An Examination of Measuring Selected Water Quality Trophic Indicators with SPOT Satellite HRV Data

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Abstract

Concurrent in situ *water quality and* SPOT *(Systeme Pour l'Observation de la Terre) satellite data were obtained for three reservoirs located in north Texas. In situ data included measurement of chlorophyll* a, *pheophytin* a, *total suspended solids, total dissolved solids, and turbidity. The* SPOT *data from locations of water samples were subset and digital data were examined in their raw states as well as numerous transformations. Low but significant correlations were observed between digital numbers and both turbidity and chlorophyll* a. *The degree of correlation was not as great as in previously reported studies using* SPOT *and Landsat data. To be useful for reservoir scale monitoring in north Texas, the techniques still need to be refined sufficiently to detect differences within the range of water quality typically found in the area under study.*

Introduction

Introduction of excessive nutrients and other pollutants into lakes, streams, and estuaries is causing significant change in aquatic environments. The nutrients greatly accelerate the process of eutrophication and cause changes in the flora and fauna of the system by changing the water quality conditions. These changes often interfere with both the uses and aesthetics of the system. Changes related to excessive nutrient loading are a serious problem in many reservoirs and can result in limits on recreational use and increases in water treatment costs (National Research Council, 1992).

Understanding the eutrophication process has improved the ability to manage water as a multi-use resource. Understanding variability of indicators of eutrophication endpoints will improve the ability to monitor water bodies and detect significant changes due to management practices. Successful lake restoration projects such as Medical Lake, Washington (Soltero *et al.*, 1981; Scholz *et al.*, 1985), Lake Washington (Edmondson, 1991), and Shagawa Lake, Minnesota (Larsen *et al.*, 1981) have emphasized the benefits gained from a thorough understanding of the eutrophication process. There is a continuing need to determine effective indicators which will aid in the monitoring of the eutrophication process.

The use of remote sensing systems to monitor both land use and water quality has greatly increased over the past 15 years. Remote sensing systems measure electromagnetic radiance as it varies with spectral wavelength. The result is a spectral signature which can the be used for the estimation of land cover and water parameters that influences light reflectance, absorbance, or backscattering. Ritchie *et al.* (1987) determined that Landsat Multispectral Scanner data can be used to effectively estimate suspended sediments in aquatic systems where the mean annual concentrations were greater than 5.0 mg/L. Lathrop and Lillesand (1986) found significant relationships between Thematic Mapper (TM) data and Secchi disk depth, chlorophyll *a* concentrations, turbidity, and surface temperature in Green Bay and central Lake Michigan. Lathrop and Lillesand (1989) also found significant correlations of SPOT-1 multispectral data with the same water quality parameters, with the exception of temperature, not measured by the SPOT-1 system. Both Lillesand *et al.* (1983), using Landsat multispectral scanner data, and Wezernak *et al.* (1976), using low altitude multispectral scanner data, determined that remotely sensed data could be used to effectively predict the trophic status of inland water bodies. Lavery *et al.* (1993) concluded that Landsat TM may have the accuracy and resolution to be useful in the monitoring of estuarine waters, but that data acquisition and cloud cover limit its temporal usefulness. These authors also found that radiometric studies show little usefulness in determining taxonomic composition of the phytoplankton communities in coastal waters.

The objective of this study was to determine the efficacy of using SPOT data for measuring the trophic status of reservoirs and lakes in north Texas. Ideally, remotely sensed data could be used to monitor trophic status at multiple points in a reservoir. A trophic status map of the reservoir could be produced, and used to monitor changes over time. However, to be useful for monitoring purposes, a "Trophic Map" must represent statistical differences across the water reservoir at one point in time, and statistical differences at one location over time. To meet this objective, selected trophic indicator data were collected from three reservoirs in a drainage basin of north Texas (Figure 1).

Methods

Triplicate surface water samples were collected at 24 sites on Ray Roberts Lake, seven sites on Lake Kiowa, and seven sites on Lewisville Lake. Collections were made on 20 July 1989. Sampling locations were limited to areas captured in the satellite image (HRV 1 585-283: N33°25', W79°01'). Surface water samples were collected concurrently with time of satellite overpass (plus or minus 0.5 hours). Water samples were

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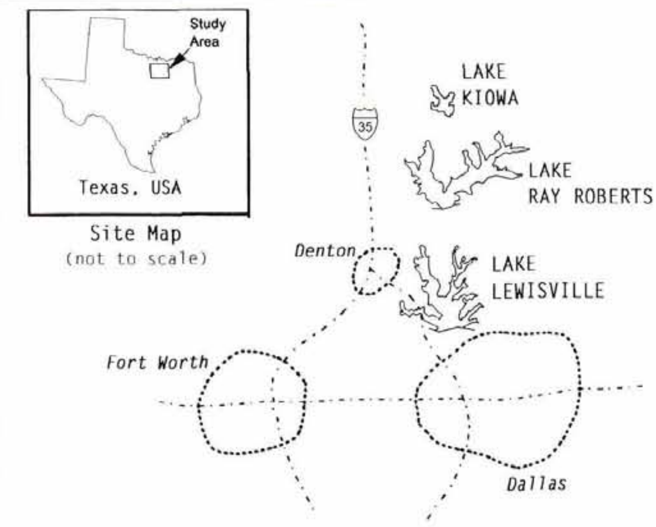

Figure 1. Location of study area in north Texas.

placed on ice in the field and returned to the laboratory for analysis. Water quality analysis included chlorophyll *a*, pheophytin *a*, total suspended solids, total dissolved solids, and turbidity following methods of the American Public Health Association (1985).

HRV digital data from the SPOT image were analyzed at the Center for Remote Sensing and Landuse Analysis (CRSLA) at the University of North Texas using Earth Resource Data Analysis System (ERDAS v7.2) software. The mean of a 5- by 5-pixel group was derived for each of the three wavelength bands at each sampling site to insure encompassing the sampling site within the 25-pixel group. Digital data, along with multiple band ratio transformations of the digital data, were examined. Multiple regression and canonical correlation were performed on the water parameters and digital values for each of the three bands and numerous band ratios.

Results and Discussion

An examination of the statistical relationship among the water quality variables found a positive correlation of 0.72 between turbidity (Tur.) and chlorophyll *a* (Chl.) (Table 1). This relationship, in conjunction with a weak relationship of turbidity to total suspended solids (0.36), suggested that most of the turbidity in these three reservoirs was dependent on the phytoplankton biomass. These findings, while not as strong, are similar to Lathrop and Lillesand (1989) findings of a strong correlation (0.942) between turbidity and chlorophyll *a*. Log transformations of water parameters did not improve any of the relationships.

Examination of the correlation matrix among SPOT band digital values shows a high relationship between all pairs of bands. These correlations ranged between 0.92 and 0.99 (Table 1). The lack of difference among the bands implies that the green wavelength band (Band 1: 0.50 to 0.59 μm), red wavelength band (Band 2: 0.61 to 0.68 μm), and near infrared wavelength band (Band 3: 0.79 to 0.89 μm) either did not change significantly at any site or changed similarly at all sites. Lathrop and Lillesand (1989) reported high correlation (r^2) between Bands 1 and 2 (0.902), but weaker correlations (0.541 and 0.74) for the other two relationships.

The correlation of water parameters with SPOT digital values (Table 1) shows only weak relationships. Total suspended solids (TSS) and total dissolved solids (TDS) ranged from 2 mg/L to 41 mg/L and 126 mg/L to 229 mg/L, respectively, but were both completely unrelated to changes in all bands. Turbidity's highest correlation was with Band 2 (0.66), but had similar relationships to Band 1 and 3. Chlorophyll *a* followed the same trend as turbidity with its highest correlation also occurring with Band 2 (0.56). This similar trend was expected as it appeared that the predominant source of turbidity was in the phytoplankton biomass.

Table 1. Correlation Coefficients (r) among the Water Parameters and Digital Values for Ray Roberts, Lewisville, and Kiowa Lakes on 20 July 1989

	TSS	TDS	Tur	Chl	Phe	Band 1	Band 2	Band 3
TSS	1.00							
TDS	−0.08	1.00						
Tur	0.36	0.02	1.00					
Chl	0.19	0.22	0.72[a]	1.00				
Phe	−0.38	0.10	−0.35	−0.38	1.00			
B-1	0.10	0.10	0.57[a]	0.48[a]	−0.15	1.00		
B-2	0.01	0.07	0.66[a]	0.56[a]	−0.19	0.92[a]	1.00	
B-3	0.02	0.08	0.62[a]	0.54[a]	−0.16	0.95[a]	0.99[a]	1.00

$n = 38$
[a]significant at $\alpha = 0.05$

Moore (1980) found that the longer wavelengths comprising Bands 2 and 3 had a high response to phytoplankton and suspended sediments. Lathrop and Lillesand (1989) determined that Bands 2 and 3 exhibit poor correlation with turbidity less than 4.0 NTU and total suspended solids less than 10 mg/L, but showed a strong response to higher levels. They reported, however, that the ratio Band 2/Band 1 was more sensitive to the lower concentrations.

Applying the Band 2/Band 1 ratio did not improve the relationship with chlorophyll *a* in the north Texas reservoirs. Additional band combinations were examined to determine if more significant relationships could be uncovered. Combinations tried were Band 2 + 1, Band 2 + 3, Band 1 + 3, Band 1 + 2 + 3, Band 2/1, Band 3/1, and Band 3/2. In no case did correlation coefficients increase above the single band relationship, which was not surprising due to the high correlation of the bands with each other.

Canonical correlation analysis of water parameters (Table 2) shows that turbidity and chlorophyll *a* contribute 0.91 and 0.76, respectively, to the changes in the first (best) canonical water variable. This relationship is in agreement with the results of the regression analysis in which turbidity and chlorophyll *a* had a correlation coefficient of 0.72. The second canonical variable shows a lesser relationship between total suspended solids and turbidity with contributions of 0.90 and 0.38, respectively. The third canonical variable shows the least influential relationship where total dissolved solids and pheophytin concentrations contribute 0.42 and 0.75 to changes in the variable.

Canonical correlation of the band values and the first canonical variable (Table 3) again shows the dominance of Band 2 and the high level of agreement with the other bands. This is pointed out by the fact that the lowest correlation in

Table 2. Canonical Correlation among the Water Parameters and their Canonical Variables.

	Variable 1	Variable 2	Variable 3
TSS	−0.03	0.90[a]	−0.31
TDS	0.05	0.29	0.42[a]
Tur.	0.91[a]	0.38	−0.01
Chl.	0.76[a]	0.22	0.25
Pheo.	−0.31	−0.13	0.75[a]

$n = 38$
[a]significant at $\alpha = 0.05$

Table 3. Canonical Correlations among Digital Values and their Canonical Variables.

	Variable 1	Variable 2	Variable 3
Band 1	0.75[a]	0.55[a]	0.37[a]
Band 2	0.93[a]	0.21	0.30
Band 3	0.87[a]	0.24	0.42[a]

$n = 38$
[a]significant at $\alpha = 0.05$

the first canonical variable was only 0.75. The remaining canonical band variables show no relationship of any great degree. These relationships indicate that Band 2 was not only the most influential, but was so similar (in its changes) to the other bands that it was given the highest weight in subsequent analysis.

Canonical correlations between the water parameters and the first 'M' canonical variable of the band values emphasizes turbidity as the primary parameter for response to changes in band reflectance values. Almost 70 percent of the variance associated with changes in band values can be attributed to turbidity (Table 4). Turbidity, however, is influenced by suspended sediments as well as the plankton densities. Total suspended solids were consistently low in all three lakes, averaging only 8.53 mg/L. The correlation between TSS and turbidity was 0.36, indicating that only a small proportion of the turbidity could be attributed to suspended solids. The higher correlation of turbidity with chlorophyll *a* (0.72) (Table 1) indicates that the suspended solids are likely to be comprised primarily, but not completely, of plankton biomass. Even though canonical correlations show turbidity to be the water quality parameter which most influences changes in band values, it still has the potential of being influenced by both suspended sediment and plankton biomass, limiting its usefulness as a monitoring tool. Chlorophyll *a*, on the other hand, is useful as a monitoring tool because of its aesthetic (color of water) and ecological importance, as well as being the most often predicted endpoint in eutrophication models. However, in our study area, chlorophyll *a* only showed a correlation of 0.56 or lower to SPOT data, limiting our ability to utilize satellite data for measuring this important water quality parameter.

Conclusions

The goal originally set out in this research effort was to determine if SPOT imagery could be used as a surrogate for water quality measurements in north Texas reservoirs. The data analyzed indicated that, while there was a significant correlation between SPOT digital data and both turbidity and chlorophyll *a*, the correlation was too low for satellite imagery to be of practical use as a monitoring tool by itself. Band 2 of the SPOT data had the best correlation to the water quality parameters, which supports Lathrop and Lillesand's (1989) results. Band ratios did not provide better correlations for the north Texas reservoirs, nor did we find correlations as high as Lathrop and Lillesand did in the Green Bay embayment of Lake Michigan or that Lavery *et al.* (1993) did in estuarine waters in Australia. The reported correlation coefficients of 0.74 (Verdin, 1985) to 0.98 (Lathrop and Lillesand, 1983) between digital data and chlorophyll *a* point to the usefulness of monitoring water quality with digital data. The correlation in this study (0.56) between digital data and chlorophyll *a* is too weak a relationship to be used as a surrogate of water quality measurements in north Texas reservoirs. To be useful for reservoir scale monitoring, the techniques still need to be refined sufficiently to detect differences within the range of water quality typically found in the area under study.

Table 4. Squared Multiple Correlations among the Water Parameters and the First 'M' Canonical Variables of Digital Values.

	M Band Variable 1	M Band Variable 2	M Band Variable 3
TSS	0.00	0.06	0.07
TDS	0.00	0.01	0.07
Tur.	0.69[a]	0.11	−0.02
Chl.	0.58[a]	0.06	0.04
Phe.	−0.23	−0.04	0.13

$n = 38$
[a]significant at $\alpha = 0.05$

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