

FEASIBILITY STUDY OF TOC AND C/N RATIO ESTIMATION FROM MULTI-SPECTRAL REMOTE SENSING DATA

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ABSTRACT:

The origin of Suspended Solid (SS) in brackish lakes is mainly divided into the plankton in water, fine clastics with terrestrial organic fragment in river water, and reworked sediments from lake bottom. Total Organic Carbon (TOC) content and mass ratio of Carbon to Nitrogen (C/N ratio) in the suspended substance in the lakes have been known to be different depending on the origin. It is expected that the origin of the Suspended Solid can be estimated by the TOC content and C/N ratio measurements. A feasibility study is conducted to estimate the TOC content and the C/N ratio of a brackish lake by using a series of data measured by a spectroradiometer, and the possibility to estimate the origin of SS is studied. Four types of wavelength selection are attempted for multiple regression analysis to estimate TOC content and C/N ratio, including the simulation of SGLI sensor planned to be onboard the GCOM-C satellite. As a result, it is found that the origin of the SS in the brackish lake can be estimated to some extent by multi-spectral visible remote sensing of TOC content and C/N ratio.

1. INTRODUCTION

Many coastal brackish lakes in the world suffer from water quality deterioration due to dense interactions between the lakes and surrounding land areas. Until now, various trials have been conducted to observe and monitor water quality and related parameters using remote sensing techniques (e.g. Sakuno et al., 2002; Oyama et al., 2009). However, the remote sensing of turbidity does not provide the information on the origin (cause) of the turbidity.

Suspended Sediment (SS) is a major contamination source of such water areas. SS consists of organic and inorganic matters caused mainly by the following three sources; (a) SS caused by planktons in water (SSp), (b) SS of fine clastics with terrestrial organic fragment in river water flowing into the lakes (SSr), and (c) SS caused by reworked sediments from lake bottom (SSb). It has been suggested from water analyses of brackish lakes that Total Organic Carbon (TOC) content and the mass ratio of organic carbon to total nitrogen (C/N ratio) in such lake areas depend on the above mentioned materials from different sources. In addition, it has been recognized that waters dominated by SSp, SSr or SSb have somewhat different colors when examined visually. These findings suggest that multi-wavelength visible remote sensing could be used to estimate TOC content and C/N ratio by some techniques. If such attempt is successful, it becomes possible to estimate the cause of SS and turbidity in the lakes, which could then be used for various scientific and operational purposes.

In this paper, the feasibility of the remote sensing of TOC content and C/N ratio is studied using the spectral reflectance data obtained from spectroradiometer and in-situ data samples in Ohashi river connecting Lakes Shinji and Nakaumi, Shimane Prefecture Japan. These estimation may provide the information about the origin of SS in the lakes. In the following sections, we describe the characteristics of TOC content and C/N ratio, estimation methods, results of the estimation, and the evaluation of the result.

2. PROPERTIES OF TOC AND C/N

It has been shown that in brackish lakes, TOC content and C/N ratio of SS depend on its origin (Bordowskiy, 1965a, 1965b; Müller, 1977; Prahl et al., 1980; Ertel and Hedges, 1984; Hedges et al., 1986; Sampei and Matsumoto, 2001) as summarized in Table 1.

Origin of SS	C/N (Mass ratio)	TOC [%]
Plankton (SSp)	5~6	20~40
River water (SSr)	15~90	5~6
Bottom sediment (SSb)	6~8	0.5~3

Table 1. C/N ratio and TOC content in SS from major origins.

When SSp is dominant, C/N ratio and TOC content follow the composition of phyto-plankton. High C/N ratio in SSr is caused by the fact that the organic material in SSr is dominated by plants over land which contain much cellulose having less nitrogen. Relatively low TOC content in SSr stems from high concentration of inorganic materials in SSr. TOC content in SSb is the lowest in the three type of SS. This is because inorganic materials from rivers are accumulated in the bottom sediment. Since SSb contains dead phyto-plankton, C/N ratio of SSb becomes similar to that of SSp. Utilizing these differences in C/N ratio and TOC content, we can estimate the origin of SS in brackish lakes.

3. OBSERVATION

Spectroradiometer (Opt Research Inc., HSR-8100) observations along with in-situ water sample acquisitions have been conducted in Ohashi River connecting Lake Shinji and Nakaumi (133°04'E, 35°28'N). Between November 2007 and July 2008, 16 samples were obtained. Examples of spectral reflectance are shown in Figure 1 for the case where C/N or TOC takes its maximum value. As found from this figure, spectral shape is significantly different depending on samples. It was found that correlation coefficients between C/N and spectral reflectance and between TOC and spectral reflectance have large wavelength dependences with the maximum values

of about 0.5. Similarly, it was also found that the “sensitivity” of reflectance to the changes in C/N ratio and TOC content has significant wavelength dependence. These results suggest that by using spectral reflectance at multiple wavelengths can provide better estimation of C/N ratio and TOC content.

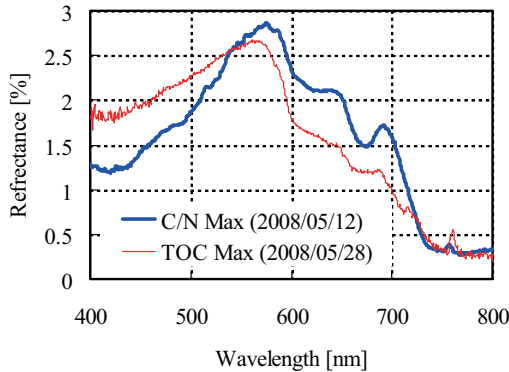


Figure 1. Examples of reflectance spectrum when C/N or TOC takes its maximum value among the 16 samples.

4. MULTIPLE REGRESSION ANALYSIS

4.1 Wavelength selection

C/N ratio and TOC content are estimated by using multiple regression analyses. Wavelengths for the regression analyses are selected using the following four methods:

- (1) Max-min-based method: This method uses several wavelengths at the local maximum or minimum of the reflectance spectrum when TOC content or C/N ratio from in-situ water sample analysis takes the maximum value. The resulting five wavelengths are 562, 576, 675, 684, and 692 nm.
- (2) Maximum correlation method: Simple correlation coefficients between TOC content or C/N ratio and spectral reflectance are found to have significant wavelength dependence. This method uses several wavelengths at which the correlation coefficient takes local maxima. The resulting six wavelengths are 538, 600, 605, 634, 708, and 720 nm.
- (3) Maximum difference method: This method uses the “differential reflectance spectrum”, which is the difference in reflectance spectra when TOC content (or C/N ratio) obtained from in-situ water sample analysis takes their maximum and minimum values. It is expected that the differential reflectance spectrum is a measure of “sensitivity”. Wavelength selection is made in such a way that the absolute values of differential reflectance spectra take their local maxima. The resulting five wavelengths are 582, 598, 641, 691, and 696 nm.
- (4) SGLI simulation method: In this method, observations with the SGLI onboard the GCOM-C satellite which will be launched in FY2013 (JAXA, 2010) are simulated by averaging the spectroradiometer data over the 10 or 20 nm bandwidth of the visible channel of SGLI. We postulate the use of VN3 (443 nm, Δλ = 10 nm), VN4 (490 nm, Δλ = 10 nm), VN5 (530 nm, Δλ = 20 nm), and VN7 (673.5 nm, Δλ = 20 nm) channels.

4.2 Multiple regression models

By making multiple regressions of in-situ-obtained TOC content or C/N ratio versus reflectance values at the wavelengths described above, model equations are obtained. Some of the equations are shown below. In the equations, *y* represents TOC content or C/N ratio, and *r_{nmn}* represents the reflectance at the wavelength *nmn*.

Max-min-based method:

(a) TOC estimation

$$y = 67.5r_{562} - 86.3r_{576} + 50.7r_{675} - 24.6r_{684} + 11.7r_{692} + 22.2 \tag{1}$$

(b) C/N estimation

$$y = 5.48r_{562} - 6.96r_{576} + 4.40r_{675} - 10.23r_{684} + 9.09r_{692} + 6.08 \tag{2}$$

For other methods, similar model equations are also derived.

4.3 Comparison of estimation accuracy

Estimation accuracies of TOC content and C/N ratio from the four multiple regression models are examined using the adjusted multiple regression coefficient and RMS errors between observed and estimated values of TOC content and C/N ratio. Table 2 lists the comparison of estimation accuracies by the four methods.

Estimated quantity	Estimation method	Adj. multiple corr. coeff.	RMS error
TOC content (%)	(1) Max-min.	0.55	5.56
	(2) Max correl.	0.60	4.99
	(3) Max difference	0.75	4.62
	(4) SGLI simul.	0.34	6.58
C/N ratio	(1) Max-min.	0.84	0.18
	(2) Max correl.	0.50	0.28
	(3) Max difference	0.50	0.30
	(4) SGLI simul.	0.45	0.32

Table 2. Summary of estimation accuracy (adjusted multiple correlation coefficient and RMS error).

As shown in Table 2, the maximum difference method gives the best estimation accuracy for TOC content, while the max-min-based method gives the best accuracy for C/N ratio. Figure 2 shows the correlation between estimated and observed values of TOC content using the maximum difference method and between estimated and observed values of C/N ratio using the max-min-based method. These indicate that reasonably good estimations are obtained both for TOC content and C/N ratio.

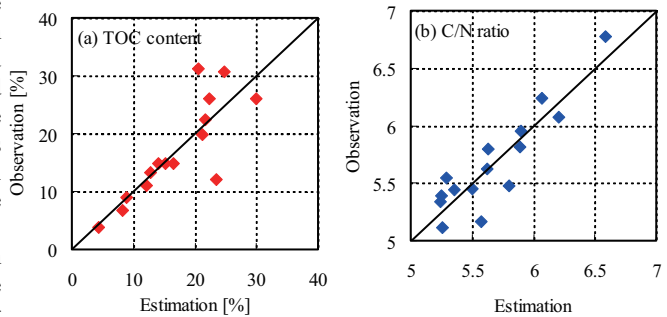


Figure 2. Correlations between estimated and observed values of TOC content and those of C/N ratio. Thick solid lines indicate the perfect correspondence between estimated and observed values.

5. ESTIMATION OF ORIGIN OF SS

A goal of this study is to estimate the origin of SS for deeper analysis of the water quality assessment of brackish lake through the combination of TOC content and C/N ratio estimates. To evaluate the feasibility to achieve this goal, it is required to estimate the accuracy of the estimates more rigorously. For this purpose, we calculate 95% confidence

interval estimates of TOC content and C/N ratio. The confidence interval of TOC content ranges between 5 and 16% depending on the estimation method and samples. When compared with Table 1, it is suggested that the accuracy of TOC estimate is marginal to discriminate SS_p from SS_b. In contrast, the confidence interval of C/N ratio, ranging between 0.2 and 0.8, is sufficiently accurate to discriminate SS_p or SS_b from SS_r.

In order to show the feasibility of estimating the origin of SS clearly, C/N versus TOC diagram is plotted in Figure 3. In this figure, three ellipses indicated as “plankton”, “river water”, and “bottom sediment” show approximate ranges of TOC content and C/N ratio for SS_p, SS_r, and SS_b, respectively. Observed values are shown by ×, and estimated values are shown by ◆ with 95% confidence interval as vertical and horizontal bars.

It is found that observed and estimated values scatter between SS_p and SS_b, suggesting that they mainly consist of SS_p and SS_b. As mentioned above, however, quantitative ratio of SS_p to SS_b appears to be difficult to estimate because of the large estimation errors of TOC content. In contrast, the discrimination of SS_r from SS_p or SS_b could be made accurately because the C/N ratio of SS_r is much larger than the confidence interval of C/N ratio estimation. In the case of SGLI simulation (not shown in Figure 3), estimation accuracies are somewhat worse than other methods; however, at least the discrimination of SS_r from others should be possible.

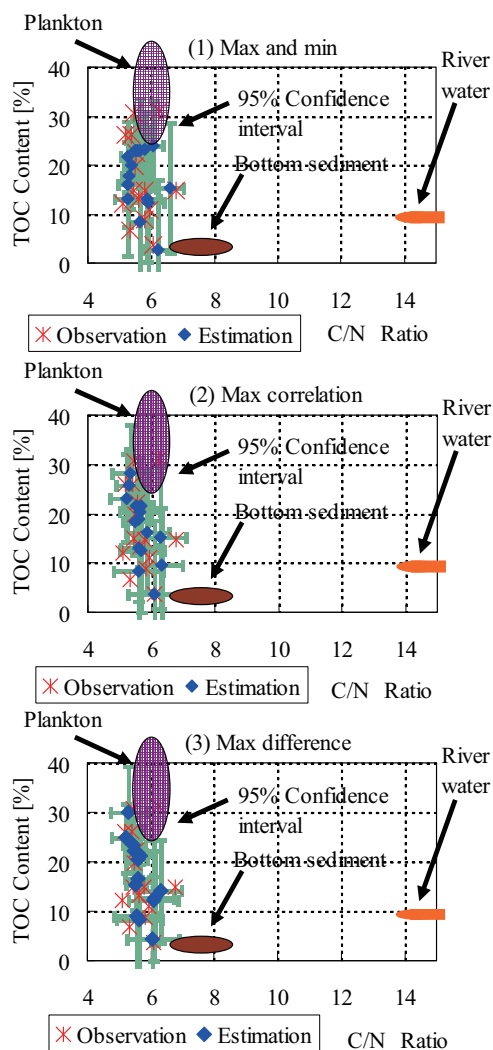


Figure 3. C/N ratio versus TOC content diagram.

6. CONCLUSION

In this paper, we described a feasibility study to estimate TOC content and C/N ratio in a brackish lake in order to connect the result to the estimation of the origin of SS, because TOC content and C/N ratio in SS depend on its origin; that is, the plankton in water (SS_p), fine clastics with terrestrial organic fragment in river water (SS_r), and reworked sediments from lake bottom (SS_b). For this study, spectral reflectance data measured by a spectroradiometer as well as TOC content and C/N ratio derived from water sample analyses were used. Four types of wavelength selection method were attempted for multiple regression analysis to estimate TOC content and C/N ratio; that is, (1) max-min-based method, (2) maximum correlation method, (3) maximum difference method, and (4) SGLI simulation method. Estimation accuracy was evaluated from multiple correlation coefficients, RMS error, and the width of 95% confidence interval of estimated TOC content and C/N ratio. It was shown that the method (3) provides the best accuracy in the TOC estimation, while the method (1) is best for the C/N estimation.

From the evaluation of estimation accuracies shown above, it was concluded that the extraction of SS_r is possible from the difference in C/N ratio. On the other hand, the discrimination of SS_p from SS_b is marginal because of the insufficient accuracy in TOC content estimation. Nevertheless, these results suggest that multi-spectral remote sensing has a possibility of estimating TOC content and C/N ratio that are useful parameter to make detailed analyses of the cause of SS distribution in brackish lakes.

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