COASTAL WATER CHLOROPHYLL ESTIMATION USING LANDSAT TM

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ABSTRACT

This work was performed in Ubatuba, São Paulo coast, to assess Landsat 5/TM information of chlorophyll concentration (Chla) studies in the ocean. Twenty four water sampling stations were determined and the following parameters were sampled: chlorophyll a, yellow substance, total suspended solids and Secchi depth. TM digital image was previously corrected and an average of nine pixels values of each coordinate point was obtained from TM band 1,2 and 3. A linear correlation analysis between water parameters and reflectance data was applied and it was observed the correlation coefficients between Chla and TM1, TM2, TM3, TM1/TM2 and TM3/TM2, respectively:0.84, 0.92, 0.86, 0.91 and 0.71. A model to estimate Chla from TM bands was determined by using a stepwise multiple regression. The resulting model included TM2 band (R^2 adjusted=0.84).

KEY WORDS: Remote Sensing, Ocean water chlorophyll.

1.0-INTRODUCTION

The phytoplankton pigments (chlorophyll a) synthetize organic matter from inorganic matter by using the solar energy. It is responsible for around 95% of marine photosynthesis, being the main primary producer of the ocean and regulating the CO_2 levels in the atmosphere(Perry, 1986).

The chlorophyll pigment can be used as an indicator of primary production level, physical oceanographic phenomena, etc (Tyler and Stumpf,1989).

The conventional sampling methods for determining chlorophyll concentration are expensive, time consuming. These aspects explain the poor spatial distribution of the resulting data sets and prevent their interpolation and extrapolation. Remote sensing data can minimize those time and spatial sampling problems by providing a synoptic view of the area under study (Perry, 1986; Platt and Sathyendranath, 1988).

The remote sensor signal results from the interection between the solar radiation and both water and atmosphere (Kirk, 1986).

Pure water presents high absorption in the red and infrared region of the eletromagnetic spectrum. The water spectral response is changed by their optically active components such as pigments, organic and inorganic matter and organic dissolved substances.

Suspended inorganic matter are the main light scatters within the aquatic environment. Size, shape and concentration are the main factors explaining the amount of scattering by inorganic matter(Novo et al., 1989).

Yellow substances are mainly absorbed in the short wavelenghts. At high concentrations they cause a decrease in chlorophyll model sensitivity (Tassan, 1988).

Each phytoplankton pigment presents its typical absorption curve. The pigment composition varies according to the phytoplankton species. Chlorophyll a is the main pigment and absorbs at 435nm and 670-680 nm. The chlorophyll concentration in the water can be detected through remote sensing techniques since changes in its spectral absorption and scattering coeficients affect water color.

Since the early fifties, water color has been used as an indicator of water components such as chlorophyll concentration, inorganic matter and yellow substance. In 1972, with the Landsat program, there was an increase in the use of remote sensing data for estimating chlorophyll concentration (Sturm, 1980). The poor spectral and spatial MSS/Landsat resolution prevented the operational use of this sensor system for primary production assessment. With the advent of CZCS featured to ocean color monitoring, there was an increase in chlorophyll algorithm development (Gordon et al. 1983). With the CZCS discontinuity in 1986, TM/Landsat data started to be considered for chlorophyll model development (Lathrop and Lillesand, 1986; Tassan, 1987; Grunwald et al. 1986; Braga, 1988; Novo and Braga, 1991, Khorran et al. 1991; Ekstrand, 1991).

TM/Landsat data were applied to derive chlorophyll estimates in the range between 0.1 to 17 mg/m^3 in regions of low inorganic matter concentration (Lathrop and Lillesand, 1986; Tassan, 1987; Khorran et al, 1991; Novo et al. 1991).

In Brazil, remote sensing applications to marine environment water quality are still incipient. Among the main contributions to this subject is Guanabara bay study (Braga, 1988). Considering the large brazilan coast and the high cost of collecting data over that huge area, remote sensig applications to this subject has been encouraged. As a part of this effort, the objective of the present study is to assess the TM/data suitability to estimate surface chlorophyll concentration in ologotrophic environment.

The Ubatuba study area is located in the Northern coast of São Paulo State (southern Brazil) at 23° 28'S and 45° 4'W. This area was selected as test site because it is a region which has been intensively studied by the São Paulo University Oceanographic Institute since 1984. The region is characterized by clear waters and very low chlorophyll content. In the last decade the area is also undergoing a heavy urban occupation.

2.0-METHODOLOGY

The methodology envoled the following main steps: 1- simultaneous acquisition of TM/Landsat data (path 218/ row 76) and water samples; 2- Water sample analysis in laboratory; 3- TM digital data processing; 4- Statistical data analysis.

2.1- Ground Truth Data Acquisition and Analysis

Water samples were colected at 24 sites in Ubatuba within a three hour interval of the Landsat overpass. The sample site location was determined by referencing it to outstanding features in the coast and islands. Its position was plotted on a nautical chart (latitute and longitude).
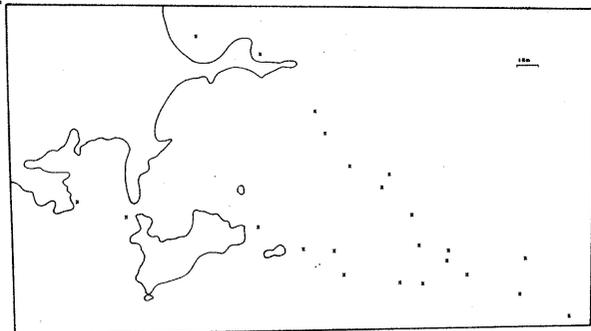

Figure 1- The location of the sample sites in Ubatuba - Sao Paulo- Brazil.

Water samples were collected at two different dephts: 1- at the surface to represent the water column whose components are potentially more effectively detected by the sensor system.; 2- at the Secchi depht, because of its relationship with the euphotic depht.

Secchi depht (Zse), salinity and temperature were measured in situ. Water samples were filtered on the boat and preserved at low temperature (Golterman et al., 1978).

Chlorophyll a (Chla) was determined using the acetona extract method and spectrophotometric measures. Total suspended matter (TSS) was determined by gravimetric methods. Yellow substance (YS) concentration was expressed in terms of its absorption coeficients determined by spectrofotometric measures at 380, 420 and 450 nm.

2.2-Digital Data Processing

Digital data analysis was performed at the Interative Image Processing System (SITIM) developed by the National Institute for Space Research (INPE). After selecting the study area subscene, digital data were submitted to the following procedures:

a- geometric correction of the image was performed using an existing georreferenced image. A nearest neighbour interpolator was applied for the geometric transformation. The corrected image presented a residual error of 19 meters.

b- atmospheric correction was performed using the method developped by Chavez (1987).

c- sample site geographic coordenates location and transformation into image row and column so as to collect the digital number values for band TM1, TM2 and TM3 from a 3 by 3 window around each sampling area.

d- calculation of the average digital number for each 3 by 3 window at TM1 ,2 and 3 bands and TM1/TM2, TM3/TM2 band ratio determinations.

2.3- Statistical Analysis

A correlation matrix was obtained for all water sample variables (Chla, TSS, YS, Zse) and remotely sensed data (TM1,TM2, TM3, TM1/TM2, TM3/TM2 digital numbers). The same data set were submitted to a stepwise multiple regression analysis to identify the best set of TM bands (independent variables) to estimate chlorophyll concentration. The final selection of the model was based upon the following criteria suggested by Whitlock et al (1982): 1- adjusted R^2; 2- F-value; 3- Durbin-Watson statistic; 4- standard error of estimate.

To assess the suitability of that model, it was applied to another TM data set

over the same geographical area. The estimated and observed chlorophyll distribution were introduced into a geographical information system so as to be compared.

3.0- RESULTS AND DISCUSSION

3.1- Oceanographic and Digital Data Analysis

Water quality data are summarized on Table 1. TSS data are missing since there were technical constraints to an accurate concentration determination. Taking into account historical data and Secchi depht measurements they were assumed to be very low during studied date. The Chla concentration was very low as well, but it was the most important optically active water component at that time.

Table 1- Results of the water parameters measurements.

Variable	Mean	Maximum	Minimum
Chla(mg/m^3)	0.864	2.34	0.19
YA	0.11	0.4	0.0
Secchi(m)	13.44	20.5	2.5

The yellow substance concentration expressed as absorbance at 380 nm was also low, what was expected since Ubatuba coast does not have typical mangrove formation, which is one of the most important source of dissolved organic matter in coastal zones. The low chlorophyll concentration also prevents a significative in situ production of yelow substance.

Secchi depht measures were high what is explained by the low concentration of the optically active components: TSS, Chla and YS. This is a common clear water situation in the Ubatuba region, which indicates that there was not a penetration of the ACAS (South Atlantic Central Water) water mass. This fact can be also confirmed by the vertical profile of temperature and salinity data collected during the ground mission.

TM digital data also are very low indicating that they are responsive to water mass characteristics. The relationship between digital values and water variables are fully explored in the next section.

3.2- Linear Regression Analysis

The regression analysis between water variables and TM data are shown in Table 2.

Table 2 - Correlation matrix between water variables and digital data

	TM1	TM2	TM3	TM1/TM2	TM3/TM2
Cla	0.84*	0.92*	0.86*	-0.79*	-0.63*
Ys	0.01	0.04	0.16	0.16	0.10
Zse	-0.84*	-0.86*	-0.74*	0.79*	0.67*

* significant at 99 percent level

As shown in Table 2 , yellow substance was not found to be signicantly correlated with TM digital numbers. It can be explained by its low concentration what makes the TM sensor system insensitive to its presence in the water.

Inspite of the low Chla concentration, however, this variable was highly and positively correlated to TM1, TM2 and TM3 digital numbers. The use of band ratios however did not improve the correlation. As a matter of fact, the correlation between Chla and the ratios decreased and became inverse. The high and positive correlation between Chla and TM band 1 and 2 was expected since both are sensitive to green light, and there is an increase in the green reflectance as chlorophyll increases. This increase is related to the phytoplankton refractive index in the green region of the spectrum (Kirk, 1986). It can be observed in Figure 2 which shows the increase of green radiance as the chlorophyll concentration increases
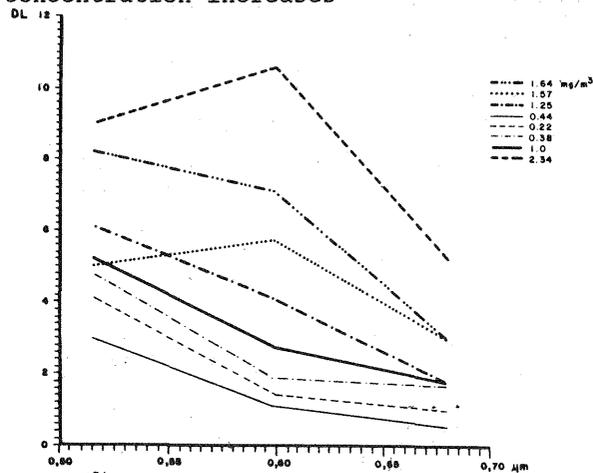

Figure 2- Change in digital levels as a function of chlorophyll pigment concentration

The positive correlation for TM3 band was not expected since there is a secondary chlorophyll absorption band centered at this region. A possible explanation for this behaviour is given by Figure 3 (Lathier, 1957 apud Yentsh, 1980), where a high phytoplakton scattering in the red region is observed. When the phytoplakton radiance curve takes into account both scattering and absorption coefficients there is an increase in the reflectance towards the red edge.
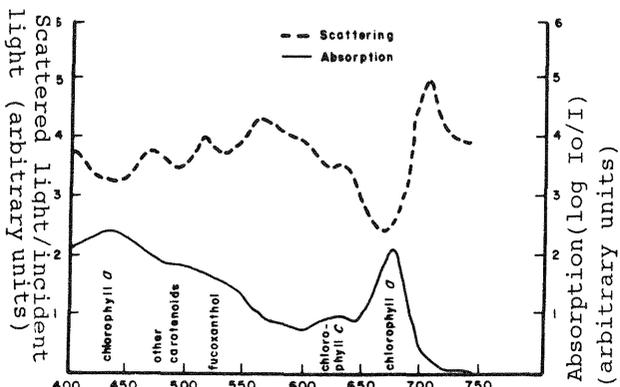
Figure 3- Light scattering at 90° and algal absortion measured in an integratin sphere.
From Lathier, 1957 apud Yentsh, 1980.

TM band ratios were inversely correlated to Chla. The higher correlation observed in the TM1/TM2 ratios was expected since it is the most used index for low chlorophyll concentration (Gordon et al., 1983; Kirk, 1986).

The Secchi depth was highly and inversely correlated with TM bands. The highest correlation was observed with TM 1 what can be explained by the higher transmission coeficient of blue and green light into non productive oceanic water (Kirk, 1986).

The high correlation between Chla concentration at Secchi depht and TM2 can also be explained by the higher transmission coeficient of green light, which makes it sensitive to a deeper water column.

The results of this multivariate analysis show that chlorophyll is the most important optical active water component influencing the water color in the Ubatuba area.

3.3- Stepwise Regression Analysis

Based upon the results of the previous section, an inverse model was attempted by using Chla as dependent variable in stepwise regression analysis. Table 3 presents the results of the stepwise regression.

Table 3 - Stepwise regression results

Depend. Varible	R2 Adj	Var.	SEE	Durbin Watson	F value	% error
Chla	0.8	TM2	0.24	1.56	113.38	28

The best fit model was:

Cla = 0.143314 + 0.208373 TM2

As observed in Tabel 2 the best remote sensing variable to estimate chlorophyll in this date is the TM2 band. The inclusion of only one TM band into the model can be explained by the high colinearity among this sensor chanels. This high colinearity is related to the poor sensor spectral resolution and to the fact that it is not a sensor designed to study aquatic environment. Its broad bands are suitable for land applications envolving high reflective targets. In spite of this limitations, however, useful data from aquatic environment can be derived.

From the statistic data on Table 3 it can be observed that the model is trustworth since there is no correlated errors and a reasonable R^2 adjusted value.

3.4- Model Extention Assessment

The avarage difference between observed and estimated chlorophyll data was 0.33 mg/m^3. Analysing this difference, it was observed a low underestimate and overestimate to high and low concentratios, respectively.

The surface distribution maps of this situations were nearly similar. In map of estimated concentration it was not observed the highest concentration area.

4.0- CONCLUSION

This study was performed in a cooperation between INPE and Sao Paulo University Oceanographic Institute. The preliminary results identified the Chla as the most important optically active water component, providing a useful methodology to estimate chlorophyll concentration in oligotrophic environment.

The model suggested will be applied for differents seasons in the same area for testing its aplicability, and will be compared with data truth.

Acknowledgments:

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