Evaluation of Spectral Similarity of Water in Urban and Rural Reservoirs Using Cluster Analysis

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Evaluation of Spectral Similarity of Water in Urban and Rural Reservoirs Using Cluster Analysis

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Abstract. The objective of the study was to compare the spectra of two reservoirs: a urban reservoir (Santo Anastácio) and a rural reservoir (Orós) and to measure their similarity by means of cluster analyses. Sixteen radiometric measures were carried out in each reservoir, using the FieldSpec®3 Hi-Res spectroradiometer. Water samples were taken at 30cm depth, concurrently with spectral measurements, for analytical determination of chlorophyll-a (Chl-a) and total suspended solids (TSS). Electrical conductivity (EC), pH, and Secchi depth transparency (SD), were also measured. Cluster analysis, based in the agglomerative hierarchical method of the spectra resulted in three groups. Group 1 was characterized by high concentrations of Chl-a, ranging from 61.97 to 171.91 µg/L. Group 2 by Chl-a, ranging from 14.79 to 57.19 µg/L and Group 3 where the opticall active component controlling the water reflectance was the SST with concentration varying between 15.25 to 99.00 mg/L. All spectra from Santo Anastácio (Urban) reservoir were classified in the group1, whereas the spectra from Oros were included in Groups 2 and 3. The results show that the cluster-analysis technique of

the water spectra can be used to discriminate water masses of urban reservoirs from those of rural reservoirs provided that their optically active components are different.

Keywords. Hyperspectral Remote Sensing, Multivariate Statistics, Water Quality.

Introduction

The arid and semi-arid environments around the world are very susceptible to degradation caused by human action, mainly due to its extreme hydrological variability. This fact that decreases water availability increasing the need of surface reservoirs. Those reservoirs, however, are exposed to various degrees of pollution depending on their geographical location. Urban watersheds, in general, have a large amount of pollution sources. Part of the pollution generated in urban regions comes from runoff over impervious areas, garbage dumps or industrial waste (ARAÚJO, 2003, BECKER et al., 2009). In rural watersheds, the pollution sources are related to land use and land cover, mainly related to agricultural activities in ecologically fragile areas and animal waste. Some of the water components which affect their quality can be monitored by remote-sensing instruments (RUNDQUIST et al., 1996; LODHI et al. 1997, BARBOSA, 2005). The presence of optically-active substances in the water results in different patterns of absorption and backscattering of the electromagnetic radiation, what alters the water colour rendering different spectral signatures which can be related to different water types. In this study, the spectral behavior of two reservoirs (urban and rural) are submitted to cluster analyses in order to assess their similarity and how the spectral features respond for differences in water quality.

Material and methods

This study included two reservoirs: one urban and one rural. The urban reservoir is Santo Anastácio, located on the Pici Campus of the Federal University of Ceará, in Fortaleza, the capital of the state of Ceará in Brazil, at the coordinates, 03°04'S and 38°35'W. The climate in this region is Aw' with an average annual rainfall of 1,523 mm and annual potential evapotranspiration of 1747 mm. The reservoir belongs to the Ceará River basin, which has a drainage area of 14.3 km^2. The reservoir accumulates 192,000 m^3 of water in a watershed hydraulic of approximately 12.8 ha. This reservoir is surrounded by the neighborhood of Alagadiço, Amadeu Furtado, Pici, Cachoeirinha and Bela Vista. Almost half of the reservoir flooded area (42 %) is owned by UFC (Figure 1).

The rural reservoir is Orós, which dams the Jaguaribe River (Figure 1). It is located between the coordinates, 6°8'31''S to 6°20'26''S and 38°54'56''W to 39°13'28''W, 450 km away from the capital, Fortaleza. The reservoir is located in the south-central part of the state, with a climate classified as type BSw'h', with an average annual rainfall of 800 mm and average annual evapotranspiration of 1,900 mm (MALVEIRA, 2009).

It has a storage capacity at a bleed rate of 1.9 billion m^3 of water and a surface area of approximately 190 km^2, being the second largest surface reservoir in the state. Politically, the watershed of the Orós reservoir (35,000 ha) is part of three municipalities in Ceará: Iguatu, Quixelô and Orós (DNOCS, 2011). The resevoir watershed is occupied mainly by agriculture characterizes by intense use of fertilizers and cattle raising in its banks.. The reservoir alos receives the untreated sewage of many nearby urban areas and and is subjected to many fish-farming projects (ARRAES, 2010).

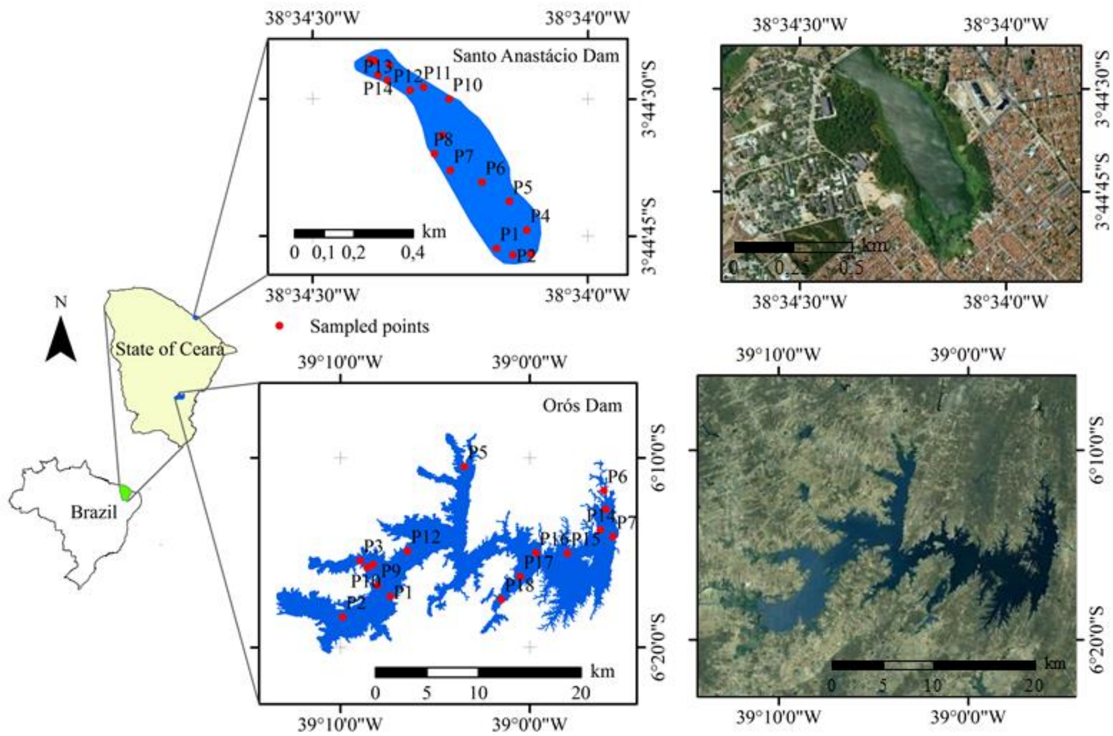

Figure 1. Collection points and location of reservoirs in the state of Ceara, Brazil

In each reservoir, sixteen water reflectance spectra were acquired between 10:00 to 14:00 on the 28th October 2010 and 11th March 2011, for the Santo Anastácio and Orós, reservoirs respectively. The samplin sites were randomly distributed along the reservoir so as to represent the water properties of the entire water body (Figure 1).

The measurements were carried out wiht an ASD FieldSpec ® 3 Hi-Res spectroradiometer, with a field of view (FOV) of 25°, spectral resolution of 1 nm and covering the spectral range of from 350 to 2500 nm. A reference plate of Spectralon, representing a Lambertian surface, was also used. At the same time, samples of surface water in the reservoirs were taken at a depth of 30 cm for laboratory determination of chlorophyll-a (Chl-a) and total suspended solids (TSS) concentration. The parameters pH, electrical conductivity (EC) and Secchi transparency (SD) were determined in situ.

The reservoir spectra were then grouped together based on their degree of similarity by means of cluster analysis using the agglomerative hierarchical method available in the Statistical Package for Social Sciences - SPSS v.16.0 software. The Euclidean distance (the sum of squares of the differences)) was addopted as similarity measurement. The clustering algorithm used was the Ward method (HAIR J.R. et al., 2005). For the definition of an optimal number of clusters, we used "a clustering coefficient" based on the principle that sudden increases in the value of a clustering coefficient would represent the fusion of different elements. The number of clusters depends on the greater or lesser degree of homogeneity it is wished to impose on the formed group (ANDRADE et al., 2002). In a dendrogram, these increases are represented by the greatest values of the rescaled distance for aggregate combination (DILLON & GOLDSTEIN, 1984).From the groups formed, the mean data of the parameters used for characterizing the waters were analyzed by mean testing and compared by t-test ($p<0.01$).

Results and discussion

The spectral behavior of of the water in both reservoirs can be observed in Figure 2. The analyses of the spectra in Santo Anastácio reservoir (Figure 2a) displayed features related to chlorophyll-rich waters. Low reflectance of 400-500 nm, due to the absorption of the pigments at 430 nm and the high absorption in this region by water; maximum reflectance in the green region, around 550 nm, and minimum reflectance in the red region, around 668 nm, due to absorption of the Chl-a (RUNDQUIST,et al. 1996; GITELSON, 1992). Furthermore, it is possible to observe peaking in the infrared region, with a magnitude greater than that of the peak in the green region in most samples. This behavior was also observed by Londe et al. (2011).and can be related to highly eutrophic water samples, where the spectrum in the infrared region is more influenced by the scattering of phytoplankton cells than by energy absorption by water in the same region. According to Araújo (2003) and Becker (2009), the main impacts suffered by this body of water are eutrophication and garbage intake.

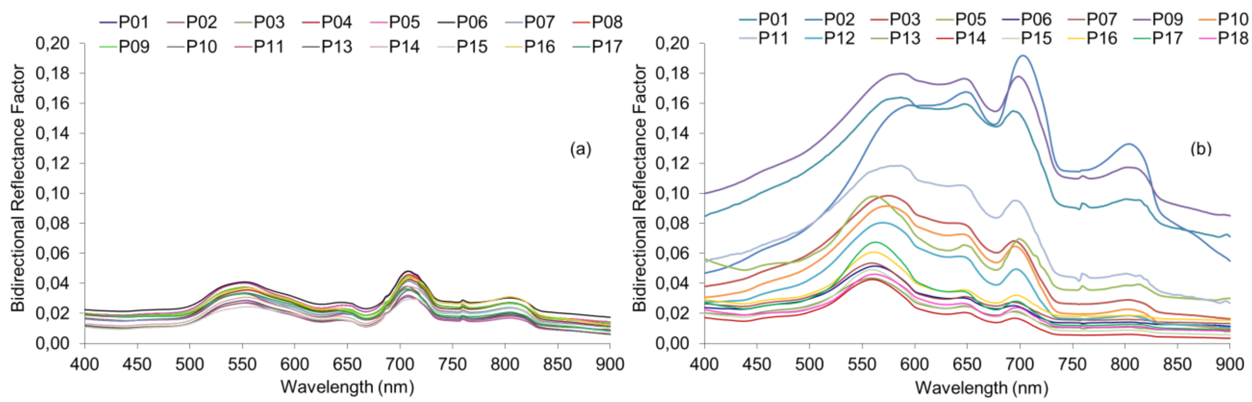

Figure 2. Spectral behavior of the waters of the urban reservoir, Santo Anastácio (a), and the rural reservoir, Orós (b)

According to Figure 2b, the Orós reservoir presented two spectrally distinct water masses. In the lower part of the reservoir, the spectra showed features indicating the presence of Chl-a (GITELSON, 1992), at concentrations well below those observed the urban reservoir. The reflectance the upper part of the Orós reservoir presented in terms of amplitude, a larege reflectance related to higher concentrations of TSS (GOODIN et al., 1993; LODHI et al., 1997).

The number of clusters resulting from the cluster analyses was based on the percentage change between the agglomeration coefficient of consecutive clusters and on the degree of homogeneity of the group. Thus, the first larger variation on the agglomeration coefficients was 31%, when reducing the number of clusters from 4 to 3. In the dendrogram (Figure 3), which matches the rescaled coefficients of agglomeration, the lowest coefficient corresponds to 0 and the highest to 25, and the optimum cut-off point is given by the distance value of just above 6.09.

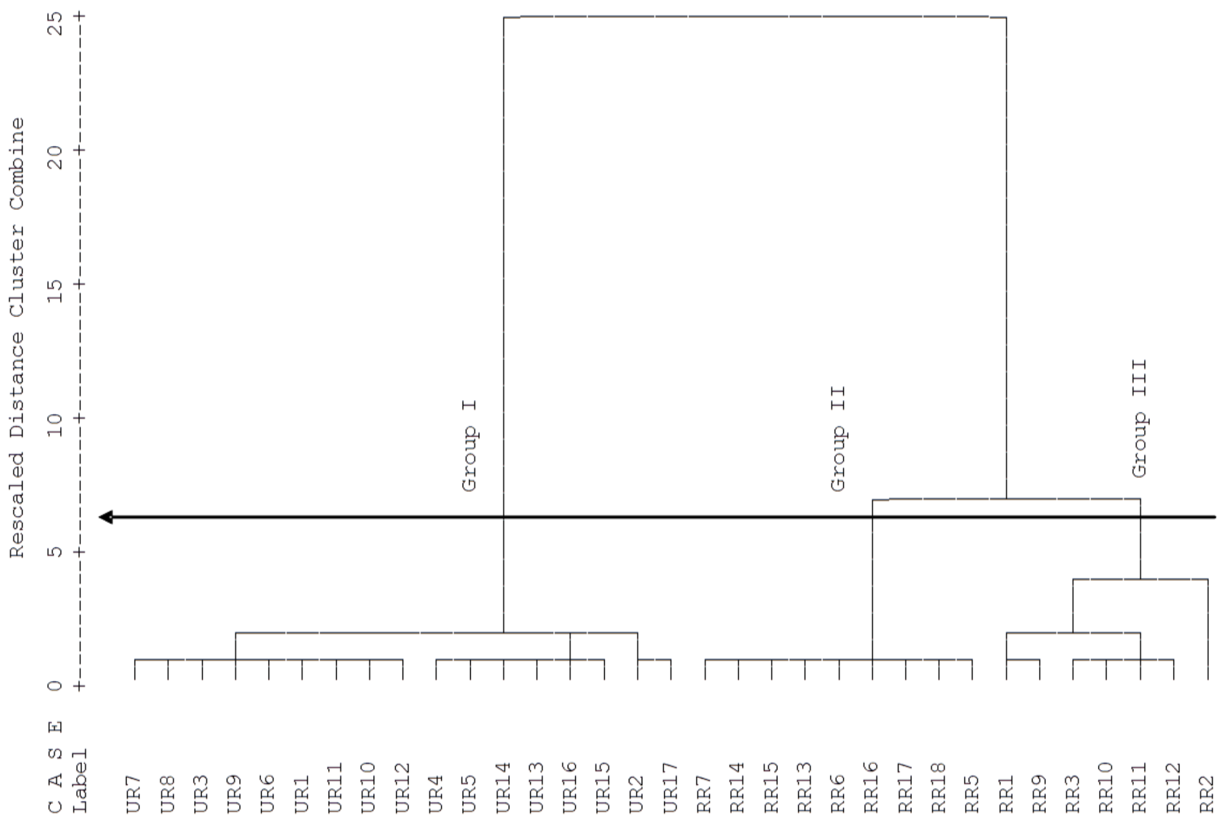

Figure 3. Dendrogram of the clustered spectra of the rural (RR) and urban (UR) reservoirs

The average composition of the attributes used as indicators of the water quality of each spectral group formed, can be seen in Table 1. It can be noted that there were no significant differences by t-test ($p<0.01$) for pH between groups, and a significant difference for EC and SD. For the concentration of TSS, Groups 1 and 3 differed from Group 2, and for the concentration of the Chl-a, Group 1 differed from Groups 2 and 3.

Group 1 was formed only by water from the urban reservoir (Santo Anastácio), and Groups 2 and 3 composed of water coming from the rural reservoir (Orós), Figure 3. The determining attribute for the formation of Group 1 were was the high concentrations of Chl-a, ranging from 61.97 to 171.91 µg/L. The shape and amplitude of the spectra of this group were molded by the high concentrations of Chl-a, this being the main optically-active component. According to Araujo (2003), more than half of the area of the watershed of the urban reservoir (Santo Anastácio) is occupied by housing with approximately 100 people per hectare, much of which is without any form of infrastructure. It receives large quantities of sewage and garbage, both rich in nutrients.

The determining attribute in Group 2 was also Chl-a, with concentrations ranging from 14.79 to 57.19 µg/L. This is a group made up of points located at the lower part of basin hydraulic of the rural reservoir, where the shape and amplitude of the spectra of this group were molded by Chl-a, the main optically-active component, however at concentrations below those observed in Group 1.

Table 1. Mean values of the variables under study for similar groups of water, defined by the technique of cluster analysis

Variable	Group	N	Mean	
CE (mS/cm)	1	16	0.845875	a[1]
	2	9	0.307444	b
	3	7	0.260429	c
pH	1	16	8.515625	a
	2	9	8.701111	a
	3	7	8.62	a
TSS (mg/L)	1	16	37.13375	a
	2	9	7.555556	b
	3	7	30.57143	a
SD (m)	1	16	0.27125	c
	2	9	0.968889	a
	3	7	0.427143	b
Chl-a (mg/m^3)	1	16	121.0706	a
	2	9	27.49507	b
	3	7	29.40814	b

[1]: means not followed by the same letter, between groups within each variable, differ by t-test, $p<0.01$

The main component in Group 3 was the TSS, with concentration rangin from 15.25 to 99.00 mg/L, due to entrainment of sediments by river water. This is a group made up of those points located in the upper part of the rural reservoir (confluence of the Jaguaribe and Faé rivers), where the shape and amplitude of the spectra of this group were molded by the TSS (BARBOSA, 2005), this being the main optically-active component of these waters.

Conclusion

The technique of cluster analysis allowed the distinction between urban and rural reservoirs, according to the predominance of their optically-active constituents. The observed results reflect the spectral behavior of water with characteristics of nutrient input, which in the urban reservoir studied is derived mainly from domestic sewage. The rural reservoir reflected characteristics of runoff water originating in degraded areas, as well as waters enriched by nutrients present in the surrounding areas of crop-growing and pasture.

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