Satellite Image Processing and Mathematical Modeling of the Growth of Cyanobacteria to Determine the Level of Environmental Contamination in the Tiete River Beach

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Abstract: - In this study satellite images obtained from LANDSAT (series 5 and 7) were used to obtain a correlation between the level of contamination in the Tiete river beach near the city of Lins, Sao Paulo (Brazil). Using data from samples taken in the river, geo-referenced, a mathematical model of the growth of cyanobacteria was created to understand the ecosystem. With GPS coordinates and processing of LANDSAT images, a correlation at the pixel level with de cyanobacteria level at the same location could be calculated. With the mathematical model, the population of cyanobacteria can be determined (with a specific statistic error) and verified with the satellite images. The correlation method of pixels could be used, with images of LANDSAT to determine the contamination of cyanobacteria in the beach environment.

Key-Words: - **Image processing, environment contamination, water quality, mathematical modeling.**

1 Introduction

In this work, we were studied the use of satellite images, in this particular case, from LANDSAT 5 and 7 and CBERS 2 satellite (the CBERS agronomical series is a result from Brazil and China scientific cooperation in 1998) to estimate the cyanobacteria (CB in the text) contamination level combined with a simple mathematical model of growth of CB.

To have a model and find a correlation with satellite images, samples were acquired in the Tietê river beach and neighborhood in the river branch.

These samples sites were geo-referenced using a GPS to set the POI (point of interest) of the specific sample. Combining the satellite image processing with POI we can estimate the growth of CB and compare with the model's result and laboratory analysis.

To understanding all these features, we were divided the explanation in the following sections.

2 The growth of cyanobacteria

CB in the Tietê river is environmental issue since 2008. In that occasion, the beach was clear for use for the from Sabino county. We believe that for some particular reasons the CB starts growth spreading to the beach and the river branch.

2.1 Simple Mathematical Model

Modeling bacterial growth had been used for a long time [2]. In this study we used the model to an approach to estimate the bacterial growth and concentration of CB in their natural habitat in the Tietê River.

The model discussed here aims to show the behavior of the growth and decay of the population of CB [3], using samples of specific sites and measured electrochemical parameters of water.

The model considered for the local eco-system for the CB, is in Figure 1.

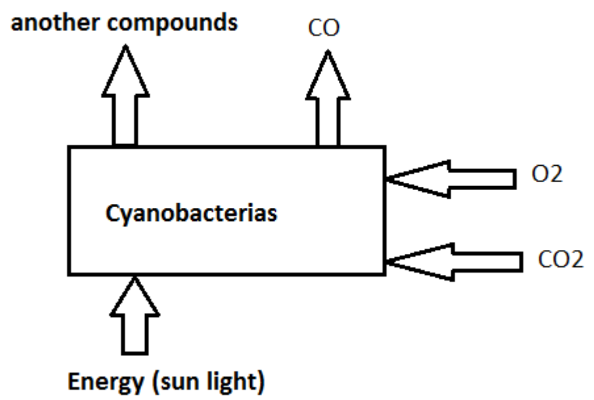

Figure 1 – Simple model used to study the CB.

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$$\frac{dx(t)}{dt} = \left(f(x,I,\delta) - \int_0^T x(t-T)d(t)\right)x(t)$$

Equation 1 – Simple mathematical model for CB growth and decay.

According to the Equation 1, we have : δ is the temperature, f is the biological clock of CB, I is the sun light intensity on the site, x is the CB concentration, T is the time constant for maximum CB cycle for absorption of model inputs and outputs, according with Figure 1.

This model [4] refers to light intensity and temperature on parameters that are already being monitored. The function f, CB determines the bacterial growth.

Once *y=f(x)* is determined by the biological clock, a function of the empirical growth of CB in the river, y was obtained by the method of Levemberg-Marquadt fitting the data samples.

We have founded for y, an expression that can be seen in Equation 2 [5] and decay as Equation 3.

$$y = y_0 + Ae^{(-0.5(x-x_c)/w)^2}$$

Equation 2 – Function y, used in the model.

$$y_2 = Be^{-(t/T)x}$$

Equation 3 – Second hand of Equation 1.

We can see in Figure 1, a graphic situation for the values collected for each samples in the sites.

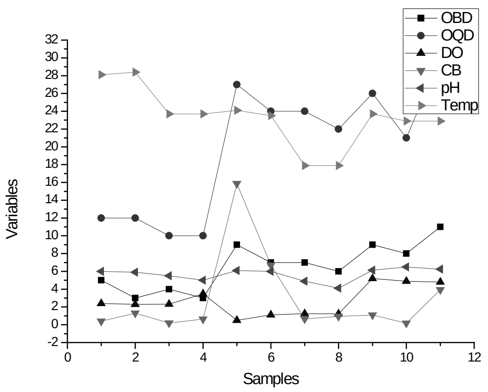

Figure 1 – All the parameters, for each site sample, used in this study.

We can see in Figure 2, the electrochemical parameters used for the model. These parameters we were used, whit the help of an automatic station. (Details can be seen in WSEAS publication referenced [1]).

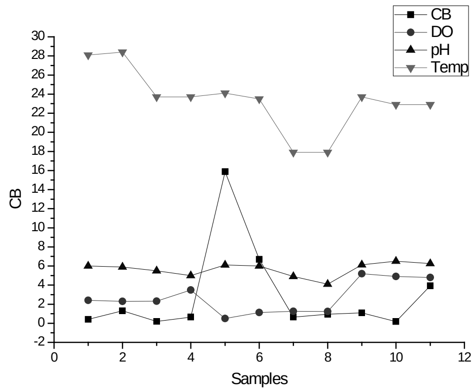

Figure 2 – Electrochemical parameters for modelling. Another parameters, as shown in Figure 1, we were used for a best fitting, and initial model conditions.

The parameters that are possible to be obtained by means of direct monitoring in this case are pH, DO and temperature (*Opus. Cit.*[1]) It can be observed that when the temperature is stabilized around 24^{o}C and pH around 6.7 there is an increase in population (sample 5) of CB.

The model predicts the growth of the colony according to the environment variables, as said before.

3 Problem Solution

3.1 The model results

Figure 3 shows the model's result (for one sample) for the values shown in Figure 1. It´s not necessary to remember, that all the data were used to fitting the model.

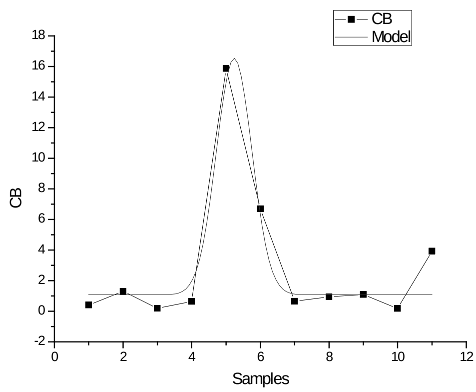

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Figure 3 – Example of model's result for sample 5.The model output is the thin line without the markers.

3.2 Image processing and Correlation whit the sample data and modeling

We were presented in this papers the firsts results for the satellites images.

Once the samples were collected in the sites(POI's with a GPS system) the laboratorial analysis were performed, model fitted, using satellite images, we can search for a correlation between the number of CB individuals (concentration) [6].

In Figure 4 we have a photo of the study site and in Figure 5 one of the LANDSAT images of the region, in the state of São Paulo (Brazil).

Figure 4 – Satellite image of the beach in the Tietê river (large white area shown in the photo)

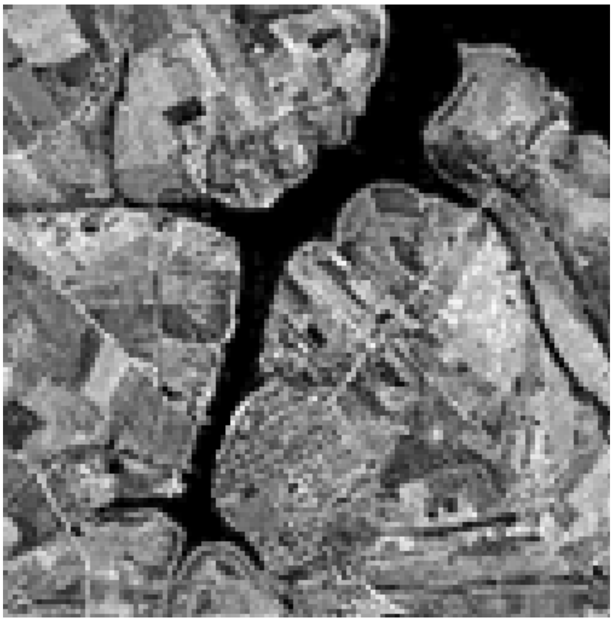

Figure 5 – LANDAT TM sensor image, band 5, of the same area shown in Figure 4 (Scale 1:3).OBS.: Some IR and NIR image detail, cannot be seen because gray level transformation of image, to this paper format.

Using a simple mathematical inverse operation over all the image pixels we can obtain the result shown in Figure 6.

Figure 6 – Image from Figure 5, inverted.

In the region of the branch of the Tietê River, it can be seen the CB (scattered pixels). We define the cumulative distribution function (cdf) as shown in Equation 4. [6]

$$cdf_x(i) = \sum_{j=0}^{i} P_x(i)$$

Equation 4 – Definition of cumulative distribution function *(cdf).*

We want to create a transformation of the type y = T(x), as shown in Equation 5, to produce a new image. By the equalization of the histogram, Equation 6, we have the result shown in Figure 7.

$$y = T(x) = cdf_x(x)$$

Equation 5 – Transformation needed for a linear output of the pixels.

$$h(v) = round\left(\frac{cdf(v) - cdf_{min}}{(MxN) - cdf_{min}}(L-1)\right)$$

Equation 6 – Equalization of the histogram *h(v)*, for an image with M x N pixels. L is the level of each pixel (RGB).

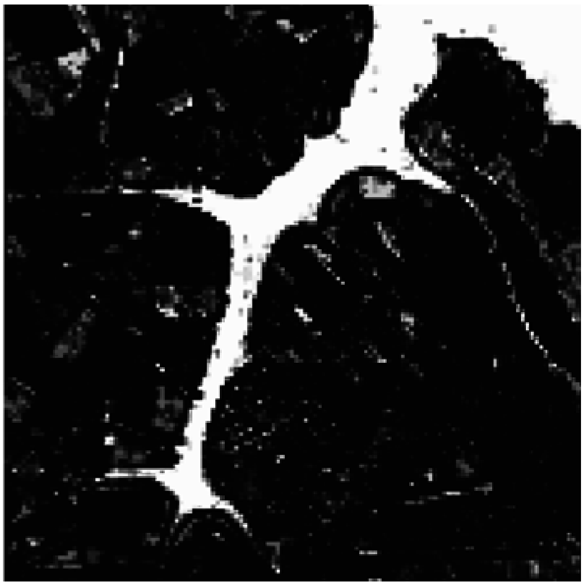

Figure 7 – Equalization of the histogram from the image from Figure 6.

Digitally subtracting the image of Figure 7 from the picture of Figure 6, the pixels that contains the information of the concentration of the CB can be highlighted, as shown in Figure 8.

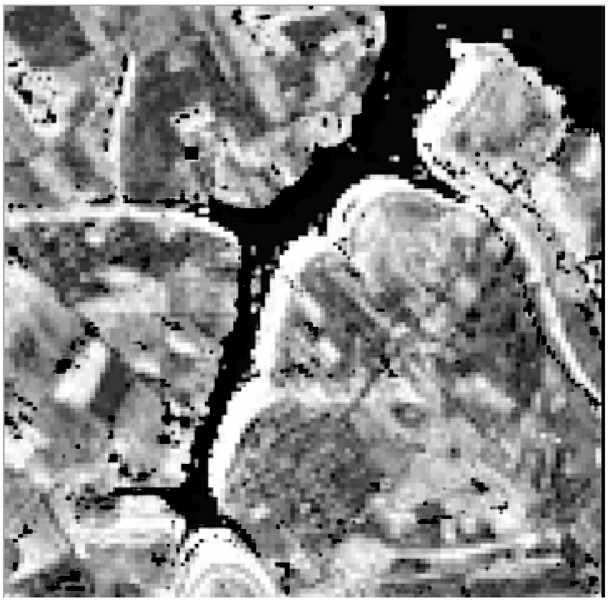

Figure 8 – Image difference for highlighted the CB pixels.

To estimate the concentration of CB, using the image of Figure 8, we need to count the pixels in the image. If we remember this image was taken from LANDSAT TM sensor, band 5, with a resolution of 0.9 km^2 per image pixel. Using this region of interest (ROI) bounded by a count of pixels, it was found that the concentration of CBs occupy an area of 11.7 km^2 (the processed image has a scale factor of 1:3).

According to the model described here and the laboratorial analysis, it was found 7.35 ug/L. The correlation of the detected area in the image, taken the average of the concentration, we found 1:1.59 CB. [7]

If we look the image more closely we can see a higher concentration, as shown in detail in Figure 9.

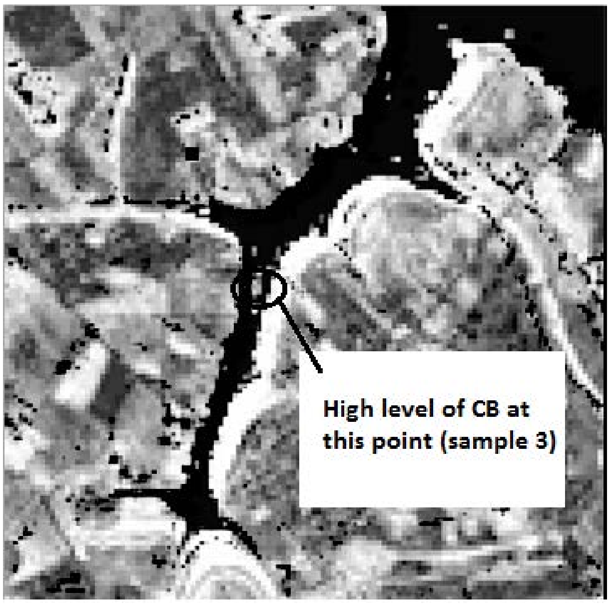

Figure 9 – Higher concentration of CB in the middle point of the beach.(Site 3 of collected samples)

In the site 3 (coordinates N0646502 S7625258), in front of the beach, the correlation pixel count of this specific site, we founded a correlation of 1:0.95, given 3.81 ug/L based on image and laboratory obtained a concentration of 3.93 ug/L.[8] [9].

This may suggest that at concentrations greater than 1 ug/L the correlation residues goes to zero [10][11].Across the river, in the opposite of point 3, there is a crop of tomatoes. The increase in concentration in this area may

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suggest that some fertilizer used in tomatoes may have been thrown into the river in the action of irrigation water and contributed to the high level of oxygen demand which was calculated in the sample in the laboratory analysis (Figure 1) [12][13][14].

4 Conclusion

The image processing up to this time of this research involves few steps that are done manually, such as the choice of the region of interest (ROI) image for the software used to count the pixels and make the calculations.

Another step that remains semi-automatic adjustment of the cut is the histogram, which must be done manually. For these steps, some algorithms are being tested. The results in this work showing promising values, so this method presented here have satisfactory correlation (r > 0.92) to estimate the concentration of CB in some specific area.

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