EUTROPHICATION ASSESSMENT THROUGH REMOTE SENSING TECHNIQUES

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ABSTRACT

This paper reports an experiment developed so as to incorporate TM/Landsat data into an eutrophication assessment system. Barra Bonita reservoir (São Paulo State) was selected as test site mainly because it has a good conventional monitoring program against which the efficiency of the remote sensing monitoring system could be evaluated. Statistical analysis of the Water Quality Index collected in the main tributaries of the reservoir allowed to identify winter time as the critic period in terms of the eutrophication. Three TM/Landsat sets were then obtained for the winter period in three different years: 1984, 1986 and 1988. Those data were digitally processed for reducing atmospheric and illumination variability among them. Changes in macrophyte population and water colour were related to changes in water trophic level.

1. INTRODUCTION

The need for hydroelectric power in Brazil has produced a large number of reservoirs. It is expected that by 2010, Brazil will have over 50000 square kilometers of terrain submerged by the reservoirs. The variety and extension of environmental disturbances related to them are not fully assessed. According to the International Commission on Large Dams the physical and biological effects of dam building are many. Among them, eutrophication represents a major threaten to the water quality. The first symptoms of eutrophication are the excessive development of plankton and macroscopic plants, a reduction in water clarity, changes in water color. The consequences of eutrophication is that the water can not readily be used for domestic and industrial supply because of the taste and odor, propensity for blocking filters and corrosiveness caused by free ions (ICLD, 1980).

In reservoirs, as distinct from natural lakes, the interface between water and land is complex, producing a large variety of water masses within them. There are complex water quality indicators in time and space. There are different nutrient inputs according to the land use, soil type, topography, sanitation schemes. The cost of monitoring water quality in such large and complex aquatic systems using conventional techniques is expensive, and will reach a point of preventing an effective

assessment of the reservoirs status, unless alternative systems are developed.

Although current remote sensing systems are not oriented to inland water monitoring (Tassan, 1987; Tassan, 1988), there are experimental evidences that information on suspended sediment concentration chlorophyll and aquatic macrophytes can be retrieved from TM/Landsat data.

This paper reports preliminary results of a project carried on at Barra Bonita Reservoir with the objective of integrating both "in situ" and remotely sensed data to assess the eutrophication process from 1984 to the present. The Barra Bonita reservoir was selected as test site mainly because it has a good conventional monitoring system against which the efficiency of the remote sensing techniques could be assessed.

2. METHODS2.1 - IMAGE SELECTION

Remotely sensed data used in this study were selected taking into account the seasonal variation of the Water Quality Index (WQI) collected in the main tributaries of the reservoir. The statistical analysis of the WQI allowed to identify the winter time as a critic period in terms of the reservoir's eutrophication process. During the winter there is an increase in the water retention time within the reservoir causing a nutrient concentration in the reservoir (Tundisi and Tundisi, 1988). Three TM/Landsat sets were then obtained for the winter period in three different years: 1984, 1986 and 1988.

2.2 - IMAGE ANALYSIS

The scenes were digitally processed and transformed into reflectance images in which the pixel value can be easily converted into the "apparent reflectance value" (Godoy Jr and Novo, 1989). The reflectance image was then submitted to stripping and haze removal. Reflectance ratios were obtained for 13 sample sites in a selected subscene of 512 by 512 pixels and compared with the existing in situ data. Statistical tests were applied to the reflectance ratios to test the hypothesis that no significant changes were detected in the remotely sensed water quality along time and among the reservoir samples.

2.3 - REFLECTANCE RATIOS

Based on previous findings of Kim and Linebaugh (1985), Tassan and Sturm (1986), Tassan (1988), TM visible bands were applied to obtain reflectance ratios as retrieval variables. The Ratio TM1/TM2 is widely applied in the algorithms for chlorophyll pigment detection and quantification. It is based on the fact that an increase in chlorophyll concentration causes a decrease in the blue reflectance and a shift of the the maximum water reflectance towards the green. So, a decrease in the blue/green ratio can be related to an increase in the chlorophyll content within the water volume. The Ratio TM2/TM3 is not found in the literature as a retrieval variable for suspended sediment. Tassan (1988) has suggested the TM2 as a retrieval variable for sediment or a combination of bands to produce the retrieval variable for sediment concentration meeting the requirement of low sensitivity to both pigment concentration and atmospheric correction uncertainty (Tassan and Sturm, 1986). The ratio TM2/TM3 is based on Moore (1977) findings that, an increase in suspended sediment concentration causes a shift in the maximum water reflectance towards the red and infrared range of the spectrum. In this sense, one would have the same reasoning in comparing the ratios for chlorophyll and sediment: an increase in both of the ratios would imply in an increase in the pigment and in the sediment concentration respectively. A high correlation between the ratios would imply in a high correlation between chlorophyll and sediment concentration.

3. RESULTS

Table 1 presents some water quality parameters for the reservoir during the period under the study. Those data were found in Tundisi and Tundisi (1988) and Calijuri (1988). From 1984 to 1988 there was a decrease in the chlorophyll content, and up to 1986, this decrease is related to a sharp decrease in the primary production. The trophic state, classified in terms of chlorophyll content changed from eutrophic to mesotrophic (Calijuri, 1988). If Sech depth is applied to classify the trophic level, however, the trophic level remains eutrophic during the period. As Sech Depth is readily affected by suspended sediment concentration inputs to the reservoir, which may or may not be related to nutrient increases in the aquatic system, the chlorophyll derived trophic index can be considered more reliable. This decrease in the reservoir Trophic Level can be related to Water Quality Control actions during the period. In fact, if the WQI for the main reservoir's tributaries is analyzed along this period, it is observed an improvement in water standards from 1984 to 1987 (data for 1988 were not available). According to water quality reports (DAEE 1988) 80% of the pollutant load have been removed from Piracicaba and Tiete rivers during this period, what can explain the decrease in the trophic level.

Table 2 presents the reflectance ratios for each sample and for each year, and the related statistics. The analyses of Table 2 indicates a certain variability among the samples. If the spatial change rate from upstream to downstream samples is taken into account, one can observe that there is a decrease in chlorophyll index and in the suspended matter index towards downstream. This change rate can be expressed through the simple linear correlation coefficient between the variable and the upstream distance of each

sample site. These coefficients are -0.50 and -0.49 in 1984, -0.89 and -0.90 in 1986, 0.55 and -0.40 in 1988 for chlorophyll and suspended matter respectively. The stations where in situ water quality data were collected are located in the half way between up and downstream transept. So, from one date to the other their representativeness in terms of the whole water system is variable. The overall decrease in the remotely sensed indices indicates that water optical properties are changing downstream, what is expected since domestic and industrial waste inputs decrease as distance from São Paulo Metropolitan area increases. This trend was not found in 1988 for the chlorophyll index.

TABLE 1

"IN SITU" WATER QUALITY PARAMETER FOR BARRA
BONITA RESERVOIR

YEAR	TSM	CHLOR	PP	SD	TISc	TISs	SOURCE
1984 *	-	10.0	600.0	-	53	-	Tundisi & Tundisi, 88
1986	2.74	2.22	92	1.40	38	55	Calijuri, 88
1988	4.72	5.82	-	1.20	47	57	Tundisi, 89

TSM - Total Solid Matter in Suspension (mg/l)

Chlor - Chlorophyll concentration ("g/l)

PP - Primary Production (mgC/m*day)

SD - Sech Depth (m)

TS - Trophic State

* - for the whole reservoir

Taking into account the average value, one can observe that the ratio variable which indicates chlorophyll concentration presents a slight decrease in value from 1984 towards 1988, what agrees with the in situ trends. The ratio variable indicating suspended matter concentration does not agree with the trend shown by in situ data. Those data indicate an increase in TSM concentration from 1986 to 1988 whereas, the remotely sensed data indicates a decrease.

The differences between remotely sensed indices among the dates however are not sufficient to indicate a real change in water properties. A statistical test applied to the data showed no significant differences in the b/g and g/r ratio values between 1984 and 1986, 1986 and 1988, 1984 and 1988. The TM data sensitivity to changes in chlorophyll and sediment content in this case was not enough to overcome the radiometric and atmospheric correction uncertainties. According to Sydor (1980) the background intensity of the light scattered by the atmosphere and the water surface is comparable to the volume scatter from 3mg/liter of suspended sediment. The differences in the in situ TSM concentration is 3mg/l from one year to the other, are within the insensitivity range of the sensor (Table 3).

TABLE 2
REFLECTANCE RATIOS FOR BARRA BONITA RESERVOIR

	YEAR	1984		1986		1988	
	SAMPLE	b/g	g/r	b/g	g/r	b/g	g/r
Downstream direction ↓	1	0.88	0.82	1.03	0.93	0.84	0.81
	2	0.92	0.83	1.04	0.88	0.84	0.81
	3	0.92	0.84	1.00	0.85	0.84	0.76
	4	0.92	0.80	1.00	0.88	0.80	0.76
	5	0.92	0.84	1.00	0.85	0.80	0.75
	6	0.85	0.82	0.96	0.83	0.80	0.80
	7	0.88	0.82	0.83	0.80	0.80	0.75
	8	0.88	0.78	0.73	0.79	0.80	0.75
	9	0.88	0.82	0.83	0.73	0.80	0.75
	10	0.88	0.79	0.78	0.72	0.88	0.74
	11	0.88	0.83	0.78	0.78	0.92	0.74
	12	0.88	0.82	0.83	0.75	0.88	0.78
	13	0.88	0.78	0.83	0.75	0.88	0.78
	AVERAGE	0.89	0.81	0.90	0.81	0.84	0.77
	CV	2.2	2.4	11.0	7.4	4.7	3.9

TABLE 3
RATIO AVERAGE AND "IN SITU" PARAMETERS

YEAR	b/g	chl	g/r	TSM
1984	0.89	10.0	0.81	-
1986	0.90	2.2	0.81	2.7
1988	0.84	5.8	0.77	4.7

If ratio variables are not sensitive to changes in trophic level along the time, remotely sensed data can still be used to indirectly evaluate the trophic level through the detection of macrophyte infestation in the reservoir. Figure 1 shows the macrophytes distribution in the test site from 1984 to 1988. There was a decrease in the macrophyte stands in the period what can be related to a decrease in the reservoir trophic level.

4. CONCLUSION

Preliminary results indicated that reflectance ratios were not sensitive to changes in the reservoir trophic level from 1984 to 1988. Procedures

suggested by Sydor (1980) so as to increase the sensitivity of remotely sensed data to changes in trophic level is being applied to the data. Macrophyte infestations however can be readily mapped and related to the reservoir trophic state.

Studies are underway in the Barra Bonita Reservoir. Simultaneous remotely sensed data and in situ data are being collected over the reservoir at a larger number of stations and under different environmental conditions so as to assess better approaches to the remote detection of aquatic ecosystem's eutrophication processes.

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Fig. 1 - Macrophyte infestation.