Multi-Spectral Remote Sensing for Evaluating Chl.-a of Water Body

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1.INTRODUCTION

Remotely sensed data processed to spectral reflectance can provide spatial maps of wide scaled regional natural environments or digital indices (RVI, NDVI, PVI, etc.) to be used in "Modeling", and also has been the most suitable method for periodically monitoring natural environments. Additional in situ sampling and spectral reflectance can aid in verification of satellite analysis. In this study, we focused on the variations in spectral responses of chlorophyll-a content water body, and its distribution & flow pattern before and after purification operations. However, quantitative analysis of remotely sensed data has been difficult in terms of various water quality parameters. Also, the radiometric features of lake water principally depend on several optically active water components. Those components vary its proportion in composition and concentration with changes in time and weather, and induce a high variability of lake water optical properties. The lake water may produce chlorophyll-a (referred to as Chl-a) and additional dissolved organic matter transformed from bordering area. Therefore, to reduce the above mentioned unwanted disturbances and to emphasize the spectral response of satellite band data, a specially combined radiometric correction was applied to both original sets of Landsat Thematic Mapper (referred to as TM) band data used in this study. Further, for well estimation and verification, the data from several field campaigns were synchronized with the satellite observations.

2. STUDY SITE

Lake Inbanuma with an area of 11.55 km^2 is located approximately 40 km northeast of the Tokyo metropolitan area. Lake Inbanumuma is formed by two reservoirs, the northern and the western water control reservoirs. These two reservoirs are mutually connected by a channel. The catchment area, which includes 7 cities, 6 towns, and 2 community villages is approximately 514 km^2. Five branch rivers, all originating from the Tone River flow into the western reservoir. The inflow water of this lake mainly comes from rainfall and pumping up from the Tone River. The final destination of outflow from the Ohwada Pump House is Tokyo Bay, while that of the SakanaoSluice Gate passes through the Inba Pump House into the Tone River. However, chronic pollution of Lake Inbanuma by human initiated drainage, algae or aquatic vegetation has been discussed as a regional environmental issue. Also, it has been reported that over all water quality on average is much worse in the northern reservoir then

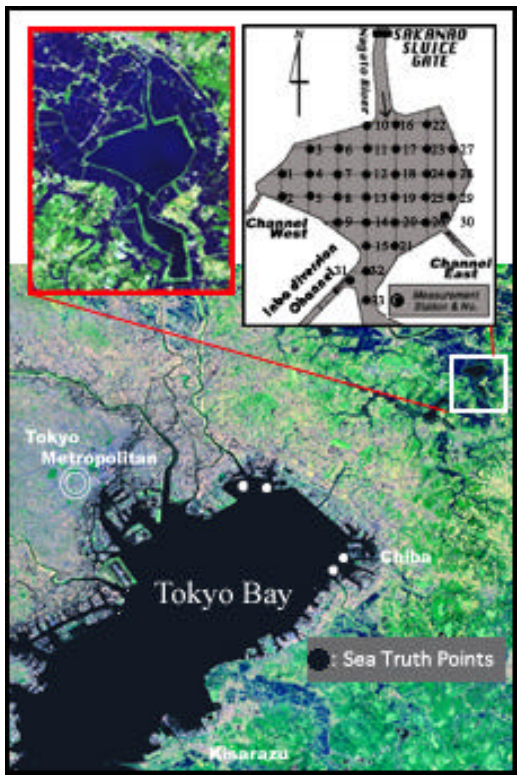

Plate 1 *Landsat composite imagery featuring geological location of study area and its vicinity in Northwestern Chiba, Japan.*

in the western reservoir. Therefore, since 1985, for purification, the "open-and-shut operation" that discharges lake water down two diversion channels has been periodically attempted at several plural sluice gates. Plate 1 shows Geological location of the Inbanuma as a study area and its vicinity in Northwestern Chiba, Japan.

3.METHODOLOGY

3-1. Field Measurement of Spectral Features of High Chl-a Content Water

Reflectance spectra varied substantially in overall magnitude as well as in curve forms related to wavelength dependent absorption patterns and their interplay with particle scattering (Schalles, Gitelson, and et al., 1998). Field measurements has carried out using pond water in our campus, which is consisted in high concentration algae laden based Chl-a water. In General, the spectral ratio (NIR/VR) of near infrared (NIR) and visible red (VR) bands was principally employed to evaluate the regional vegetation. Also, it has been discussed and

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水環境における Chl-a が示す分光スペクトル特性のリモートセンシング

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determined whether it is a suitable band combination for water quality assessment. Figure 1 shows spectral reflectance curves of model water (water containing artificial Chl-a) made from distilled water and various concentrations of chlorella powder. The prominent optical features correlating with high Chl-a content were the absorption maximum at 675 nm and the reflectance peak around 720 nm. Also it was found that those specific features appeared above approximately 100 $\mu g/\ell$ of Chl-a concentration. Therefore, in the case of hyper trophic water region with more than 100 $\mu g/\ell$, the spectral ratio (RVI) of near infrared (NIR) and visible red (VR) bands can be useful in classifying water regions with high Chl-a content. In the case of below of that, the Gordon method can be the most suitable one.

3-2. Field Campaign by the Synchronized Site-Surveying

The best season for field campaigns to assess the trophic state is during the bioproductive season that starts in May and runs through June (Oki, Yasuoka, and Tamura, 2001). Routine drainage operation by local government was conducted on June 4, 2005. Based upon finding of filed test, on June 4 (48 hours after the operation), a field campaign by five teams was carried out at 33 field measuring points in the Inba northern reservoir. All water samples were immediately stored in a dark cooler and transported to the laboratory as quickly as possible (within a few hours). Chl-a concentrations were determined by the 90 % acetone extraction and tissue grinding method, which is the generally excepted method for quantify Chl-a content in the chemistry and biology fields (Gilpin and Tett, 2001). Also, given data were verified by using the TD-700 Laboratory Fluorometer. The field spectra was measured with the FieldSpec Pro Spectrometer against a halon white board using an 8 degree fore optic. One team in a boat guided by a GPS system was in radio contact in order to synchronize taking of measurements. The synchronized site-surveying method advocated in our previous study (Fujii, Ohki, and et al., 2000) has an advantage in that it allows measuring conditions, such as weather, time and other conditions to be almost synchronized. Therefore, results from the synchronized site-surveying can be evaluated in parallel.

3-3. Field-measured Chl-a and Field Spectra

The average of Chl-a concentration at the was 98.2 $\mu g/\ell$, and also highest is 168.9 $\mu g/\ell$. The correlation of spectral features (NIR/VR) to measured levels of Chl-a was shown in Figure 2. This simple spectral ratio (RVI) yielded a linear correlation with an r of about 0.90. Therefore it can predict Chl-a in eutrophic lakes with a high degree of accuracy. Based upon these correlations, the field spectral ratio RVI provided us the most suitable band combination of TTM data for classifying if Chl-a concentration above 100 $\mu g/\ell$, and also Gordon method if that of below 100 $\mu g/\ell$.

4. Assessment of the Trophic State Index

Previous TSI_{CHL} studies by Thiemann and Kaufmann presented very similar tendency. A frequently used biomass-related trophic state index

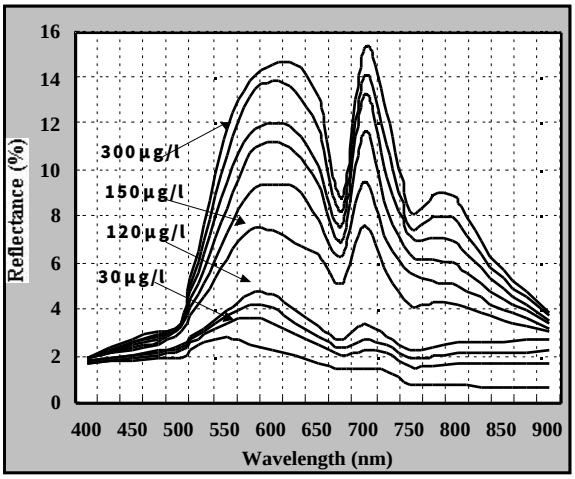

Figure 1 *Spectral reflectance features of high Chl-a. content water body shows remarkable differences in curves and also specific features appeared above approximately 100 $\mu g/\ell$ of Chl-a concentration.*

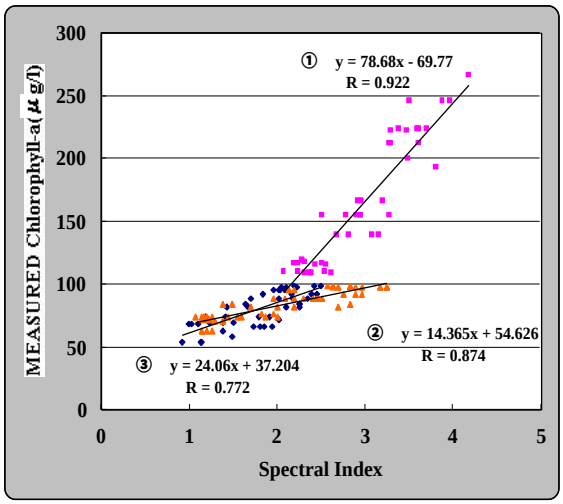

Figure 2 *Spectral reflectance features from site surveying, with comparison between RVI method and Gordon method.*

is that of Carlson, established on 1977. The Carlson's Trophic State Index (hereafter TSI) is a tool used to summarize several measurements of water quality into one index value which can be used to compare a lake to other lakes, or to historic/future data as a measure of degradation or improvement (Carlson, 1977). Three variables, Chl-a concentration, Secchi disk depth, and total phosphorus, were commonly used. In accordance with the definition of Carlson's trophic state and his formula from his previous studies, Chl-a based TSI (hereafter TSI_{CHL}) was simplified as follow;

$$TSI_{CHL} = 9.81 \ln (\text{Chl-a}) + 30.6 \qquad (1)$$

The range of TSI_{CHL} is approximately 0 to 100. From computation results, the standard deviation for Chl-a determined by field spectra is about 7 $\mu g/\ell$ (Thiemann, Berger, and Kaufmann, 1998). Low Chl-a concentrations between one to 7 $\mu g/\ell$ resulted in TSI_{CHL} of 30.5 and 50.1. On the contrary, TSI_{CHL} varied only between 77.9 and 82.6 at high Chl-a concentration of 90 to 170 $\mu g/\ell$.

5. Transformed Landsat TM Data

5-1. Pre-performing for Landsat Original data sets

Earlier studies showed that various phenomena are often found to be subtle and elusive. Particular characteristics at the water level often make image processing difficult due to several disturbances that stem from the image acquisition process even the basic principal geometric correction was already performed by regional distributor. Principal intent of additional image rectification and restoration is to correct the original image data for distortions or degradations that stem from the image acquisition process. Hence, additional digital rectification or restorations (see 1-4 below) were applied to TM original data sets (hereafter TTM; transformed TM), when was acquired on May 24, 2000 and June 4, 2005 respectively. Further, the Suspended Particle Matter (hereafter SPM) concentration for atmospheric correction has been periodically measured at four stations of the Atmospheric Environmental Monitoring Section of local Government Office. Given the average SPM concentration during 9 am to 10 am (approximately on-time with Landsat TM observation) on June 4, 2005 was 48.12_g/m^3.

1) combined radiometric correction including atmospheric correction ; to correct for haze with the aim of improving visuality
2) geometric correction to grasp accurate coordinates of site-surveying points
3) line-noise removal procedure with smoothing
4) brightness normalization for parallel evaluation using the plural data sets,

5-2. Trophic State from Landsat TTM Analysis

As mentioned above, based on the results from filed measurements and synchronized site-surveys, The regional trophic state distribution of Inbanuma on the respective dates was shown in Plates 2. From the TSI_{CHL} imageries of May 24, 2000 and June 4, 2004, the direction and pattern of lake water flow was distinctly visualized. Further, the TSI_{CHL} was classified into 8 levels of the status of water body.

May 24, 2000;

Flow just started at the pump and all gates. The TSI_{CHL} (2000) image indicates the hypertrophic state (high Chl-a concentration) in both reservoirs persists. The gradual transportation of hypertrophic water in the northern reservoir toward the western reservoir through the Inba diversion channel can be identified.

June 4, 2005;

Judging from the color pattern of the TSI_{CHL} (2005) image, the trophic state under went dynamic change. That of 2005 scene indicates that the purification campaign of slow but continuous flow at the Sakanao sluice gate was successfully carried out.

6.CONCLUSION

1) Figure 3 shows correlation between Chl-a of measured and estimated. It was nearly in direct proportion, and good agreement.
2) The process shows promise as a remotely sensed method for water quality monitoring. As a further verification of the ability of NIR/VR, the newly spectra investigation of high Chl-a content water has been periodically carried out at small pond with persistent algae in our college site since early 2004. These stored data and analyzed results provide the strong bases for process of satellite analysis.
3) Estimated Chl-a concentrations from satellite analysis using well-converted TTM data were verified by measured Chl-a from the synchronized field campaign. The lake's entire TSI_{CHL} distribution can be consequently visualized. This encourages the multi-temporal comparison of TTM data sets.
4) High resolution satellite images can be ideally suited to monitor water flow behavior. So that various information, such as direction of flow, relative difference in turbidity and location of pollutants can be provided. Also, continuous accumulation of digitally analyzed satellite data may help us determine the optimal time to discharge for purification, and would be a remarkable tool providing much needed evidence toward the effort for prevent other illegal environmental destruction factors, particularly industrial or domestic waste disposal.

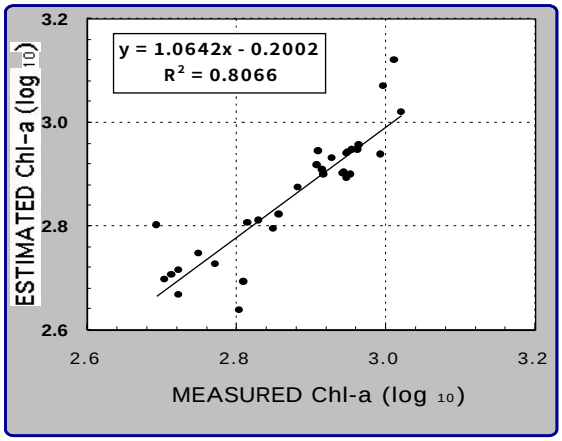

Figure 3 *Comparison between chl.-a concentration of measured and estimated shows good agreement.*

ACKNOWLEDGEMENTS

We would like to express our sincere thanks to: Dr. Y. Ogura of Chiba Prefecture for her contributing the model water analysis and molecularchemical experiments of sample water and, Dr. J.C. Dozier of the University of California for his appropriate suggestions. We also thank the many undergraduate students at the Nihon University, Survey Laboratory who made valuable contribution.

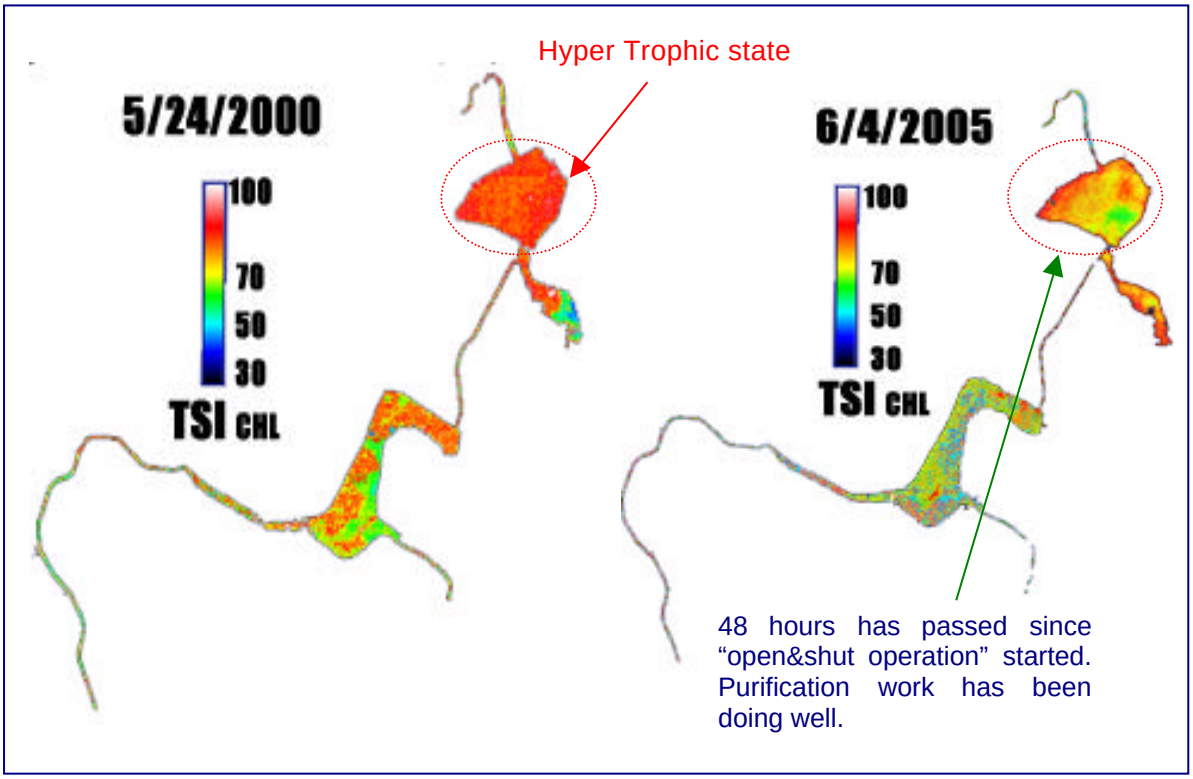

Plate 2 The regional difference of the TSI_{CHL} on May 24, 2000 shows the status at one hour after starting the "Open-and-Shut" operation, and that of the TSI_{CHL} on June 4, 2005 also shows remarkable efficacy of purification operation.

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