data analysis

Data normalisation (mean equal to zero and standard deviation equal to one) was carried out to avoid errors from the scales and units of the selected limnological variables. Principal component analysis (PCA) was then performed to identify which limnological variables best explain the difference between the study areas. To minimise the degree of difficulty in identifying significant factors in the matrix of limnological variables, Varimax orthogonal transformation or a simple rotation of the factor load matrix was used. The aim of rotating the matrix is to minimise the contribution of variables having less significance in a factor (HAIR JÚNIOR *et al*., 2005).

The Kayser Mayer Olkim (KMO) method was used to measure data consistency (HAIR JÚNIOR *et al*., 2005; SILVEIRA; ANDRADE, 2002). KMO is considered excellent when greater than or equal to 0.90, adequate between 0.70 and 0.90, admissible between 0.50 and 0.70 and unacceptable when less than 0.50 (SILVEIRA; ANDRADE, 2002). For this analysis, the SPSS v16.0 software was used.

In order to compare the limnological variables that explained the components of the PCA between the study areas, an analysis of variance (ANOVA one-way test) was applied, followed by Tukey's test to compare the mean values. The analyses were carried out using the Rstudio 3.2 software.

A cluster analysis (CA) of the study areas was performed to classify the limnological variables into similar groups using the agglomerative method. Similarity was estimated by using the squared Euclidean distance. Ward's clustering algorithm was used to define the aggregates.

Eutrophication in the environments, the intermittent river and artificial surface reservoir was calculated by means of the Trophic State Index (TSI) between the groups formed in the CA, using the equations adjusted by Lamparelli (2004). The TSI was calculated from the values for total phosphorus (mg L^{-1}) and chlorophyll *a* (µg L^{-1}). For the groups comprising the river areas, equations 2 and 3 were used respectively:

$$TSI(TP) = 10x(6-((0.42-0.36.(lnTP)ln2))-20 \quad (2)$$

$$TSI(CL) = 10x(6-((0.7-0.6x(lnCL))/ln2))-20 \quad (3)$$

For the reservoir, equations 4 and 5 were used:

$$TSI(TP) = 10x(6-(1.77-0.42(lnPT)/ln2)) \quad (4)$$

$$TSI(CL) = 10x(6-((0.92-0.34x(lnCL))/ln2)) \quad (5)$$

The mean value for the TSI in each group was calculated from the mean values of the TSI for total phosphorus and Chlorophyll *a*.

RESULT AND DISCUSSION

From the image classification (Figure 3), it can be seen that there were variations between the percentage of land use and occupation (Figure 4), highlighting a greater percentage of plant cover: dense vegetation (50.00%) and riparian vegetation (8.33%) in the Poço Verde reservoir. In the other areas (1, 2 and 3) the percentage of plant cover decreased (28.02%, 22.61%, 30.31% and 1.31%, 1.58%, 4.52% respectively), with an increase in the percentage of agricultural (32.54, 40.27%, 38.23%) and anthropogenic (35.17%, 32.73%, 23.98%) areas.

It was apparent that areas that achieved less plant cover showed an increase in the percentage of agricultural and anthropogenic areas, clearly showing the substitution of native vegetation for areas of intense cultivation (Figures 3 and 4). Analysing the spatio-temporal dynamics of vegetation in the semi-arid region of Brazil, Cunha *et al*. (2012) found that the Caatinga vegetation decreased, showing the areas under analysis to be in the process of losing vegetation. According to Fernandes *et al*. (2015), an increase in deforestation causes a reduction in the preserved Caatinga and capoeira, pointing to an increase in the areas of pasture and agriculture.

Figure 3 - Land Use and Occupation in the study areas. June 2018, Ceará

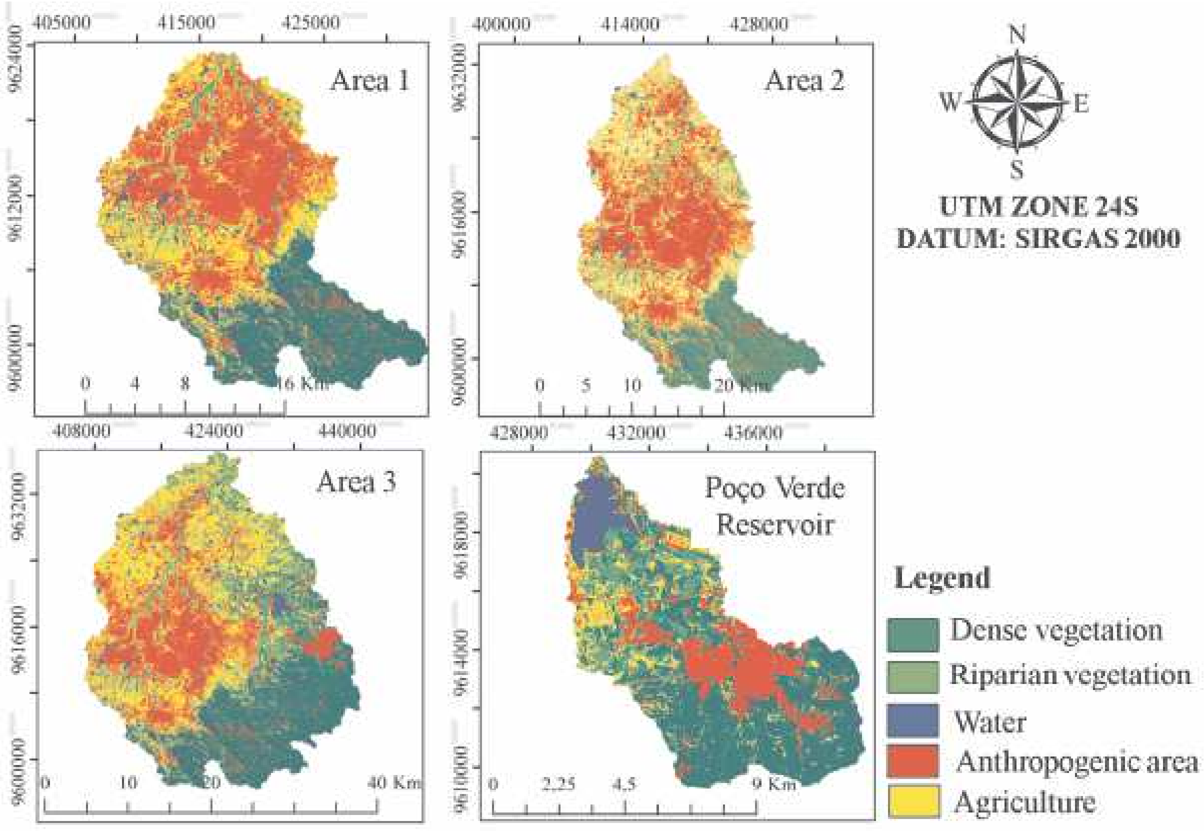
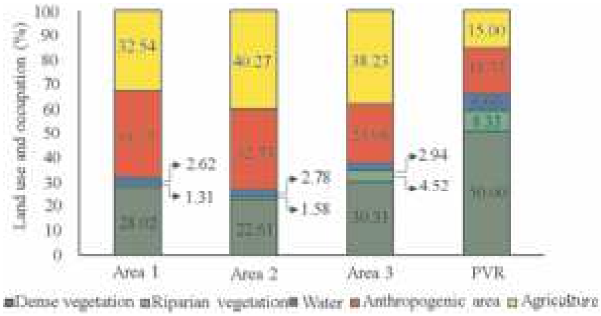


Figure 4 - Percentage of Land Use and Occupation between the Study Areas, River Cruxati and Poço Verde Reservoir. June 2018, Ceará



According to Feitosa *et al*. (2010), the increase in areas of agriculture and pasture causes a reduction in dense and riparian vegetation, increasing the physical and chemical degradation of the soil, and sedimentation, resulting in hydrographic changes, fluctuations in temperature and concentrations of nutrients and contaminants, thereby directly affecting the quantity and quality of the water (changes in the physical, chemical and biological variables).

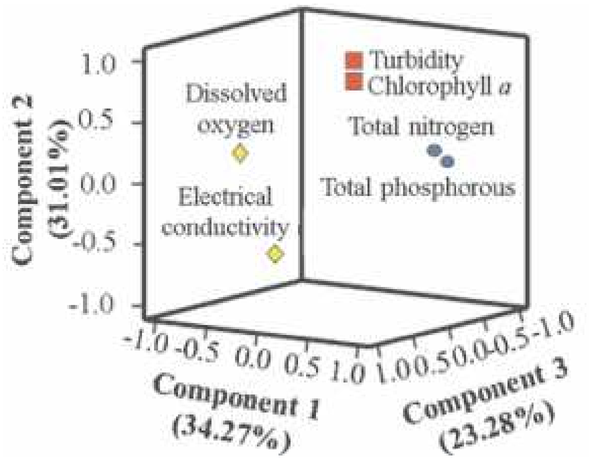
It was found from the PCA, that the three components together explained 88.57% of the total variance. The Kaiser-Meyer-Olkin sufficiency test (KMO) presented an index equal to 0.55, and was considered admissible as per Silveira and Andrade (2002). The first component explained 34.27% of the variability of the data, with the variables of total nitrogen (mg L^{-1}) and total phosphorus (mg L^{-1}) showing high, positive coefficients (>0.935) (Table 1, Figure 5).

Component 1 expresses the influence of diffuse pollution, such as runoff from agricultural and pastoral areas in the region, and the extensive use of nitrogen and phosphate fertilisers in agricultural areas (Figures 3 and 4). In this component, there is a significant influence from anthropogenic action on the concentration of nutrients in surface waters. According to Andrade *et al*. (2007), the nutrients nitrogen and phosphorus are indicators of the farming activity of production systems. Nitrogen and phosphorus are known to be the main causes of eutrophication in water sources; an excess of these nutrients in aquatic ecosystems can cause changes in lakes and reservoirs, hampering the use or function of the waterbody (LOPES *et al*., 2014a).

Table 1 - Matrix with the values of the limnological variables transformed by the Varimax algorithm and their respective weights in relation to components 1, 2 and 3

Number	Variable	Component		
		C1	C2	C3
1	Total nitrogen (mg L^{-1})	0.944	0.255	-0.057
2	Total phosphorus (mg L^{-1})	0.935	0.173	-0.221
3	Turbidity (NTU)	0.131	0.885	-0.150
4	Chlorophyll a (μg L^{-1})	0.242	0.825	0.017
5	Electrical conductivity (μS cm^{-1})	0.001	-0.452	0.856
6	Dissolved oxygen (mg L^{-1})	-0.464	0.313	0.768
	Eigenvalue	2.05	1.86	1.39
	Variance (%)	34.27	31.01	23.28
	Accumuklated variance (%)	34.27	65.28	88.57

Figure 5 - PCA showing the variables explaining components 1, 2 and 3



While assessing the quality of surface waters in the semi-arid region of Brazil, changes in water quality were seen which were due to runoff from agricultural areas and the use of fertilisers (ANDRADE *et al*., 2007; LOPES *et al*., 2014a). Another source of pollution that may contribute to this group is the domestic sewage released into water courses throughout the hydrographic basin. For the cities of Amontadas and Itapipoca, where the study areas are located, the percentage of treated sewage is 7.61% and 56.61% respectively (INSTITUTO DE PESQUISA E ESTRATÉGIA ECONÔMICA DO CEARÁ, 2019).

The second component explained 31.01% of the total variation of the data and showed Turbidity (NTU) and Chlorophyll *a* (μg L^{-1}) as the most explanatory variables (Table 1, Figure 5). This is a component that represents suspended solids. The high weight (>0.885) attributed to turbidity can be explained by the climate characteristics of the semi-arid regions, little ground cover (Figures 3 and 4) and high-intensity rainfall (Figure 2), being an important factor in the erosion process and in sediment transport. According to Araújo (2003), the average siltation rate in reservoirs of the semi-arid region is 1.85% each decade.

The variable, chlorophyll *a*, had a high weight (>0.825), and is considered an indicator of the presence of nutrients, especially phosphorus and nitrogen, as seen in component 1. The presence of chlorophyll *a* in aquatic systems represents the effect of the eutrophication process, which is the phenomenon by which an ecosystem becomes increasingly productive through enrichment with nutrients (ANDRADE *et al*., 2020; CHAVES *et al*., 2019; LOPES *et al*., 2014a). Eutrophication has an environmental impact on a global scale, and is one of the most serious problems related to water conservation (SCHINDLER, 2012). According to data from the Companhia de Gestão dos Recursos Hídricos (2019), of the 140 artificial surface reservoirs monitored in the state of Ceará, 75% were classified as eutrophic in August 2018.

Component 3 comprised the variables electrical conductivity (μS cm^{-1}) and dissolved oxygen (mg L^{-1}), which explained 23.28% (Table 1, Figure 5), expressing greater association with the variables indicating enrichment by soluble ions (weight>0.856 for electrical conductivity) and organic pollution (weight>0.768 for dissolved oxygen).

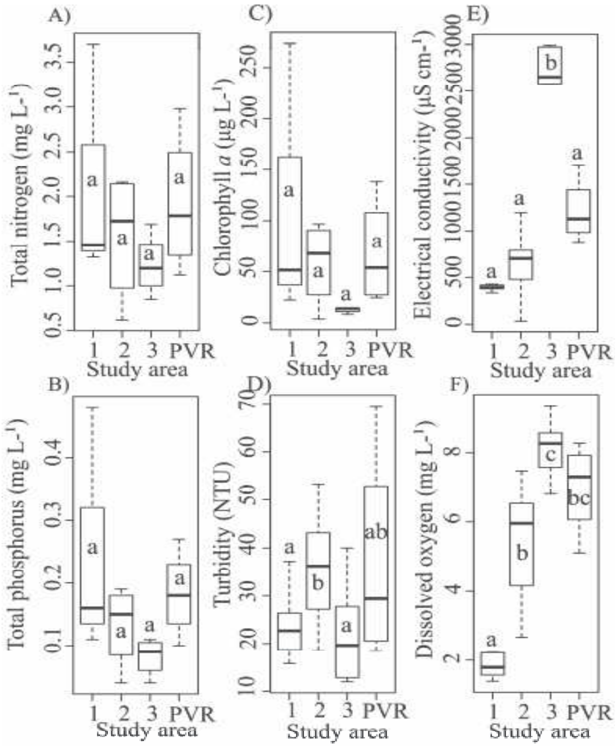
From the results of the ANOVA and Tukey's test, significant differences were seen between the areas in relation to the concentration of dissolved oxygen (mg L^{-1}), electrical conductivity (μS cm^{-1}) and turbidity (NTU) (Figure 6 - D, E and F). There was no significant difference between the study areas for total nitrogen, total phosphorus or chlorophyll *a*, (Figure 6 - A, B and C).

The low levels of dissolved oxygen seen in Area 1 (Figure 6F) may be related to a higher percentage of anthropisation and a lower percentage of riparian vegetation. This set of characteristics increases the entry of allochthonous material into the aquatic system and favours the concentration of nutrients. These nutrients are decomposed and, due to the microbial metabolism in the medium, there is a reduction in the levels of dissolved oxygen with the formation of hydrogen sulphide (WHITWORTH; BALDWIN; KERR, 2012).

In Areas 2 and 3 (Figure 6A), the increase in oxygen content can be explained by the shallower depth of the water, facilitating gas exchange. Area 3 is positioned further downstream in relation to the other two areas (1 and 2) and the PVR, which according to the river continuum concept (VANNOTE *et al*., 1980) causes widening of the channel and a consequent reduction in depth. Additionally, wind action favours the process of re-generation, a phenomenon observed in a laboratory experiment by Chu and Jirka (2003).

Similar letters indicate no significant difference in limnological variables between areas, and different letters indicate a statistical difference in limnological variables between the study areas by Tukey's test ($p<0.05$)

Figure 6 - Variations in A- Total nitrogen (mg L^{-1}), B- Total phosphorus (mg L^{-1}), C- Chlorophyll *a* (µg L^{-1}), D-Turbidity (NTU), E- Electrical conductivity (µS cm^{-1}) and F- Dissolved oxygen (mg L^{-1}), in each of the three areas and the PVR



The difference seen between areas (1, 2 and 3) for electrical conductivity, reflects the percentage of anthropogenic areas. The loss of riparian vegetation and the increase in agricultural areas may induce greater entrainment to the riverbed of sediments associated with the nutrients from fertilisers and waste from domestic animals, favouring an increase in electrical conductivity, a dynamic previously seen in another basin by Vanzela, Hernandez and Franco (2010). Due to its proximity to the sea, Area 3, may be influenced by marine aerosols, contributing to the high value for electrical conductivity (Figure 6E). According to Meireles, Frischkorn and Andrade (2007), areas that are influenced by marine aerosols present rainwater where the chloride ion is the most abundant element, followed by sodium.

The greatest value for turbidity was found in the PVR, followed by areas 2, 1 and 3 (Figure 6D). The high value found in the PVR may be associated with greater supply of nutrients, in addition to the greater depth that reduces resuspension capacity and limits internal nutrient cycling. In their study, Menezes *et al*. (2016), found that in areas of high turbidity, the particles can accommodate a large amount of pollutants and even pathogenic microorganisms, which makes it extremely important for this parameter to be determined.

In the other areas, the values for turbidity may be related to erosion of the riverbanks, considering that these areas had a lower percentage of riparian vegetation. This riparian vegetation plays an important role in filtering pollutants, such as agricultural pesticides and sediments that originate in the surrounding areas via runoff, preventing them from reaching the watercourses (MAIA; LOPES; ANDRADE, 2018). Another factor that may have favoured the increase in turbidity is the presence of agricultural areas where fertilisers percolate towards the water courses. It is important to point out that in relation to Areas 1, 2 and 3, Area 2 had a higher percentage of agriculture (40.27%) with successively greater turbidity (35.25 NTU).

The similarity of the waters between the stretches of river and the artificial reservoir of the basin of the River Cruxati during the period being monitored, and assessed using the clustering technique, formed three homogeneous groups (Figure 7).

The number of groups was defined based on the first major difference between the clustering coefficients of two consecutive groups, 1156.067 (1753.214 - 597.147). In the dendrogram (Figure 7), which corresponds to the rescaled clustering coefficients, where the lowest coefficient corresponds to 0 and the largest to 25, it is explicit that the optimal cut-off point is the distance for the value just above 3.070 after formation of the three groups, a point that corresponds to the first major difference between two consecutive coefficients, 1156.067.

The cluster analysis shows that three groups were formed from the four study areas: Group 1 (Area 1 and Area 2); Group 2 (PVR) and Group 3 (Area 3) (Figure 7). The variables that contributed to forming the groups were the physical and chemical variables, since only they showed any significant difference between the groups (Table 2).

From this group formation, it was evident that Group 2 (PVR) is more similar to Group 1 (Areas 1 and 2). This is related to the values for turbidity, which had higher values in these study areas (Figure 6D). It is important to note that the areas that comprise Groups 1 and 2 are further upstream than the other areas. According to the river continuum concept of Vannote *et al*. (1980), matter enters the system in upstream stretches, which would explain the higher turbidity values. This matter is further processed by travelling down a longitudinal gradient, generating a lower concentration of nutrients and, consequently, less turbidity in downstream areas (VANNOTE *et al*., 1980).

The formation of Group 3 was explained by the electrical conductivity. This group appears downstream of the other groups. As it gets closer to the mouth of the river, the riverbed increases, as do the levels of salts dissolved in the water, followed by changes in conductivity (VANNOTE *et al*., 1980). The high electrical conductivity may also be influenced by marine aerosols (MEIRELES; FRISCHKORN; ANDRADE, 2007).

Figure 7 - Cluster analysis between the study areas, Ceará, 2018

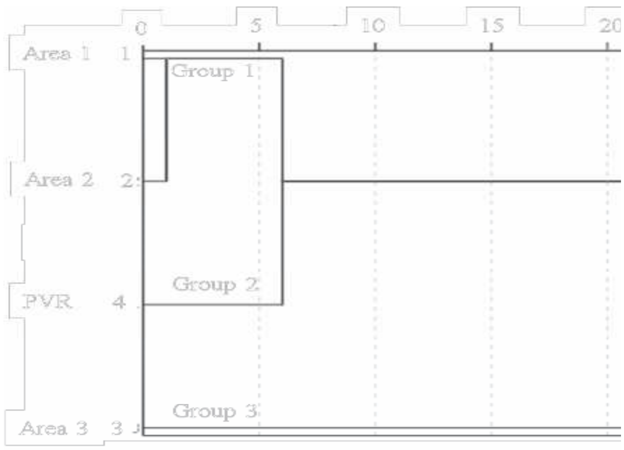
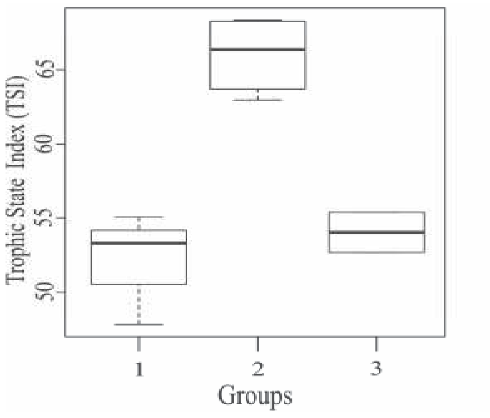


Table 2 - Statistics of limnological attributes and nutrients for each group formed in the cluster analysis, River Cruxati and Poço Verde Reservoir, Ceará, Brazil

Variable	Unit	Statistic	Group		
			1	2	3
Dissolved oxygen	(mg L^{-1})	Mean±SD	4.18 ± 2.75 a	6.99 ±1.35 b	8.14 ±0.74 b
		Minimum	0.003	5.11	6.8
		Maximum	3.98	8.27	9.35
Electrical conduct.	(µS cm^{-1})	Mean±SD	508.04±262.14 a	1212.53 ±353.49 b	2372.38±1024.30 c
		Minimum	4.64	880.00	25.77
		Maximum	850.00	1710.00	2989.00
Turbidity	(NTU)	Mean±SD	31.36 ± 14.02 a	36.70±23.12 ab	21.87 ± 8.73 b
		Minimum	15.80	18.5	12.00
		Maximum	83.10	69.5	83.10
Total nitrogen	(mg L^{-1})	Mean±SD	1.81 ± 0.98 a	1.92 ±0.80 a	1.30 ±0.35 a
		Minimum	0.62	1.12	0.85
		Maximum	3.70	2.98	1.69
Total phosphorous	(mg L^{-1})	Mean±SD	0.18 ± 0.13 a	0.18 ±0.07 a	0.08 ±0.02 a
		Minimum	0.04	0.10	0.04
		0.48	0.27	0.11	
Chlorophyll a (µg L^{-1})	Maximum	Mean±SD	83.33 ± 89.94 a	67.55 ± 52.75 a	12.67±2.90 a
		Minimum	3.73	24.54	8.36
		Maximum	273.67	138.14	14.49

Mean values followed by different lowercase letters in a column differ by F-test at a level of 1%

Figure 8 – Mean value for the Trophic State Index (TSI) of the groups formed in the Cluster dendrogram



For the Trophic State Index, the groups (1, 2 and 3) presented values of 52.04, 66.02 and 54.02 respectively, and were classified as mesotrophic, hypereutrophic and mesotrophic (Figure 8).

The high value for TSI found for Group 2 compared to the other groups (1 and 3) shows that this environment is more eutrophic, even with the more-conserved landscape structure. This result may be related to Group 2, as it is a reservoir, with a lower capacity for self-purification compared to the other groups composed of river areas.

Self-purification consists in the ability of the environment to neutralise pollutant loads (PALMA-SILVA; TAUK-TORNISIELO; PIÃO, 2007). The efficient transformation of organic compounds is greater in lotic environments than in lentic environments due to their different hydrological dynamics. This difference is mainly associated with an absence of flowing water in lentic environments, since this factor interferes with the residence time, transport, deposition and processing of suspended particles (PALMA-SILVA; TAUK-TORNISIELO; PIÃO, 2007). According to the data from the Companhia de Gestão dos Recursos Hídricos (2019), the reservoir under study reached its maximum capacity and spilled over for the last time in 2011. This long period without reaching its maximum quota or spilling over resulted in a reduction in its ability to process organic compounds, generating a higher value for the TSI.

CONCLUSIONS

1. Anthropisation causes a reduction in the oxygen dissolved in the water, while the presence of arable areas results in an increase in the turbidity of the surrounding waterbodies;
2. The PCA allowed three components to be selected that indicated the quality of the surface water, river and artificial reservoir, explaining 88.57% of the total variance. The principal factors responsible for water quality are diffuse pollution, the processes of erosion and runoff, and enrichment by soluble ions and organic pollution;
3. The limnological variables responsible for the grouping were electrical conductivity, dissolved oxygen and turbidity;
4. The TSI showed no connection to environmental conservation, with the most conserved landscape (artificial reservoir) having the highest degree of eutrophication due to the difference in water dynamics between the lentic and lotic environments;
5. Land use and occupation interfere differently in the quality of the physical, chemical and biological variables of the waters of the intermittent river and artificial surface reservoir; it is therefore necessary to evaluate landscape structure in studies of water quality.

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