DETECTION OF ALGAL BLOOMS IN A EUTROPHIC RESERVOIR BASED ON CHLOROPHYLL-A TIME SERIES DATA FROM MODIS.

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ABSTRACT

Eutrophication is a phenomenon that affects many water bodies around the world. In severe cases, eutrophication can lead to large algal blooms.

This study presents a method to detect algae blooms based on a time series of chlorophyll-a (Chl-a) concentration in the period 2001-2014. This time series is obtained from a semi-empirical algorithm generated with MODIS satellite data and *in situ* data from the Ministry of Water Resources of Cordoba Province. By detecting algae bloom dates and their statistic characterization, it is possible to define the range of Chl-a values in which the San Roque Dam is going through a bloom event.

Key words: Eutrophication, algae blooms, San Roque reservoir, remote sensing, Chlorophyll-a.

1. INTRODUCTION

Eutrophication is the process by which the primary production in a water body increases, as it is enhanced by a greater contribution of organic matter and nutrients. The enrichment of nutrients, particularly nitrogen and phosphorus, if not compensated by total mineralization, can produce effects such as fish mortality, since the decomposition of excess organic matter leads to a drastic decrease of the dissolved oxygen.

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. In severe cases, this process can lead to large blooms of algae. Algal or phytoplankton blooms are the result of a rapid increase in the algae population in an aquatic system. They may occur in both freshwater systems and marine environments and depend mainly on temperature, light and nutrient conditions [1]. Although there is no an officially recognized threshold level, a population of algae must have a concentration of hundreds to thousands of cells per milliliter to be considered a bloom, also a specific coloration in the water should be observed [2].

In order to assess the quality of water bodies, quantitative indicators are required to describe the frequency and intensity of blooms. As a first step it is necessary to describe those phytoplankton characteristics which underlie an event of this type. Richardson in [3] describes a bloom as a rapid growth of one or more species leading to an increase in total biomass. This qualitative definition, like many others, does not say anything about exceptional or unusual growth. Tett in [4] uses a chlorophyll threshold of 100 mg / l to quantitatively define exceptional blooms. This arbitrary definition does not consider the trophic state of the water body analyzed which determines the concentration values of chlorophyll that may be expected in absence of blooms. In this sense, it contradicts the conclusion of the ICES Meeting (1984), which concluded that a bloom is a deviation from the normal phytoplankton mass [5]. In addition, the definition of a bloom event should consider at a regional scale seasons patterns.

This is the case of San Roque Reservoir located approximately 600 meters above sea level in the Punilla Valley in the upper Suquía River basin (province of Córdoba, Argentina). It is the most important source of water supply in Córdoba city and presents eutrophic conditions that lead to a periodic and massive development of cyanobacteria. For this reason detection of blooms events is extremely necessary to adequately manage this reservoir.

Algal blooms are generally monitored by in situ biomass measurements, examining the species which are present. As chlorophyll-a concentration shows strong correlation with biomass, it is a widely used indicator of the trophic state [6]. Peak values of Cl-a concentration for an oligotrophic lake are about 1-10 μg l-1, whereas in a eutrophic lake they can reach 300 μg l-1. The San Roque reservoir presents values that can sometimes reach numbers close to 1000 μg l-1

It has been shown [7] that conventional water sampling programs are not adequate to report changes in phytoplankton biomass, especially during blooms conditions, when spatio-temporal variability in phytoplankton density is high. In addition, reliable monitoring of cyanobacteria blooms is even more complicated since this specie is able to regulate their buoyancy throughout the water column [8]. In this framework, remote sensing becomes an appropriate tool to monitor these algae, allowing to extrapolate in situ local measurements to a larger scale, in less time and at a lower cost.

Specifically, MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard NASA's Terra and Aqua satellites, launched in 1999 and 2002 respectively, shows high potential for monitoring water quality in inland or oceanic water bodies [9]. These two satellites provide daily information that is freely and openly available.

In a previous work, we developed a semi-empirical algorithm to retrieve chlorophyll-a concentration by analysing daily data from MODIS satellite and field measurements from San Roque Reservoir [10]. In this work we had used that algorithm to build a time series of chlorophyll-a concentration that represents daily values of this variable throughout the period 2001-2014. We present a method of identification of blooms episodes based on modelling the normal behaviour of chlorophyll-a time series, by using frequency analysis and statistical approach, in order to detect extraordinary events.

2. MATERIALS AND METHODS

2.1. Field data

Field data used in the present work were collected and generated in the context of the monitoring plan carried out by the Ministry of Water Resources and Coordination of the Ministry of Water, Environment and Public Services of the province of Córdoba [10]. The frequency of monitoring was performed monthly from December 2008 to December 2014. For this work, only chlorophyll-a concentration data were used from the central point of the reservoir, which is statistically representative of the entire reservoir [11]. Figure 1 present a map of San Roque reservoir and monitoring points.

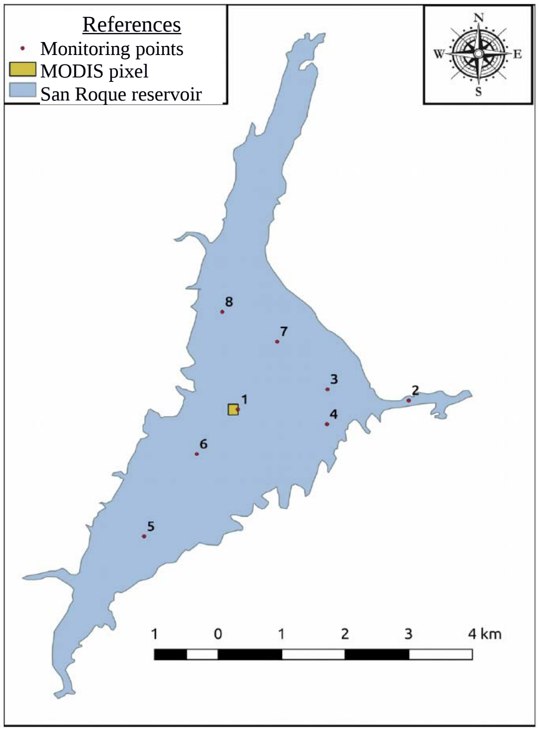

Figure 1. Map representing San Roque reservoir and monitoring points and MODIS pixel location.

2.2. Satellite data

Satellite data used in this work are from MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, which is onboard TERRA and AQUA platform operated by NASA.
We used the surface reflectance product MOD09GQ, which is corrected by atmospheric and absorption effects [12]. Particulary, we have obtained daily products, L2G, for band 1(620-670 nm) and 2 (841-876 nm) which have a spatial resolution of 250 m and Sinusoidal projection.
Figure 1 shows the pixel that was used to calculate daily chlorophyll-a concentration for San Roque reservoir. It can be observed that is localized at the center of the reservoir. This is the only pixel which correspond to pure water throughout the studied period.

2.3. Regression Model: Semi-empirical algorithm of chlorophyll-a.

Retrieval algorithm was based on a semi-empirical model of simple linear regression obtained from the satellite data and chlorophyll-a concentration measurements performed in situ, in simultaneously with the sensor pass. Once this set was obtained, the best radiometric and statistical relation of the product MOD09GQ - MODIS with field data was searched. In this sense, we have applied different bands algebra operations (logarithms, indexes, and reasons) for both MODIS products to perform a bivariate analysis.
Significant Pearson correlation values were obtained between different combinations of satellite bands and the logarithm of the Chlorophyll-a in situ concentration. Several linear models were generated between those combinations of variables that presented significance values less than 0.01. It was chosen by its best fit (r^2 = 0.69), a linear model that related the logarithm in base 10 of chlorophyll-a with the ratio between Band 1 and Band 2 [10].

2.4. Method of identification of algal blooms: HANTS.

At the ICES meeting (1984) it was concluded that exceptional phytoplankton blooms should be defined in terms of the deviation from the normal phytoplankton biomass cycle. The challenge now is to define this normal behavior. For this, a modeled times series was performed with the HANTS algorithm. The basic idea of this algorithm is to calculate main frequencies and its coefficients from Fourier series analysis of satellite data in order to model the time series. The algorithm removes outliers and replaces them with the value given by the Fourier series.
In this work we used the implemented version of HANTS developed by Markus Metz in GRASS GIS 7 Add-on [13]. Different combinations of parameters were tested, varying one at a time. In addition, the time series obtained was averaged each 8 days in order smooth it to obtain the normal behavior. Then, an own methodology that prioritizes reservoir behavior different from expected is propose.

3. RESULTS AND DISCUSSION

3.1. Time Series and Detection of algal blooms.

From the algorithm of chlorophyll-a, a concentration value for each day, free of clouds, was obtained from January 2001 until December 2014 (Figure 2). After that, HANTS algorithm was used to model a Time series without outliers.
In order to define a bloom event it has been taken a threshold based on the modelled series plus a “value” to avoid including poor representative differences as extraordinary events. In this framework, we used statistic cuantils from the distribution of the modelled series to choose that “value”. Probability equal 0.90 was used for this purpose. After that we add to the modelled series this cuantil to generate a new time series representative of a threshold, above the one a

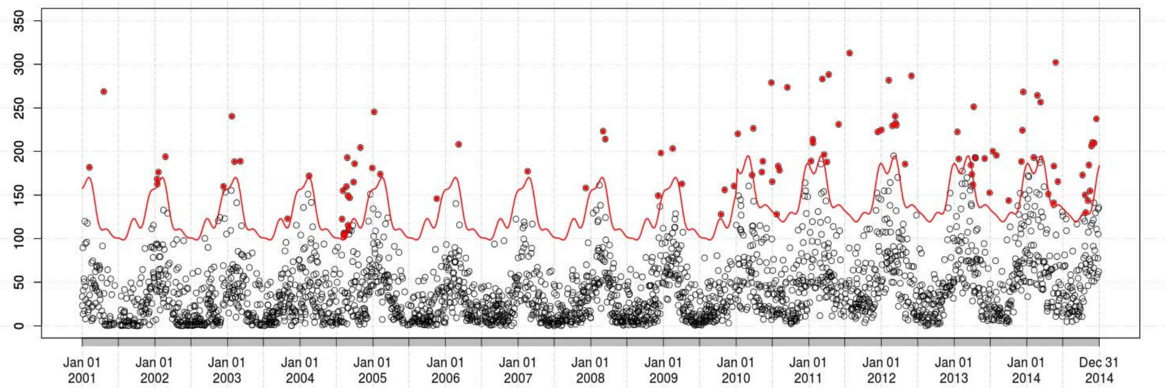

Figure 2. Original serie (black line points) plus threshold cuantil in red line. Bloom dates are represented with red dots.

measurement retrieved from satellite data can be identified as an algal bloom. Figure 2 presents in red colour the modelled series plus this cuantil, which contains seasonal and annual cycles but not extreme values, (0 a 50 mg/m^3) in the lower limit and (300 mg/m^3) in the upper one.

A statistical analysis was carried out at these dates separately, in order to characterize them. It was observed that the reservoir presents blooms throughout the year and an algal bloom can be defined by a concentration of Cl-a ranging from 103 to 313 mg/m^3, being the range of highest frequency the one from 180 to 200 mg/m^3. On the other hand, if we compare these dates with the rest of the series without them, the distribution of values is very different, with the lowest values predominating in the latter (from 0 to 50 mg / m^3) and not reaching the maximum found for blooms dates (300 mg / m^3).

4. CONCLUSSION

It can be concluded that the chosen method can be used to identify blooms, not only in the reservoir under study but in other water bodies with high biomass and abundant amounts of blooms throughout the year. This kind systems are particularly complicated to study because traditional chlorophyll-a concentration threshold may not be used.

In addition it was possible to characterize bloom events in the studied reservoir, since not reference data to define blooms were able for stakeholders. This method can be used as a reference point to compare results from the monitoring programs carried out by the government in order to implement mitigation policies. The next step of this work is to study the feasibility to develop an early warning system of algal blooms based on satellite and meteorological data.

5. REFERENCES

[1] Wetzel, R. G. (2001). Limnology: lake and river ecosystems. Gulf Professional Publishing.

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

[3] Richardson, K. Harmful or exceptional phytoplankton blooms in the marine ecosystem. Advances in marine biology, 31:301–385, 1997.

[4] Tett, Paul. The ecophysiology of exceptional blooms. Rapport et Proces-verbaux des Reunions. Conseil international pour lâ Exploration de la Mer, 187:47–60, 1987.

[5] Parker, Miles and Tett, Paul. Exceptional plankton blooms. 1987.

[6] Carlson R. E. Limnol. Oceanogr. A Trophic State Index for lakes, 22:363–369, 1977.

[7] Rantajärvi, E., Olsonen, R., Hällfors, S., Leppänen, J. M., & Raateoja, M. (1998). Effect of sampling frequency on detection of natural variability in phytoplankton: unattended high-frequency measurements on board ferries in the Baltic Sea. ICES Journal of Marine Science: Journal du Conseil, 55(4), 697-704.

[8] Paerl, H. W., & Huisman, J. (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environmental microbiology reports, 1(1), 27-37.

[9]Carder, K. L., Chen, F. R., Cannizzaro, J. P., Campbell, J. W., & Mitchell, B. G. (2004). Performance of the MODIS semi-analytical ocean color algorithm for chlorophyll-a. *Advances in Space Research*, *33*(7), 1152-1159.

[10] Germán, A., Tauro, C., Andreo, V., Bernasconi, I., & Ferral, A. (2016, June). 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* (pp. 1-6). IEEE.

[11] Ferral, A. (2013). Análisis espacio-temporal del efecto del sistema de aireación artificial en el

Embalse San Roque. Integración de datos de campo y técnicas geoespaciales. FaMAF – UNC.

[12]URL MODIS product (https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod09gq).

[13] URL grass (http://grass.osgeo.org/grass70/manuals/addons/r.hants.html)