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Water quality and anthropogenic impact in the watersheds of service reservoirs in the Brazilian semi-arid region[1]

Qualidade da água e impactos antrópicos em bacias hidrográficas de açudes no semiárido brasileiro

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ABSTRACT - The semi-arid region of Brazil is characterised by the irregular temporal and spatial distribution of the rainfall, which together with anthropogenic action causes degradation of the water quality. The aim of this study was to evaluate water quality in surface reservoirs in the Brazilian semi-arid region due to rainfall variability and the degree of anthropisation of the watersheds. Water samples were collected at the Orós, Trussu and Muquém reservoirs during August and December of 2012, April, October and December of 2013, and March and June of 2014 (dry and rainy periods). The following limnological attributes were analysed: electrical conductivity, pH, turbidity, transparency and chlorophyll-a, with the results evaluated using box plots, and the mean values compared by Student's t-test. Anthropogenic data from the watersheds contributing to the reservoirs were used to correlate limnological attributes with the condition of the watersheds during the dry period of 2013. The rainfall was not sufficient to significantly improve the water quality of the reservoirs, and in the Orós Reservoir high levels of chlorophyll-a and turbidity occurred during both periods. Anthropisation of these areas has a direct influence on the water quality of the surface reservoirs of the Upper Jaguaribe, showing a correlation with the attributes of water quality, especially with pH. Total degradation of the surface waters of the Upper Jaguaribe Basin due to land use in the watersheds is just a matter of time.

Key words: Anthropised area. Surface water. Spatial and temporal variability of precipitation.

RESUMO - A região semiárida do Brasil é caracterizada pela irregular distribuição temporal e espacial da pluviosidade que junto às ações antrópicas causam a degradação da qualidade da água. Objetivou-se neste estudo avaliar a qualidade da água em reservatórios superficiais no semiárido brasileiro face a variabilidade da precipitação e o grau de antropização das bacias hidrográficas. Foram realizadas coletas de água nos açudes Orós, Trussu e Muquém, nos meses de agosto e dezembro/2012, abril, outubro e dezembro/2013, e março e junho/2014 (períodos seco e chuvoso). Foram analisados os seguintes atributos limnológicos: condutividade elétrica, pH, turbidez, transparência e clorofila-*a* e os resultados foram avaliados através de gráficos tipo boxplot, utilizando-se a comparação de médias através do teste t-Student. Dados de antropização das bacias hidrográficas contribuintes dos açudes, para o período seco de 2013, foram utilizados para correlacionar os atributos limnológicos com a condição das bacias hidrográficas. As chuvas não foram suficientes para melhorar significativamente a qualidade das águas dos açudes, sendo que no Orós ocorreram elevados teores de clorofila-*a* e turbidez em ambos os períodos. A antropização das áreas tem influência direta na qualidade das águas dos reservatórios superficiais do Alto Jaguaribe, apresentando correlação com os atributos de qualidade da água, principalmente com o pH e a degradação total das águas superficiais da Bacia do Alto Jaguaribe em decorrência do uso do solo das bacias é ser apenas uma questão de tempo.

Palavras-chave: Área antropizada. Águas superficiais. Variabilidade espaço-temporal da precipitação.

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INTRODUCTION

The semi-arid region of Brazil lies between 2.5º S and 16.1º S, and 34.8º W and 46º W, and covers an area of around 1,542,000 km^2, where more than 53 million inhabitants live (MARENGO; TORRES; ALVES, 2017). Water availability in this region is based on the construction of small, medium and large surface reservoirs (TOLEDO; ARAÚJO; ALMEIDA, 2014). However, as a result of anthropogenic action and the long periods of drought in the region, water availability is reduced, changing the physical, chemical and biological properties of the aquatic ecosystems (BRAGA *et al*., 2015). Sampling the physical, chemical and biological attributes that affect the potability of the surface water is one of the techniques for monitoring water quality. However, water quality cannot be studied unless it is together with the physical factors inherent to the reservoir itself: size, age and location. For Libânio (2008), the characteristics of the water result from processes that take place in both the body of water and its watershed. Therefore, characterising water quality in a body of water involves preparing an overview of the main environmental factors in which it is inserted.

Studies have been carried out which relate the quality attributes of internal waters, such as the use and occupation of the surrounding area and its watersheds (BERTOSI, 2014; SILVA; AZEVEDO; ALVES, 2014; SOUZA; GASTALDINI, 2014). By analysing land use and occupation in a watershed that contributes to a body of water, it is possible to construct a profile of the composition of the waters that make up the unit, thereby employing an important support tool for monitoring the quality of the surface water. During the rainy season, little native plant cover in the watersheds leads to the entrainment of large quantities of soil, organic matter and agricultural inputs to the bed of watercourses, contributing to an increase in the concentration of solids and nutrients in spring water (DONADIO; GALBIATTI; PAULA, 2005).

The aim of this study therefore, was to analyse variations in the quality attributes of the surface waters of the Upper Jaguaribe Basin due to the seasonality of the rainfall in the region and the degree of anthropisation of the watersheds that contribute to the surface reservoirs.

MATERIAL AND METHODS

Study area

The study area from where the limnological data were collected is the Upper Jaguaribe Basin (UJB) (drainage area of 24,639 m^2), located in the southwest of the State of Ceará. The reservoirs being monitored were the Orós (capacity 1,940.00 hm^3), Trussu (capacity 301,00 hm^3) and Muquém (capacity 47,64 hm^3) (Figure 1 and Table 1).

Figure 1 - Location of the Upper Jaguaribe Basin and the Orós, Trussu and Muquém reservoirs with collection points

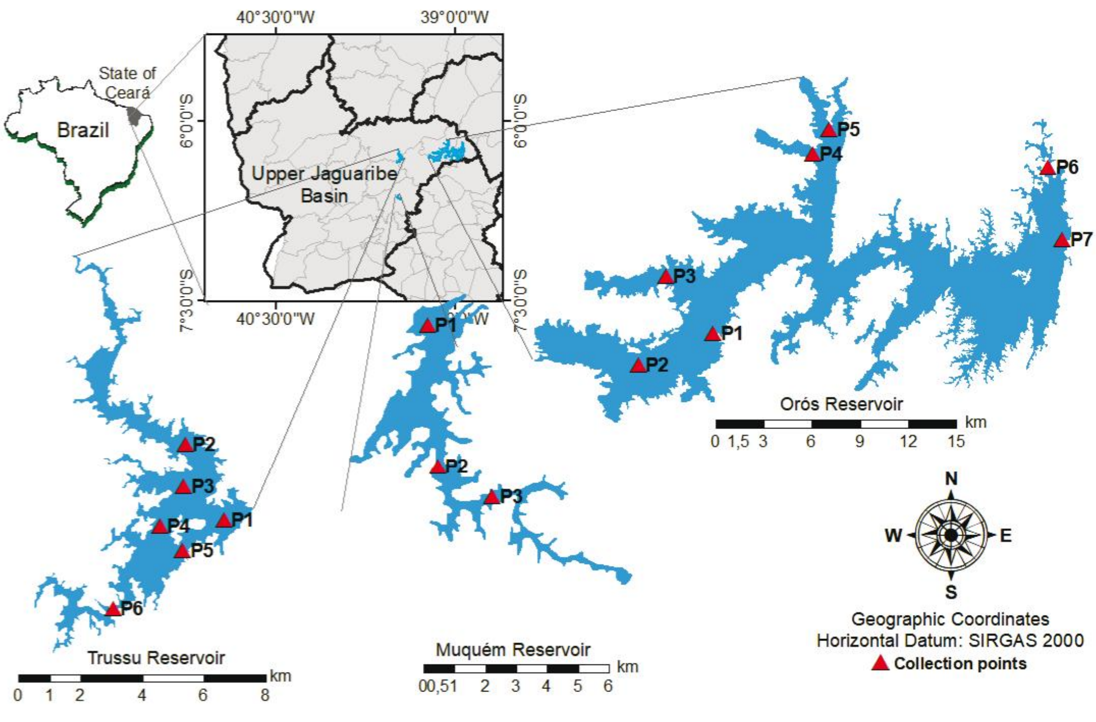


Table 1 - Technical characteristics of the Orós, Trussu and Muquém reservoirs

Reservoir	Municipality	Year of completion	Dammed river/stream	Water surface (ha)
Orós	Orós	1961	Jaguaribe River	18,772.97
Trussu	Iguatu	1996	Trussu Stream	1,625.64
Muquém	Cariús	2000	Muquém Stream	372.02

Source: FUNCEME (2009), CEARÁ (2017)

Data monitoring, collection and analysis

Seven collections were carried out in the field on the following dates: August and December of 2012, April, October and December of 2013, and March and June of 2014. As the capacity and surface size of the reservoirs were different (Table 1), the number of collection points varied for each reservoir: seven for the Orós (P1 - P7), six for the Trussu (P1 - P6) and three for the Muquém (P1 - P3).

In each reservoir the collections were distributed as follows: close to the influx of the principal tributaries, close upstream of the dam and around the areas of fish farming. In each campaign, water samples were collected for laboratory analysis of the physical, chemical and biological attributes, with readings of the pH, electrical conductivity, turbidity and Secchi transparency taken *in situ*. The samples and readings were taken at a depth of 0.30 m from the surface of the water, and the collected material was stored in previously washed opaque-plastic bottles and identified for transportation to the laboratory, where an analysis of the chlorophyll-a, pH and electrical conductivity was carried out as per APHA *et al*. (2005).

The campaigns carried out from January to May and in December were taken as representative of the rainy season, while those carried out during the remaining months were considered the dry season. The criterion used to determine which months are representative of these periods was based on an evaluation of the monthly rainfall distribution of a 30-year historical series (1984-2014) recorded at the Iguatu weather station (Figure 2); those months where the monthly rainfall was greater or equal to 50 mm were considered the rainy season, and those where the monthly rainfall was less than 50 mm were considered the dry season, as per Ferreira *et al*. (2015).

The values for pH, turbidity and chlorophyll-a were compared to the limits established in CONAMA Resolution 357/2005 for freshwater classes 1 to 3, and the limits for electrical conductivity analysed according to those adopted for irrigation water (AYES; WESTCOT, 1999), Table 2.

Figure 2 - Monthly and total annual rainfall in the district of Iguatu, Ceará, with collection dates

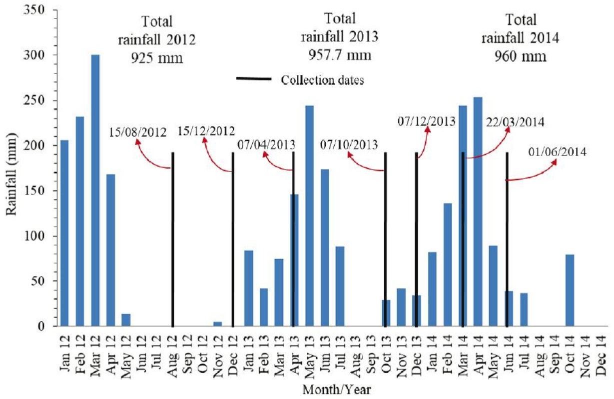


Table 2 - Proposed limits for the physical, chemical and biological attributes

Physical, chemical and biological attributes	
EC (dS m^{-1})[a]	0.7 – 3.0
pH[b]	6.0 a 9.0
Turbidity (NTU)[b]	< 100
Chlorophyll-a (ug L^{-1})[b]	10 – 60

[a] Proposed Guidelines for irrigation water, as per FAO (AYERS; WESTCOT, 1999). [b] Proposed guidelines for freshwater types I, II and III, as per CONAMA Resolution 357/2005 (BRAZIL, 2014)

Survey of the anthropisation of the watersheds

In order to classify land use and occupation, and to obtain the degree of anthropisation of the contributing watersheds at the collection points during 2013, the four Landsat 8 - OLI images referring to orbit/point 217/64, 217/65, 218/64 and 218/65 were used, dated 10/09/2013 and 19/09/2013. After atmospheric correction and combination of the image bands into RGB 543, supervised classification was carried out by the method of maximum likelihood - MAXVER, using the ENVI 4.7 software.

For anthropogenic class, areas that had undergone some type of human intervention were adopted, characterised by urban occupation (buildings, road system, etc.), as well-as deforested areas, bare soil and areas of rainfed agricultural activity. Locations in the images that were representative of this class were chosen manually, taking a considerable number of pixels as training samples.

After classification, raster files containing information on the anthropogenic class of the watersheds were transformed into vectors, which were converted into the shapefile format using the ArcMap 9.3 software, thereby obtaining the calculations for the anthropogenic areas of each watershed. The vectors of the three reservoirs were added to the result of this classification, and the maps were prepared.

Statistical analysis of the data

To analyse the behavioural characteristics of the attributes, descriptive statistics were applied to the data using box plots for the attributes collected in the three reservoirs during the rainy and dry seasons, employing the IBM® SPSS® Statistics 20 for Windows® statistical software. From the boxplot, it is possible to understand the characteristics and behaviour of the parameters under study, the central tendency (median), the variability of its values (amplitude, extremes, discrepancies) and quartiles, and interquartile ranges. The relative positions of the median, first and third quartiles give an idea of distribution asymmetry. The lengths of the tails are given by the lines that run from the rectangle to the discrepant values (ARAÚJO NETO *et al*., 2014).

After the processes of data normalisation, the statistical significance of the attributes was obtained with Student's t-test for independent samples, and the difference between reservoirs and between the dry and rainy periods was tested using Tukey's test at a level of 5%.

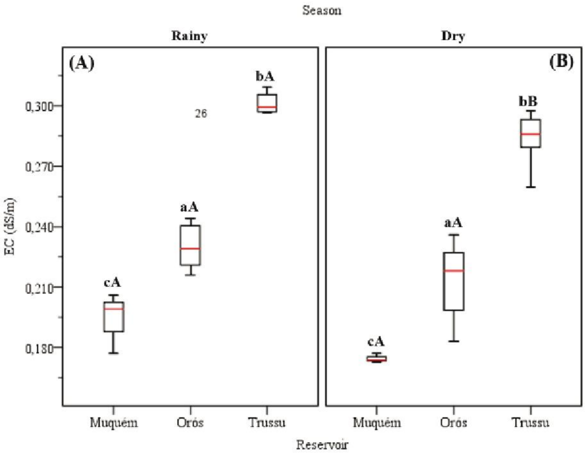
RESULTS AND DISCUSSION

The values for electrical conductivity (EC) of the waters of the Orós, Trussu and Muquém reservoirs ranged from 0.120 to 0.334 dS m^{-1}, and were therefore within the proposed limits for water to be used in irrigation (0.7 to 3.0 dS m^{-1}) (Table 2).

In general, the electrical conductivity of the water during the rainy season tends to be lower, since rainfall tends to dilute the ions. However, in this study it was found that the mean values for electrical conductivity (EC) in the three reservoirs showed a difference between the dry and rainy periods (p>0.05) only for the Orós Reservoir (Figures 3A and B).

The mean conductivity of the three reservoirs was 0.232 dS m^{-1} during the dry season and 0.252 dS m^{-1} during

Figure 3 - Boxplot of data distribution for electrical conductivity (dS m^{-1}) in the Orós, Trussu and Muquém reservoirs during the rainy (A) and dry (B) seasons



For mean values followed by the same lowercase letter in each season, the reservoirs do not differ by Tukey's test at a level of 5%. For mean values followed by the same uppercase letter between seasons, the reservoirs do not differ by Tukey's test at a level of 5%

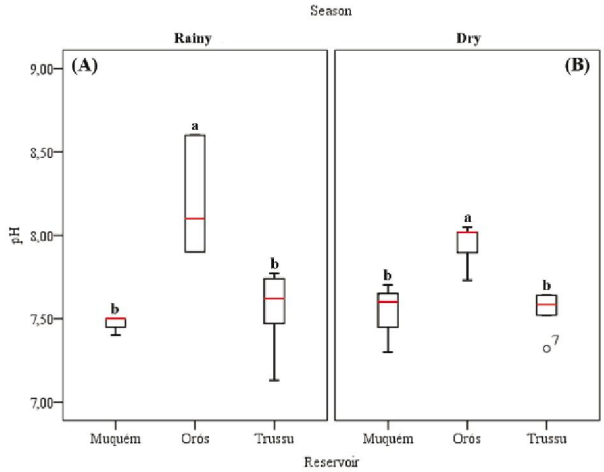
the rainy season (a total increase of 8.62% during the rainy season). The fact that the salt content did not considerably decrease as a function of the rainfall is evidence that the original source of the ions in the reservoir is associated with the soil in the region (GHEYI *et al.*, 2012; JAIN; AGARWAL; SINGH, 2007; SILVA; ARAÚJO NETO, 2016; WU *et al*., 2017). During the rainy period (Figure 3A), conductivity ranged from 0.177 dS m^{-1} (Muquém Reservoir) to 0.309 dS m^{-1} (Trussu Reservoir); however, also during this period, the greatest median value was 0.293 dS m^{-1} in the waters of the Trussu Reservoir, and the lowest (0.19 dS m^{-1}) in the Muquém Reservoir. The mean value for EC in the Orós reservoir during the rainy season was 0.229 dS m^{-1}. During this period, the difference in the mean conductivity value was highly significant (p<0.01) between the three reservoirs. Over the entire study period, values varied from 0.173 dS m^{-1} (Muquém, dry season) to 0.3090 dS m^{-1} (Trussu, rainy season). During the dry season (Figure 3B), despite the EC showing a slight fluctuation for each reservoir, between reservoirs the EC was lower - ranging from 0.173 dS m^{-1} (Muquém) to 0.297 dS m^{-1} (Trussu). The median values for conductivity during the dry season were 0.1740 dS m^{-1}, 0.218 dS m^{-1} and 0.2868 dS m^{-1} respectively for the Muquém, Orós and Trussu. The mean values were highly significant (p<0.01) between the Orós and the Trussu, and between the Trussu and the Muquém; between the Orós and the Muquem, the mean difference in conductivity during this period was slightly lower (p<0.05). This variation in conductivity between the reservoirs is attributed both to the different types of land use and cover in the contributing watersheds, and to the lithological composition of the soils where the watersheds of the reservoirs are located.

Analysing the two periods together, the greatest spatial variation in electrical conductivity occurred during both seasons in the Orós Reservoir; in short, given the length of the surface of the Orós Reservoir, together with the many uses of its watershed, it was to be expected that this attribute actually depended on the greater independent heterogeneity of the season. On the other hand, the Muquém and the Trussu presented values that were more homogeneous, with the maximum values in this study being seen in the Trussu Reservoir (Figures 3A and B). In addition to the influence of the pedological and geological characteristics of the region, electrical conductivity in reservoirs of the Brazilian semi-arid region may present high values as a result of the increase in salt concentration due to the lower volume of water, as found by Lima *et al*. (2009). In the Trussu Reservoir, the EC values may be associated with the Luvisols, which include easy-weathering primary minerals in their composition, originating from rocks of the crystalline basement (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2006). In contrast, the low values for conductivity in the Muquém Reservoir are the result of the Neosols, which are characterised by being poorly developed, shallow and with little mineral or organic material. However, when it comes to the relationship with land use and cover in the watershed, these soils are fairly susceptible to weathering if under the effects of anthropogenic action.

The pH of the three systems under study showed a variation which was below the limits established for freshwater by the National Environmental Council (Conselho Nacional do Meio Ambiente - CONAMA). This variation was between 5.30 (Muquém Reservoir) and 8.99 (Orós Reservoir), both during the dry period. Variations in pH may trigger problems in the reservoirs: at a very basic pH (>8.0), toxic ammonia, heavy metals and other salts tend to solubilise in the water, with the precipitation of carbonate salts; in contrast, more acidic pH levels (<6.0) act by increasing the concentrations of carbon dioxide and carbonic acid. In the three reservoirs, the mean values for pH remained within the normal range throughout the period under analysis, varying from 7.13 to 8.60 during the rainy season for the Trussu (Figure 4A) and Orós (Figure 4B) reservoirs respectively.

Palácio *et al*. (2009), analysing the waters of the Trussu Reservoir, also found that the variation in pH was not a response to climate conditions, and remained within the amplitude range irrespective of the time of year. Lopes *et al*. (2014), researching the spatial-temporal variability of the waters of the Orós Reservoir using clustering techniques, found that the pH varied between 7.40 and 9.40, remaining close to the limit of 9.0 established by CONAMA for freshwater.

Figure 4 - Boxplot of pH data in the Orós, Trussu and Muquém reservoirs during the rainy (A) and dry (B) seasons



For mean values followed by the same lowercase letter in each season, the reservoirs do not differ by Tukey's test at a level of 5%

Hydrogen potential is considered one of the most important environmental variables and at the same time one of the most difficult to interpret, as it can be influenced by a large number of factors. Among other factors, the pH in surface waters can be altered by the direct supply of fulvic and humic acids from the decomposition of vegetation found on the banks or in the reservoir, by transforming the organic matter through microbial action, or by the addition of pollutants and contaminants to the body of water (GONCHARUK, 2014; MOSTOFA *et al*., 2013). In most cases, variations in the range of pH in surface waters may be associated with the geological condition of the site, explained mainly by the richness of carbonates and bicarbonates in the chemical composition of the soils in which the reservoirs and their respective drainage basins are inserted (LEITÃO *et al*., 2006). Factors related to anthropogenic action, or to other types of use and occupation of the area surrounding the reservoir, were found by Carneiro, Kelderman and Irvine (2016) not to be the only factors responsible for variations in the pH values of the water. In the case of the Brazilian semi-arid region, where rainfall is less than evaporation, it is common to find pH values greater than eight. Studies carried out in surface waters in other watersheds in the State of Ceará have shown that the pH in the region tends to vary between 7 and 9 (ANDRADE *et al*., 2007). Variations in pH on the surface of the reservoir occur due to its location in a region with high evaporation, a situation in which it is also prudent to associate the various localised uses for the water that are seen along the waterbody. It is also known that pH values are directly related to aquatic life, where a range of between 4 and 11 is considered suitable for its maintenance and development; values below or above this range can cause the immediate death of aquatic animals and plants, compromising the quality of the water (SÁ, 2012).

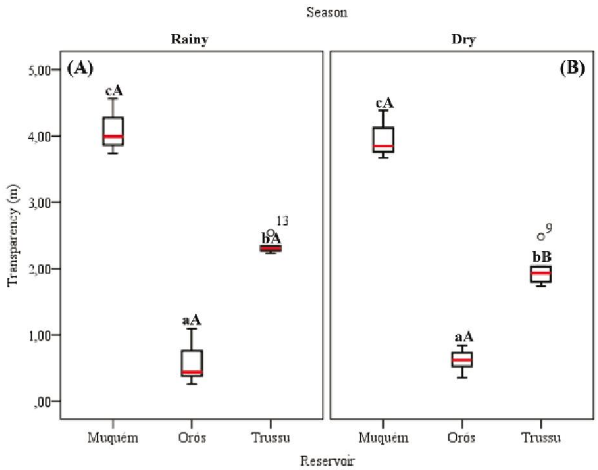
In each reservoir the variation in pH was smaller during the dry period (Figure 4B), except for the Muquém Reservoir, which also showed little variation in pH during the dry season, when the maximum value was within the limit of 75% of the values found (Figure 4B). During both the dry and rainy periods, the pH of the waters of the Orós Reservoir was higher than of that of the Trussu (p<0.01); the waters of the Muquém Reservoir displayed a mean pH that was statistically equal to the waters of the Trussu (p>0.05) and different from the mean values found in the Orós Reservoir. It can be seen that in terms of pH, the waters of the three reservoirs are in a state of balance, irrespective of the period being rainy or dry (AL-TAANI, 2013; GRIBRIL *et al*., 2011; ROTHENBERG *et al*., 2017).

The distribution of transparency values during the two study periods showed that variations in data were similar for each reservoir during both the rainy (Figure 5A) and dry (Figure 5B) periods; the highest transparency values were seen in the waters of the Muquém Reservoir, the lowest in the Orós, and intermediate values in the Trussu. Only the Trussu Reservoir showed a significant difference in transparency (p<0.05) between the dry and rainy periods, demonstrating that the rainfall had an effect on the mean values of this parameter.

The high values for transparency in the Muquém Reservoir may be associated with the preservation of the riparian forest around the reservoir, as well as the ground cover in the watershed. Also, for the three reservoirs under study, the Muquém is the newest and the surrounding native vegetation is better preserved. Transparency in the Muquém Reservoir reached 5.42 m (the highest of the system), unlike the Orós Reservoir, where it was 0.09 m during the rainy period. The low transparency of the waters of the Orós and Trussu Reservoirs confirmed in this study is related to the degree of eutrophication of the waters, since the supply of nutrients such as nitrogen and phosphorus that are entrained from agricultural areas and also added to the waters by fish farming in the reservoirs, favours the development of phytoplanktonic organisms, reducing the transparency of the water column (BRAGA *et al*., 2015; WIEGAND; PIEDRA; ARAÚJO, 2016).

Turbidity in the three bodies of water remained well below the maximum limit of 100 UNT, ranging from 0.05 to 40 UNT, especially in the Orós Reservoir, where

Figure 5 - Boxplot of the data for water transparency in the Orós, Trussu and Muquém reservoirs during the rainy (A) and dry (B) seasons



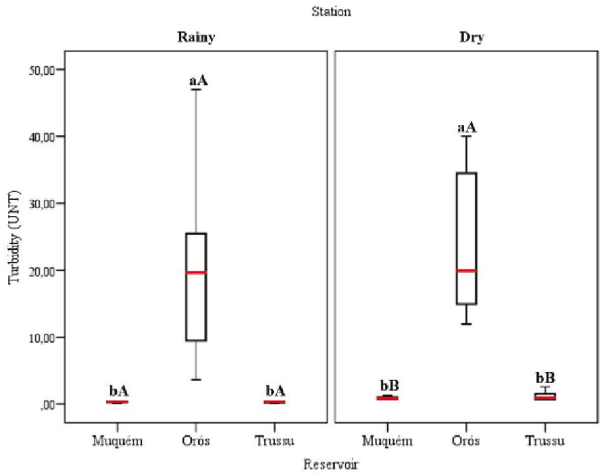
For mean values followed by the same lowercase letter in each season, the reservoirs do not differ by Tukey's test at a level of 5%. For mean values followed by the same uppercase letter between seasons, the reservoirs do not differ by Tukey's test at a level of 5%

the highest values for this attribute were found during both the rainy and dry seasons (Figures 6A and B).

While in the waters of the Orós Reservoir this attribute ranged from 3.67 UNT to 47 UNT (rainy period), it did not exceed 2.57 UNT in the Trussu and Muquém reservoirs; so much so, that for each period the mean turbidity in the Orós Reservoir showed a highly significant difference (p<0.01) when compared to the mean turbidity found in both the Trussu and Muquém reservoirs. During both periods, the waters in these reservoirs showed no difference between turbidity, as this parameter varies depending on the presence of substances in suspension, i.e. finely divided suspended solids or solids in a colloidal state. This is because such particles originate mainly from the entrainment of materials from areas with no plant cover, whereas in both the Muquém and Trussu reservoirs the margins still show considerable cover, with few farms or areas of exposed soil. However, in the Orós Reservoir, the opposite can be seen, i.e. degradation of the riparian forest is predominant throughout the reservoir, with the ground completely bare of vegetation. The range of turbidity values in the Orós Reservoir is attributed to the spacing of the sampling points, which include very shallow sites, such as the influx of the rivers to the reservoir, to deeper sites, such as the area close upstream of the dam.

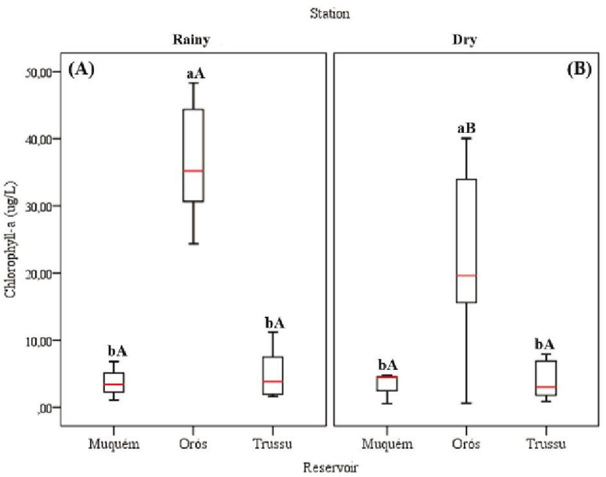
The total rainfall during the period had a significant effect on the levels of turbidity of the waters of the Muquém and Trussu reservoirs only (Figures 7A and B). Lima and Garcia (2008) found higher values for turbidity during the rainy season compared to the dry

Figure 6 - Boxplot of the data for water turbidity in the Orós, Trussu and Muquém reservoirs during the rainy (A) and dry (B) seasons



For mean values followed by the same lowercase letter in each season, the reservoirs do not differ by Tukey's test at a level of 5%. For mean values followed by the same uppercase letter between seasons, the reservoirs do not differ by Tukey's test at a level of 5%

Figure 7 - Boxplot of the data for chlorophyll-a in the waters of the Orós, Trussu and Muquém reservoirs during the rainy (A) and dry (B) seasons



For mean values followed by the same lowercase letter in each season, the reservoirs do not differ by Tukey's test at a level of 5%. For mean values followed by the same uppercase letter between seasons, the reservoirs do not differ by Tukey's test at a level of 5%

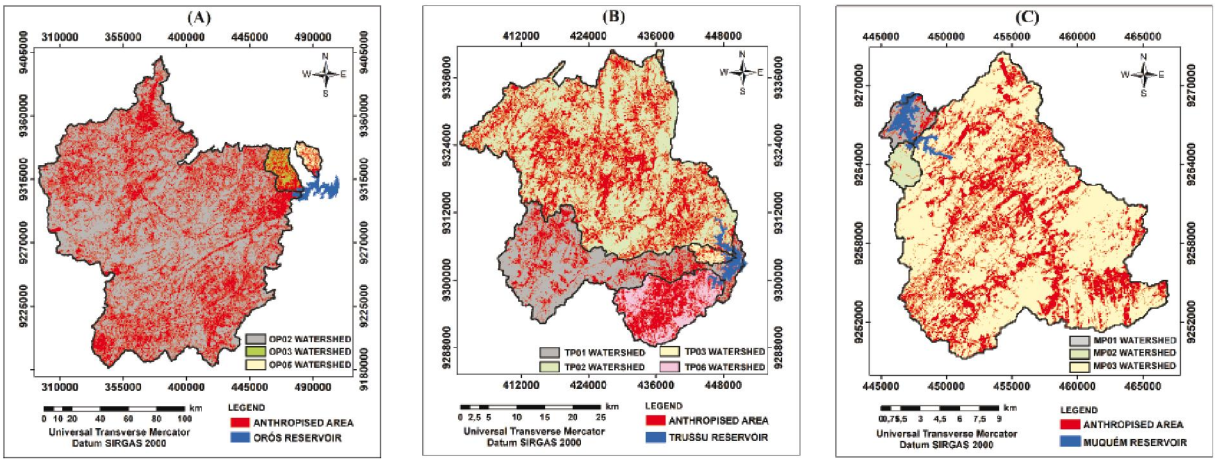
season in reservoirs located in the State of Sergipe. Lopes *et al*. (2014), again studying spatial variation in turbidity in the waters of the Orós Reservoir, reported that the highest values were found at sampling points located in the upper part of the reservoir and during the rainy season in the region. As for maximum values and range, turbidity proved to be an important attribute for differentiating between the optical characteristics of the three reservoirs analysed in this study. The high values for turbidity in the Orós Reservoir in relation to the other two reservoirs, are associated with erosion of the reservoir banks and to the presence of sewage and industrial effluent, factors that increase the turbidity of the water (LIMA; GARCIA, 2008). Chlorophyll-a is present in the three reservoirs during both periods, with a difference in mean value between the rainy and dry periods seen only in the Orós (Figures 7A and B), showing that rainfall contributes to the higher values for chlorophyll-a in that reservoir.

The greatest variation in the value of chlorophyll-a was found in the Orós Reservoir, but only during the dry period. This large variation occurs due to the range of values seen between sampling points: during the dry period it is common to find points with a high concentration of phytoplankton at places where the water level of the reservoir is lower, as in the case of the influx of the River Jaguaribe to the reservoir. During the rainy season, chlorophyll-a ranged from 24.26 to 48.32 mg L^{-1} (Figure 7A), and from 0.61 to 40.03 mg L^{-1} during the dry season (Figure 7B). Lopes *et al*. (2014) found the levels of chlorophyll-a in the same reservoir varying between 2.00 and 60.24 mg L^{-1}.

In both the dry and rainy periods, the Orós Reservoir showed a significant difference ($p<0.01$) in chlorophyll-a levels compared to the Trussu and Muquém reservoirs (Figures 7A and 7B). The graphs show the high variation in this attribute in the Orós Reservoir during both periods, demonstrating that in addition to the values of chlorophyll-a being high, the variation in the reservoir is also considerable. A variation in chlorophyll-a in the Orós reservoir was also reported by Batista *et al*. (2013), and was related to the phosphorus content of the reservoir and the variation in transparency over the surface. Chlorophyll-a was highest in the Orós Reservoir and during the rainy period. The chlorophyll-a content of one sample in the reservoir was above the limit established by CONAMA for freshwater (10-60 ug L^{-1}). High values for chlorophyll-a in reservoirs in Ceará are common due to fluctuations in the water level of these reservoirs (periods of drought and flooding) and to the enrichment of the water as a result of the nutrient load received by the reservoirs. This situation is a reminder that chlorophyll is one of the main pigments responsible for photosynthesis, and is related to the biomass of phytoplankton, its productivity, and its physiological state.

From the data for land use and occupation in the Alto Jaguaribe Basin, representative maps were prepared showing the distribution of anthropisation in the ten sub-basins of the streams contributing to the collection points in the Orós, Trussu and Muquém reservoirs (Figure 8).

Figure 8 - Map of anthropisation of the watersheds contributing to the collection points in the Orós (A), Trussu (B) and Muquém (C) reservoirs, for 2013



The generated maps clearly show the state of degradation of the Upper Jaguaribe Basin, and agree with Frota and Nappo (2012) and Sousa, Melo and Silva (2013). As for the characteristics of the watersheds of each reservoir, there is a predominance of Luvisols in the Trussu, of Neosols in the Muquém, and of both types of soils in the Orós.

Analysing the percentage of anthropisation in the watersheds which contribute to the collection points in the three reservoirs, Table 3 highlights the Orós Reservoir, with the OP03 watershed showing the highest percentage of anthropisation - 57.64%, and where the total area is 51,749.35 ha. In OP02 and OP05, anthropisation varied from 36.16 to 37.86% respectively. The watershed of the Jaguaribe River contributes to OP02, and that of the Giqui Stream contributes to OP05, where agricultural and livestock activities can be found, among others. In contrast, the smallest percentages of anthropisation are seen in the Muquém Reservoir, with a variation of 6.77 (MP02) and 28.96% (MP03). The Trussu Reservoir, for which four contributing watersheds were analysed in this study, showed anthropisation which ranged from 27.50 (TP03) to 48.44% (TP06). Araújo Neto *et al*. (2017) found changes in groundwater quality in the Trussu watershed due to changes in land use and cover.

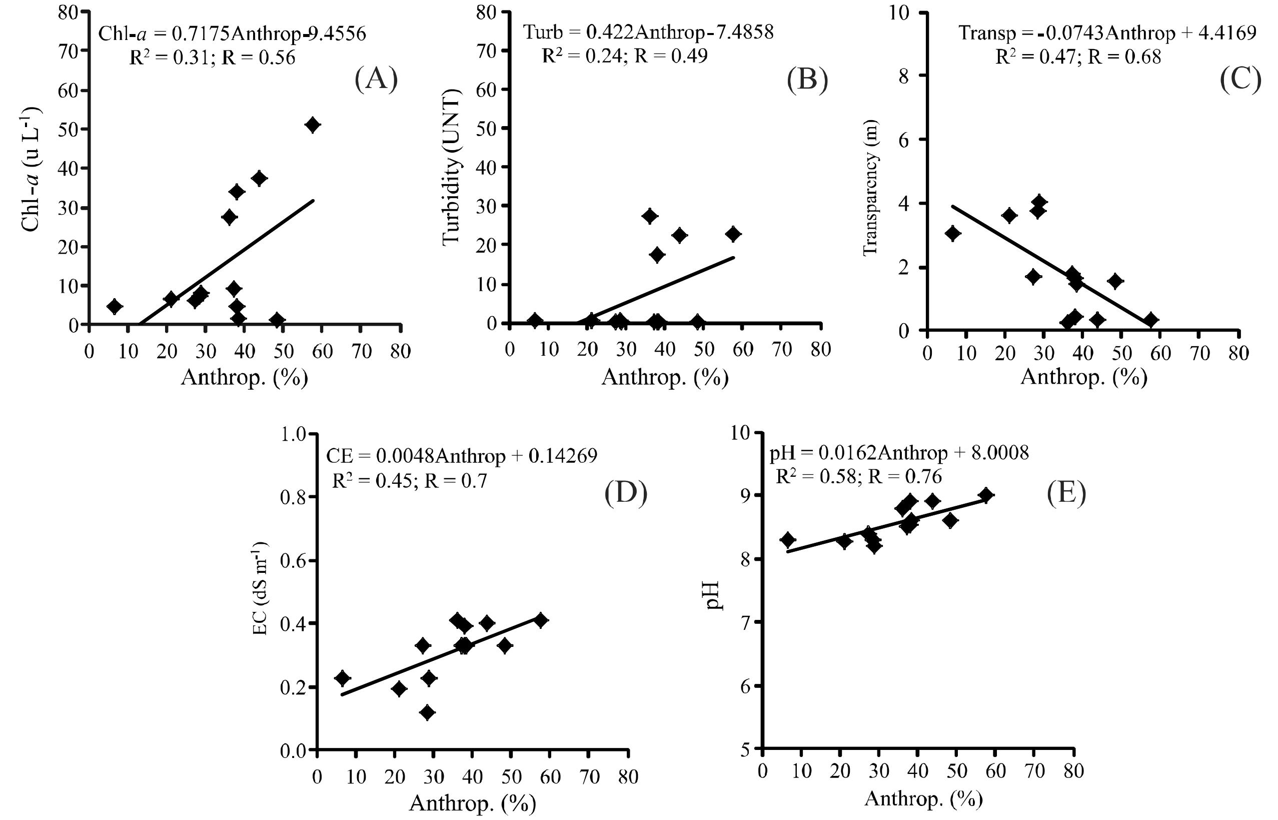
The correlation between the percentage of anthropisation of the watersheds and the attributes of water quality in the three reservoirs was evaluated for November 2013, being representative of the dry season, as shown in Figure 9.

Table 3 - Degree of anthropisation (%) of the watersheds contributing to the collection points, and values of the parameters analysed in the three reservoirs, for November 2013

Sub-basin	Anthropisation (%)	Chl-a (ug L^{-1})	Turbidity (UNT)	Transparency (m)	EC (dS m^{-1})	pH
OP02	36.16	27.5	27.5	0.23	0.41	8.80
OP03	57.64	51.2	23	0.33	0.41	9.00
OP05	37.86	33.9	17.4	0.42	0.39	8.90
TP01	37.24	9.31	0.1	1.81	0.33	8.50
TP02	38.36	1.59	0.1	1.46	0.33	8.60
TP03	27.50	6.23	0.1	1.70	0.33	8.40
TP06	48.44	1.31	0.1	1.55	0.33	8.60
MP01	28.33	7.46	0.65	3.78	0.12	8.30
MP02	6.77	4.62	0.5	3.05	0.23	8.30
MP03	28.96	8.15	0.15	4.04	0.23	8.20

OP: Collection points in the Orós Reservoir; TP: Collection points in the Trussu Reservoir and, MP: Collection points in the Muquém Reservoir; Chl-a: Chlorophyll-a

Figure 9 - Linear correlation between the percentage of anthropisation in the watersheds contributing to the collection points and chlorophyll-a (A), turbidity (B), transparency (C), electrical conductivity (D) and pH (E) in the waters of the Orós, Trussu and Múquem reservoirs



Transparency showed a negative linear correlation with the percentage of anthropisation (Figure 9C). This tendency was expected, because as the degree of degradation of the vegetation in an area increases, the greater the entrainment of particles and materials that are deposited in the body of water, reducing its transparency. According to Table 3, the lowest value for water transparency was seen in the Orós Reservoir, together with the highest percentage of anthropisation (57.64% in the sub-basin of OP03), with a correlation of 0.49.

For chlorophyll-a, the regression model presented a correlation coefficient (R) of 0.56. As the percentage of anthropisation of the watersheds increased, the levels of chlorophyll-a in the water also increased (Figure 9A). An increase in chlorophyll-a in the waterbody may be associated with the degradation process of the watershed, with nutrients supplied by tributaries or released directly into the basin.

Turbidity showed low dependence on the anthropisation of the watersheds (Figure 9B). Even so, this parameter showed a direct positive tendency with the anthropenic data, demonstrating that even when the turbidity of the water is low, it tends to be directly influenced by the percentage of degradation of the contributing watershed. Souza and Gastaldini (2014) found a strong relationship between water turbidity and the agricultural areas of rural watersheds in the State of Rio Grande do Sul. Electrical conductivity (Figure 9D) and pH (Figure 9E) also showed a positive relationship with the degree of anthropisation of the areas, with a correlation of 0.67 and 0.76 respectively. The EC of the water does not specifically determine which ions are present, but contributes to a possible recognition of environmental impacts that occur in the drainage basin, caused by the release of industrial waste, mining, sewage, etc. As for pH, this parameter is indicative of the potential chemical reactivity of rocks and soils, and is strongly influenced by the geological characteristics of the watershed where a reservoir is located. Furthermore, hydrogen potential may be modified by the release of effluents into bodies of water through the microbial transformation of organic matter. Water quality in the Orós, Trussu and Muquém reservoirs correlated with the degree of degradation of their contributing watersheds, agreeing with Silva, Azevedo and Alves (2014), who studied the water quality of the Upper

Paraíba River in areas with different types of land use, and found that the water quality of a forest source was better than that of sources used for agricultural purposes.

CONCLUSIONS

1. The quality attributes of the surface waters of the Upper Jaguaribe Basin are directly influenced by the degradation of the watersheds of the reservoirs and by the temporal variability of the rainfall in the region; for large bodies of water in the region, as is the case of the Orós Reservoir, the rainy period afforded no improvement in water quality;
2. Irrespective of the period being dry or rainy, the waters of the Orós Reservoir still have high levels of chlorophyll-a and turbidity, demonstrating that for this reservoir, the sources that contribute to an increase in this attribute continue to act independently of climate conditions, which is worrying for the state of this waterbody;
3. In the three reservoirs under analysis, pH showed the strongest correlation with the percentage of anthropisation of the watersheds of the reservoirs; it was evident that the degradability of the surface waters of the Upper Jaguaribe Basin, which results from the type of land use, is also dependent on the temporal condition, considering that this study included three reservoirs of different ages, but with marked anthropisation of their watersheds.

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