Spectral Monitoring of Algal Blooms in an Eutrophic Lake Using Sentinel-2

Conference Paper · July 2019

DOI: 10.1109/IGARSS.2019.8898098

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SPECTRAL MONITORING OF ALGAL BLOOMS IN AN EUTROPHIC LAKE USING SENTINEL-2

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ABSTRACT

Eutrophication is a process in which elevated organic matter and nutrients raises the primary production of a water body. As a result, the productivity of phytoplankton and biomass are very high at all trophic levels. During bloom event, the spatial and temporal distribution of this phenomena is difficult to be observed using conventional water sampling methods. This work advance the state of the art by using Sentinel-2 (S2) images to estimate chlorophyll-a (chl-a) concentration with an empirical model. Specifically, the model uses band 8 (NIR) and band 4 (red) to predict chl-a concentration during an algal bloom event in San Roque lake, Córdoba, Argentina. Nevertheless, novel spectral ratio for algae composition patterns has also been created using bands 8a and 9. The results show that S2 has the potential to monitor bloom events in eutrophic lakes.

***Index Terms*—** Eutrophication, phytoplankton, Sentinel-2, Chlorophyll-a, empirical model, spectrometry.

1. INTRODUCTION

Eutrophication is the process in which the primary production of a water body increases with the contribution of organic matter and nutrients. Eutrophic waters have high scores of productivity and biomass at all trophic levels. Thus, eutrophication processes produce quantitative and qualitative changes in the phytoplankton community and may lead to algae blooms [1]. Although there is no a unique formally defined threshold level, a population of algae must have a concentration of hundreds to thousands of cells per milliliter to be considered as a bloom [2].

This research is conducted in collaboration with the EC-H2020 EOXPOSURE project (http://www.h2020-eoxposure.eu/) and PIODO-2018 from MINCYT.

In order to assess the quality of water bodies, quantitative indicators are required to describe the frequency and intensity of blooms. Chlorophyll-a concentration (chl-a) is widely used as an indicator of biomass and to characterize the trophic state of water body [3]. In the case of San Roque Reservoir, Córdoba, Argentina these frequent eutrophic conditions lead to periodically and massive development of algae. As this water body is the most important source of water supply in the Province, the detection of blooms events is extremely important. Algal blooms are monitor in the lake solely by *in situ* measurements. However, during blooms events when the spatial distribution of phytoplankton biomass is high, conventional water sampling is not enough to characterize the distribution of the algae [4].

In this framework, remote sensing becomes an essential and effective tool to monitor algae bloom. In the passed decades, Landsat and MODIS program had been successfully used to monitor chlorophyll-a in San Roque reservoir [5, 6, 7]. Sentinel 2 provides very high spatial, temporal and spectral resolutions in comparison to precedent programs. Therefore, the expectation is that the prediction of algae bloom will be improved accordingly [8, 9]. The main objective of a water management program in San Roque is to integrate S2 imaging with *in situ* data to identify bloom events and to characterize the trophic level of the reservoir. In this work, we analyze and validated the method using multitemporal S2 and *in situ* data collected during different bloom events.

2. MATERIALS AND METHODS

2.1. Field data

Field data used in this work was collected and generated in the context of a monitoring program is carried out by the Ministry of Water, Environment and Public Services of the province of Córdoba [10, 4]. San Roque reservoir is located in Villa

Carlos Paz city in Cordoba province, Argentina at 31° 22′ 56″ S, 64° 27′ 56″ W and at 643 meters above sea level. The location of the sampling stations are shown in figure 1.

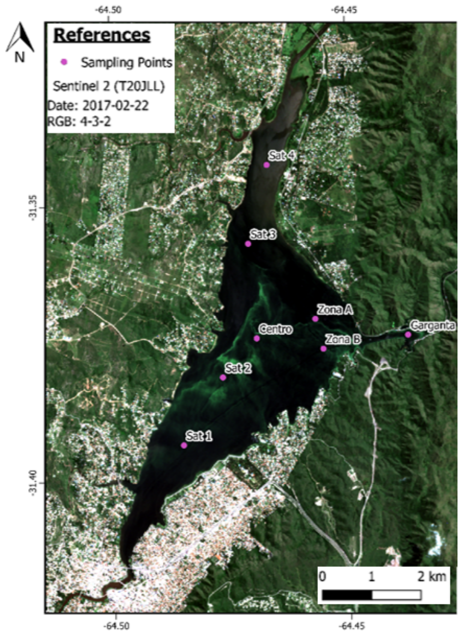


Fig. 1. Satellite imagery from Sentinel 2A MSI, 22/02/2017, T20JLL and sampling points in pink.

For this work, imaging and *in situ* data collected on the 22/02/2017 and 14/11/2018 were used to develop and validate the chlorophyll-a model, respectively. The concentrations of chl-a measured in the lake on the two acquisition dates are presented in Table 1. On the 22/02/2017, leaving reflectance spectra and phytoplankton composition were acquired in "Centro" and "Zona B" stations according to standard methods [11].

Table 1. Field data from San Roque Dam.

Site	LAT(S)	LON (W)	Chl-a 2/22	Chl-a 11/14
Centro	31 22 31.2	64 28 9.5	127.1	221.32
Zona A	31 22 20.4	64 27 17.8	53.8	117.48
Zona B	31 22 39.1	64 27 18.1	288.5	52.31
Garganta	31 22 26.4	64 26 30.9	197.1	69.38
SAT 1	31 23 39.3	64 29 3.6	27.6	84
SAT 2	31 22 55.1	64 28 33.2	132.2	73.42
SAT 3	31 21 54.8	64 27 46.8	94.7	341.98
SAT 4	31 21 38.8	64 28 18.5	56.7	703.12

2.2. Satellite data

The package Sen2cor, was used for atmospherically correct Sentinel 2A data. The satellite spectra were obtained in the location of each sampling point, using an average window of 3x3 pixels.

2.3. Regression Model: Chlorophyll-a estimation

Chl-a retrieval were obtained using an empirical model and a linear regression between the imaging and *in situ* collected during dedicated measurement campaigns. Different combinations of S2 bands were used to perform bi-variate analysis (i.e logarithms, indexes, and ratios) and pearson correlation for obtaining Chl-a concentration. Following the results, a ratio model is created and validated using data from a different date.

3. RESULTS AND DISCUSSION

3.1. Chlorophyll-a model

The result of the empirical model found high correlation between Band 8 (NIR) and Band 4 (Red). Similar observations found in previous studies that used mathematical functions and included red and infrared bands to estimate chl-a concentration in inland eutrophic waters ([12],[13],[14],[15]). It is important to mention that this spectral region is not affected by other vegetable pigments [13]. In addition, according to [13, 14, 15], for eutrophic waters these wavelengths (red and infrared) are preferable for estimating moderate to high chl-a concentrations ($>$ 10 mg/m3). In our study, following the result of the empirical model, a linear ratio index was developed with a fit of 0.62 and significant p-value of 0.0199 (figure 2) to classify chl-a concentration in the S2 images of the lake (figure 3).

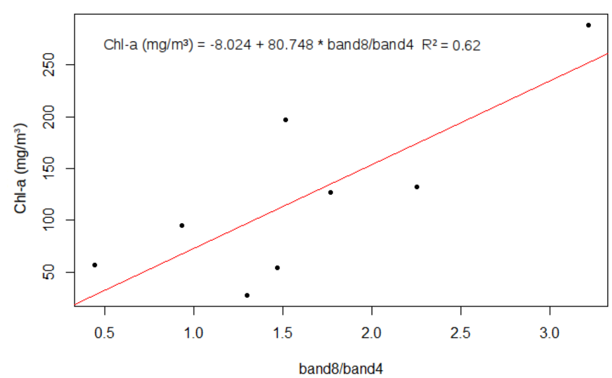
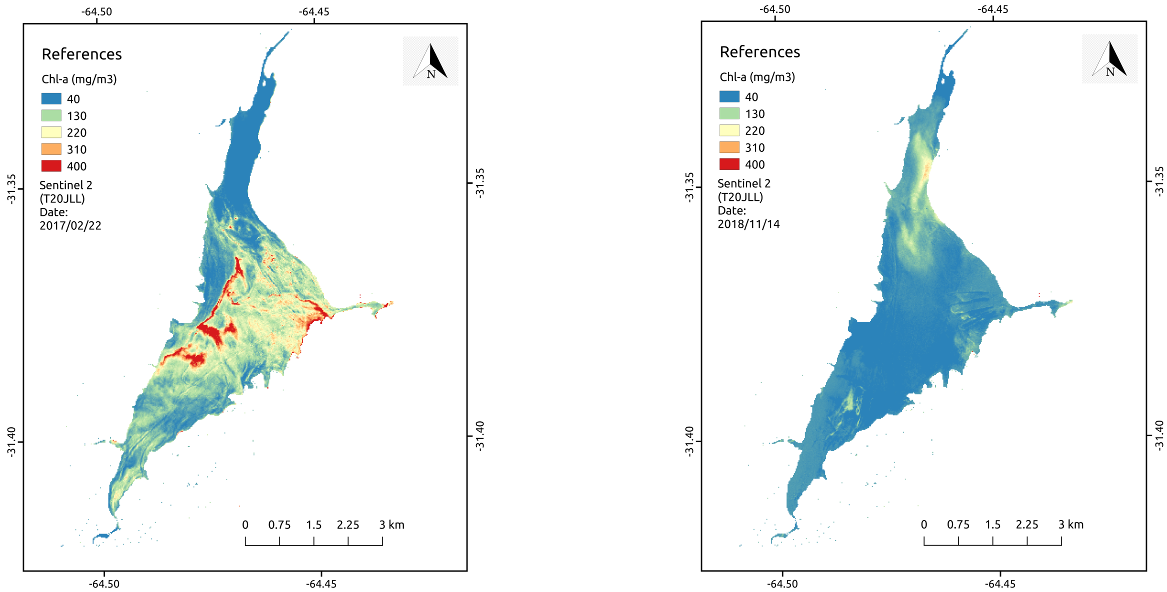


Fig. 2. Linear Model which relates chl-a (mg/m3) concentration and band 8 and band 4 ratio.

The results of the validation process using a ground truth data found an accuracy of 0.785 (r^2) and a significant p-value of 0.0034.

3.2. Algae composition analysis

Figure 4 presents the algae distribution of 4 sampling stations in San Roque during the bloom event of 22/02/2017.

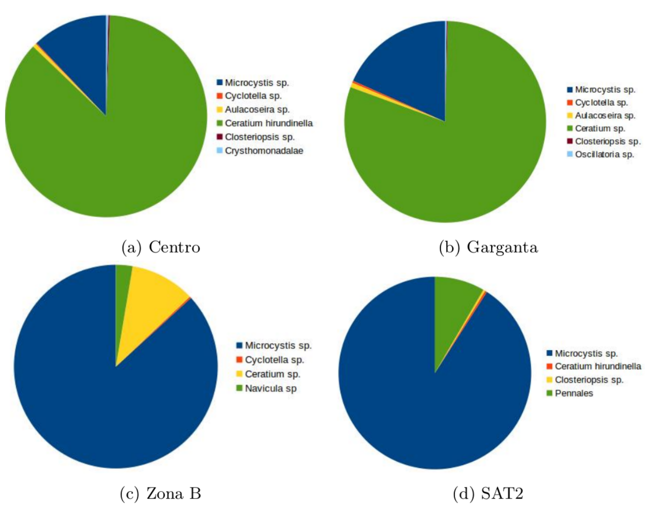


(a) 22/02/2017

(b) 14/11/2018

Fig. 3. Satellite imagery from Sentinel 2A MSI T20JLL and chl-a (mg/m3) estimation in San Roque lake.

It shows the predominance of Ceratium hirundinella (a) and (b) and of Microcystis species (c) and (d). A range of 9600 and 1500000 ORG/L and 320000 and 2600000 ORG/L were measured for Ceratium Hirundinella and Microcystis, respectively. This very high concentration value of Microcystis are classified as HABs (harmful algal blooms) [16].



(a) Centro (b) Garganta (c) Zona B (d) SAT2

Fig. 4. Phytoplankton proportion composition over different sites assessed during the algal bloom of 2017/02/22

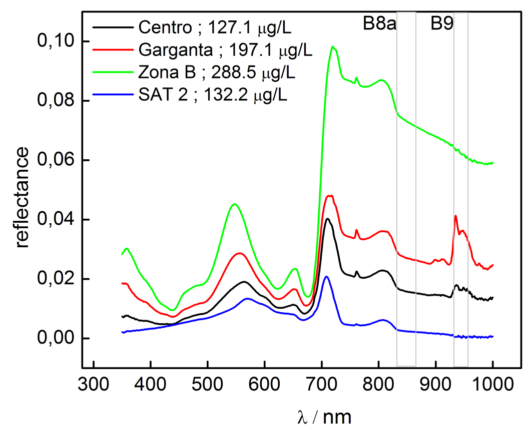


Fig. 5. Field reflectance spectrum's acquired during the algal bloom of 2017/02/22. Sentinel 2-MSI band widths (B8a and B9) are marked in black vertical lines

Figure 5 presents the reflectance spectra collected in the corresponding *in situ* sites in Figure 4. A spectral peak related to Ceratium hirundinella is observed in the wavelengths region 900 to 960 nm. These wavelengths are corresponded to band 9 of S2 (marked in figure 5). In a location where Microcystis is more abundant ("Zona B" and "Sat 2"), the peak is not present. Accordingly, we found that normalized reflectance ratios for band 8a (centered at 864 nm) and band 9 (centered at 945 nm) exposed these algae composition patterns. Specifically:

$\hat{\rho}_{8a} = \frac{\rho_{8a}}{(\rho_{8a}+\rho_9)/2}$; $\hat{\rho}_9 = \frac{\rho_9}{(\rho_{8a}+\rho_9)/2}$

This ratio was selected after finding that $\hat{\rho}_9(Centro)/\hat{\rho}_9(ZonaB)$ is equal to 1.16 (greater than one) while $\hat{\rho}_{8a}(Centro)/\hat{\rho}_{8a}(ZonaB)$ = 0.90 (lower than one). These preliminary results will be further analyze and validate using other multi-temporal data and for other location.

4. CONCLUSIONS

San Roque lake is the main drinking and recreation sources for the population living in this semiarid region. The promising results presented in this paper, found that S2 is an efficient tool to monitor algae bloom in eutrophic lakes characterized with high variability of biomass (in time and space). Nevertheless, this study shows the capability of the sensor to monitor the concentration of algae species including HABs of cyanobacterias and big blooms of Ceratium hirundinella. Future work will focus on improving the accuracy of the retrievals by combining multi-temporal data and in creating a prediction model using big earth data and machine learning algorithms.

5. REFERENCES

[1] Robert G Wetzel, *Limnology: lake and river ecosystems*, Gulf Professional Publishing, 2001.

[2] Brian Henderson-Sellers and HR Markland, *Decaying lakes*, Wiley, 1987.

[3] Robert E Carlson, "A trophic state index for lakes1," *Limnology and oceanography*, vol. 22, no. 2, pp. 361–369, 1977.

[4] Anabella Ferral, Velia Solis, Alejandro Frery, Alejandro Orueta, Ines Bernasconi, Javier Bresciano, and Carlos M Scavuzzo, "Spatio-temporal changes in water quality in an eutrophic lake with artificial aeration," *Journal of Water and Land Development*, vol. 35, no. 1, pp. 27–40, 2017.

[5] Alba Germán, Carolina Tauro, Marcelo C Scavuzzo, and Anabella Ferral, "Detection of algal blooms in a eutrophic reservoir based on chlorophyll-a time series data from modis," in *Geoscience and Remote Sensing Symposium (IGARSS), 2017 IEEE International*. IEEE, 2017, pp. 4008–4011.

[6] Anabella Ferral, Velia Solis, Alejandro Frery, Alejandro Aleksinko, Ines Bernasconi, Carlos marcelo Scavuzzo, et al., "In-situ and satellite monitoring of the water quality of a eutrophic lake intervened with a system of artificial aireation," *IEEE Latin America Transactions*, vol. 16, no. 2, pp. 627–633, 2018.

[7] Andrea Guachalla Alarcón, Alba German, Alejandro Aleksinkó, María Fernanda García Ferreyra, Carlos Marcelo Scavuzzo, and Anabella Ferral, "Spatial algal bloom characterization by landsat 8-oli and field data analysis," in *IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium*. IEEE, 2018, pp. 9292–9295.

[8] Nguyen Thi Thu Ha, Nguyen Thien Phuong Thao, Katsuaki Koike, and Mai Trong Nhuan, "Selecting the best band ratio to estimate chlorophyll-a concentration in a tropical freshwater lake using sentinel 2a images from a case study of lake ba be (northern vietnam)," *ISPRS International Journal of Geo-Information*, vol. 6, no. 9, pp. 290, 2017.

[9] M Tawfik, HAAM Farag, and MS Salama, "Sentinel-2 red-edge bands capabilities on retrieving chlorophyll-a in turbid water: case study: Lake burullus, egypt," 2014.

[10] Alba Germán, Carolina Tauro, Verónica Andreo, Inés Bernasconi, and Anabella Ferral, "Análisis de una serie temporal de clorofila-a a partir de imágenes modis de un embalse eutrófico," in *Biennial Congress of Argentina (ARGENCON), 2016 IEEE*. IEEE, 2016, pp. 1–6.

[11] Eugene W Rice, Rodger B Baird, Andrew D Eaton, Lenore S Clesceri, et al., "Standard methods for the examination of water and wastewater," *Washington: APHA, AWWA, WPCR*, vol. 1496, 2012.

[12] Anatoly A Gitelson, Giorgio Dall'Olmo, Wesley Moses, Donald C Rundquist, Tadd Barrow, Thomas R Fisher, Daniela Gurlin, and John Holz, "A simple semi-analytical model for remote estimation of chlorophyll-a in turbid waters: Validation," *Remote Sensing of Environment*, vol. 112, no. 9, pp. 3582–3593, 2008.

[13] A Gitelson, "The peak near 700 nm on radiance spectra of algae and water: relationships of its magnitude and position with chlorophyll concentration," *International Journal of Remote Sensing*, vol. 13, no. 17, pp. 3367–3373, 1992.

[14] Anatoly A Gitelson, John F Schalles, and Christine M Hladik, "Remote chlorophyll-a retrieval in turbid, productive estuaries: Chesapeake bay case study," *Remote Sensing of Environment*, vol. 109, no. 4, pp. 464–472, 2007.

[15] Herman J Gons, "Optical teledetection of chlorophyll a in turbid inland waters," *Environmental Science & Technology*, vol. 33, no. 7, pp. 1127–1132, 1999.

[16] Donald M Anderson, Patricia M Glibert, and Joann M Burkholder, "Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences," *Estuaries*, vol. 25, no. 4, pp. 704–726, 2002.