FEASIBILITY STUDY FOR THE ESTIMATION OF CHLOROPHYLL-A USING MEASURED SPECTRAL REFLECTANCE IN THE EUTROPHIC LAKE -LAKE KOJIMA CASE STUDY IN FY2009

Y. Sakuno [a, *], N.Nishi [a], T. Tachikawa [b]

[a] Graduate School of Engineering, University of Hiroshima, 1-4-1 Kagamiyama, Higashi-Hiroshima, 739-8527, Japan - sakuno@hiroshima-u.ac.jp, m102873@hiroshima-u.ac.jp
[b] Graduate School for International Development and Cooperation, University of Hiroshima, 1-4-1 Kagamiyama, Higashi-Hiroshima, 739-8527, Japan -m100130@hiroshima-u.ac.jp

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KEY WORDS: spectral reflectance, water quality, *eutrophic lake*, red edge, chlorophyll-a, GCOM, SGLI

ABSTRACT:

The objective of this study is to evaluate the performance of the two-band model in estimating Chl.a in Lake Kojima, Okayama Prefecture, Japan as representive example of Case II waters, and to assess the accuracy of Chl.a estimation. To evaluate the model's performance, a portable spectroradiometer (MS 720) was used to measure surface spectral radiance reflectance in the visible and near-infrared range of the spectrum using a small vessel in April 2009, July 2009, October, 2009, and January 2010. Water samples were collected to measure Chl.a (2.6-20.0 μg/l) and Secchi disk transparency (0.5-1.5 m). Thirty-two data sets of spectral reflectance/Chl.a were collected. After normalized processing had been conducted, the reflectance data were compared with the Chl.a data. As a result, a strong linear relationship was established between the analytically measured Chl.a and two-band model R(700)/R(670), where R is reflectance at wavelength n (r=0.80). RMSE of Chl.a estimation using the two-band model was below 2.7 μg/l. This result corresponds to past case studies in Chesapeake Bay, USA and Kasumigaura, Japan. Chl.a estimation techniques such as the single-band model, two-band model, and the LCI model using a data set in Lake Kojima are tested for the determination material of a SGLI Chl.a model. As a result, even when some models were applied, the correlation with observed Chl.a was about r=0.5. However, the correlation of the area average in the lake was very high (r=0.9 or more). Therefore, we recommend incorporation of this technique for routine monitoring of water quality using hyper-spectral sensor data such as Hyperion or SGLI in coastal and large estuarine waters like Lake Kojima in the future.

1. INTRODUCTION

Lake Kojima located in Okayama Prefecture is one of the most eutrophic lakes in Japan. Recently, water pollution is still a big problem though the water pollution situation has improved due to various efforts by the administration and civilian organizations. Therefore, it is very important to monitor the water pollution distribution of the lake. Detailed water quality distribution measurement in the lake and its changes is not mainstream though Okayama Prefecture has continuously researched internal production based on water quality surveys in the inflow river and the lake up to now (Takano et al, 2007).

Water quality distribution estimation, conducted by Okayama Prefecture and the National Institute for Environmental Studies using satellite LANDSAT data in the past, is performed in the lake because of this demand for water quality data. However, satellite sensors, designed originally to observe continental areas, have difficulty with the observation cycle and cloud coverage. Moreover, because sensitivity to water is very poor, satellite sensors are not in widespread use in general as a water quality monitoring tool. In fact, satellite remote sensing has not been tried in the lake since this report. On the other hand, "water quality remote sensing technology" that measures water quality from a satellite is at a practical stage in the open sea, and special satellite ocean color sensors such as SeaWiFS and MODIS, etc. have been developed. And it has become possible to observe the water quality of the ocean (chlorophyll-a, which is the chief index of the amount of phytoplankton: Chl.a) from satellite data every day. However, this ocean color sensor had the problem of extremely difficult estimation of Chl.a in waters like Lake Kojima, which had become very impure and were comparatively narrow because of the point and inorganic matter whose resolution is about 1 km. Moreover, examples of measuring spectral reflectance at the coast or lakes compared with the open sea (especially in Japan) are few.

On the other hand, new ocean color sensor SGLI with GCOM-C1 for the coast to monitor offshore water quality is ready for its launch in 2013 (Igarashi et al, 2009). SGLI is the machine succeeding ocean color sensor GLI with satellite ADEOS-2 in Japan. A water quality estimation model for the coast or lakes is now being developed for the project. However, the development of a water quality detection technique for turbid coast and lakes (called Case II for ocean color remote sensing) is late in the water quality remote sensing field.

From the above-mentioned background, basic research for detailed Chl.a estimation in Lake Kojima by SGLI in the future was conducted in the present study. First of all, a spectral reflectance/Chl.a data set is concretely collected in the field, and the spectral reflectance characteristics of this lake and the relationship to Chl.a were grasped. Next, the effectiveness of Chl.a estimation when the latest chlorophyll estimation techniques such as the single-band model, two-band model, and LCI using a data set are used is examined. Finally, the model is verified using MODIS data as simulated data of SGLI.

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* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

2. METHOD AND DATA

2.1 Study area

Lake Kojima is located to the south of Okayama Prefecture in southwestern Japan (see Figure 1). This lake was made to strengthen drainage and the reclamation dyke for securing rainwater, prevent salt damage to farmland, and reduce swales that had increased due to land reclamation around Kojima Bay. It is the second-largest artificial lake, excluding dam lakes, in the world after IJsselmeer in the Netherlands. It has a mean surface area of 11 km2, a mean depth of 1.8 m, and a maximum water depth of 9 m. Sasagase River and Kurashiki River, which are located northwest of the lake, are the main water supply for Lake Kojima.

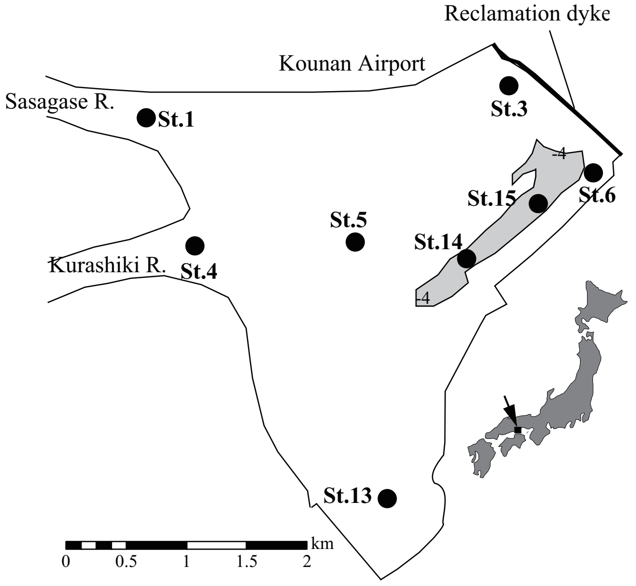


Figure 1. Sampling points in Lake Kojima, Okayama Prefecture, Japan

2.2 Chl.a estimation model

In this study, some Chl.a estimation techniques such as the single-band model, two-band model, and the LCI model using the data set are tested.

$$Chl.a \propto R_i \text{ or } Chl.a \propto R_i / R_j \quad (1)$$

Here, R is reflectance and *i* and *j* are bands. The LCI (linear combination index and linear uniting index) model that Frouin (2006) advocated is applied to assess the feasibility of Chl.a estimation using SGLI data. The LCI method is a simple atmospheric correction technique for cancelling the influence of aerosols by an operation between the following channels.

Reflectance (*Rt*) at the top of the atmosphere observed by satellite is shown by the following approximate expressions.

$$R_t(\lambda) = R_r(\lambda) + R_a(\lambda) + R_w(\lambda) \quad (2)$$

Here, λ, *Rr*, *Ra*, and *Rw* are wavelengths, the reflectances from atmospherical molecules and aerosols, and in-water reflectance, respectively. It is only *Rw* that relates to Chl.a by Equation (2), and elements of the remainder become noise. In addition, because *Rr* of Equation (2) can be calculated from the atmospheric pressure, etc. comparatively easily, Equation (2) is transformed as follows.

$$R_t(\lambda) - R_r(\lambda) = R_a(\lambda) + R_w(\lambda) \quad (3)$$

When *Rt*(λ) and *Rr*(λ) are defined as LCI, LCI is shown by the following equation.

$$LCI = \sum_{i=1}^{k} a_i R_{tr}(\lambda_i) = \sum_{i=1}^{k} a_i R_a(\lambda_i) + \sum_{i=1}^{k} a_i R_w(\lambda_i) \quad (4)$$

k (band) is a coefficient here requested for each band $a_i Ra(\lambda_i)$ accumulation to become just 0 in the meaning to which 3 or 4 and usual a_i remove the influence of the atmosphere. At this time, because the LCI becomes the linear combination of the in-water reflectance element of 3 - 4 selected band, it doesn't contain information on the atmosphere, and only information in-water will be contained.

First of all, clause 1 of Equation (4) is shown by the following equation as how to obtain a_i of Equation (3).

$$\sum_{i=1}^{k} a_i R_a(\lambda_i) = 0 \quad (5)$$

In addition, Equation (5) can be approximated by the following polynomials.

$$\sum_{i=1}^{k} a_i \lambda_i^{nj} = 0 \quad (6)$$

n_j is a coefficient that depends on the aerosol type. nj for which the Frouin set for GLI is [2, 1, 0] and n_j for which the JAXA MODIS near realtime data base for Japanese coast for MODIS with 500-m resolution is [1, -0.3]. Coefficient ai of three bands of SGLI was calculated by using the latter nj value [1, -0.3.] this time. As a result, the calculation equation of LCI for SGLI is shown in Equation (7). Comparison of the bands used to calculate LCI using SGLI and 500-m resolution MODIS data is shown in Table 1.

$$LCI_{SGLI(3band)} = R_{tr}(443) - 1.743 R_{tr}(565) + 0.716 R_{tr}(865) \quad (7)$$

LCI for MODIS with 500-m resolution led by JAXA (header information of JAXA MODIS HDF data) is shown by the following expressions.

$$LCI_{MODIS(3band)} = R_{tr}(466) - 1.503 R_{tr}(554) + 0.485 R_{tr}(857) \quad (8)$$

In general, LCI and Chl.a have a high correlation and are shown finally by the following equation.

$$Chl.a = 10^{m\times LCI+n} \tag{9}$$

Here, *m* and *n* are constants. The function whereby Chl.a is obtained from LCI can be made according to the above-mentioned procedure. This time, the measurement spectral reflectance data correspond to *Rw* of Equation (3). Therefore, there is sure to be a relationship like Equation (9) between Chl.a as for LCI obtained from the spectral reflectance data. In the present study, LCI is calculated from the measurement reflectance data, and the correlation with measured Chl.a is examined.

Table 1. Comparison between SGLI and MODIS bands used in the LCI model

Sensor	λ_1(nm)	λ_2(nm)	λ_3(nm)
SGLI	443(VN3)	565(VN6)	865(VN10)
MODIS	466(Band3)	554(Band4)	857(Band2)

2.3 Water sampling and field spectral data

Water sampling and field spectral measurements were performed on April 10, 2009 (spring) , July 24, 2009 (summer), October 21, 2009 (autumn), and January 21, 2010 (winter). The number of samples was eight in different months (see Table 2). The parameters chosen for measurement included physical parameters (e.g., Chl.a, transparency, salinity, and water temperature). In this study, Chl.a was mainly analyzed and assessed. Depth relatively became deep (deeper than 4 m) in the vicinity of St.14 and St.15 compared with other points, and salinity of about 0.5-2.0% was observed at the bottom of the lake. Portable chlorophyll meter Aquafluor (Turner Design Inc.) and a Secchi disk board of 30cm in the diameter were used respectively for the measurement of Chl.a and the transparency.

Field spectra were measured with a portable MS720 spectrometer (EKO Inc.). The MS720 radiometer has a spectral range between 350 and 1,050 nm. Its spectral resolution is about 3.3 nm. The measurements were taken from the boat platform above the lake surface about 0.5 m in the vertical downward direction. The measuring position was oriented to the boat side within the light propagation area to minimize sun glare from waves, but far away from the effect of the boat's shadow. After normalized processing had been conducted, the reflectance data were compared with the Chl.a data.

Table 2. Sample number and Chl.a in different seasons of FY2009

Date	Apr.10 2009	Jul.24 2009	Oct.21 2009	Jan.21 2010
Chl.a (μg/l)				
MIN	8.0	2.6	8.2	3.7
MAX	11.9	10.1	18.2	20.0
Point number	8	8	8	8

2.4 Specification of GCOM-C1 SGLI

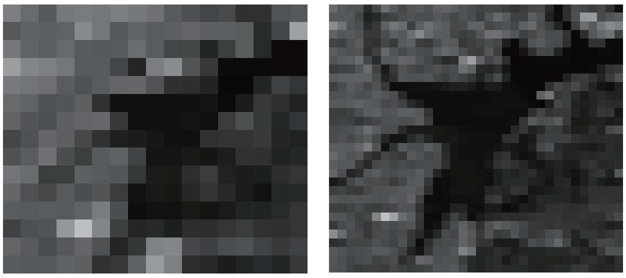
SGLI (Second-generation Global Imager) installed in GCOM-C1 that is the object of this study is an ocean color sensor that requires a spatial resolution of 250 m, and its launch is scheduled for 2013 from JAXA, Japan. The main specifications of SGLI (central wavelength, width of wavelength, and spatial resolution) are shown in Table 3.

Table 3. Central wavelength (λ), band width (Δλ) of wavelength, and spatial resolution of GCOM-C1 SGLI

Band	λ (nm)	Δλ (nm)	Spatial resolution (m)
VN1	380	10	250
VN2	412	10	250
VN3	443	10	250
VN4	490	10	250
VN5	530	20	250
VN6	565	20	250
VN7	670	10	250
VN8	670	20	250
VN9	763	8	1000
VN10	865	20	250
VN11	865	20	250

2.5 MODIS data for validation

The MODIS data used in the present study are Rayleigh-corrected reflectance data (binary data called SR11 data) of MODIS with 500-m resolution offered by JAXA for free. In these data, the scale-down data to 500-m resolution from MODIS Band1 (646 nm) and Band2 (857 nm) with 250-m resolution are stored. As for the scale of the MODIS data, the image in Figure 2 is a reference.



(a) 500m resolution (b) 250m resolution

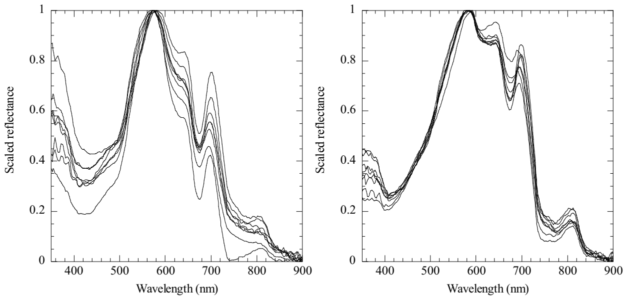
Figure 2. Comparison between a 500-m resolution image (500-m MODIS) and a 250-m resolution image (SGLI) simulated by ASTER data of 15-m resolution

3. RESULTS AND DISCUSSION

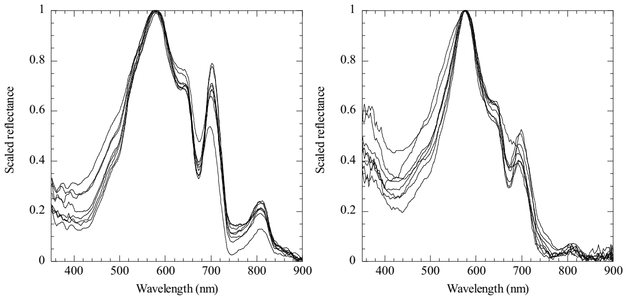
3.1 Spectral reflectance characteristics of Lake Kojima

Figure 5 shows measurement spectral reflectance of the water surface at eight points for each by four time in Lake Kojima. The average of Chl.a distribution at each time in the lake is shown in Figure 4. From these figures, the maximum of the spectral reflectance is about 580 nm (near SGLI VN6), and it is understood to be absorbed greatly in wavelength that is shorter or is longer than it. Especially, the minimum in the vicinity of 670nm±50nm and the maximum in the vicinity of 700nm±50nm show a feature shape of waves because of absorption and scattering and the fluorescence of the chlorophyll. Such a spectrum feature was similar to the spectrum characteristic of the eutrophic waters in various places such as Chesapeake Bay in USA (Gitelson et al, 2007), Lake District in Germany (Thiemann and Kaufmann, 2002), Lake Kasumigaura in Japan (Oki and Yasuoka, 1996), and Lake Shinji and Lake Nakaumi in Japan (Sakuno and Matsunaga, 2008). In addition, reflectance is usually often treated as 0 in the open sea as for the vicinity of 800nm±20nm. However, the maximum of reflectance in this band is seen in the lake.

On the other hand, Chl.a estimation of eutrophic waters is performed using the spectral characteristics of this 670 - 720 nm in various places. Figure 5 shows the relationship between the reflectance ratio in typical open sea and the coast. The coast model (reflectance ratio of 670 nm and 700 nm) showed a high correlation (r=0.80) compared with the open ocean model (reflectance ratio of 430 nm and 580 nm). RMSE of Chl.a estimation using the two-band model was below 2.7 μg/l. However, this simple coast model cannot be used because to our regret, there is no observation band of about 700 nm in SGLI. Therefore, it is necessary to develop a Chl.a estimation model in Lake Kojima for SGLI also.

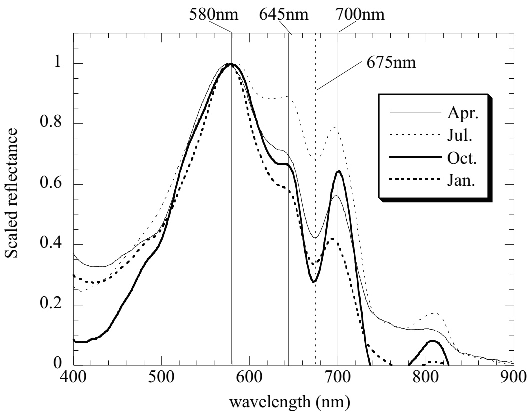


(a) Apr. 2009 (b) Jul. 2009

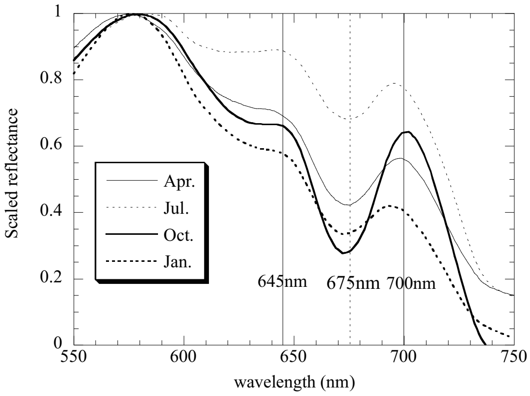


(c) Oct. 2009 (d) Jan. 2010

Figure 3. Characteristics of spectral reflectance in Lake Kojima, FY2009.

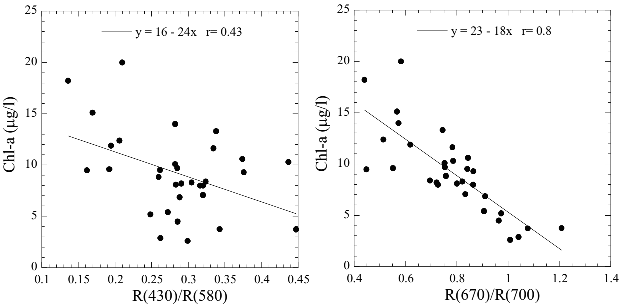


(a) 350-900 nm



(b) 550-750 nm

Figure 4. Average spectral reflectance in Lake Kojima, FY2009.



(a)ocean algorithm (b)coast algorithm

Figure 5. Relationship between reflectance ratio based on a typical Chl.a estimation model in open ocean and coast and Chl.a

3.2 Relationship between the Chl.a estimation model for SGLI and Chl.a

The relationships between reflectance using a single band of SGLI and observed Chl.a and that between the reflectance ratio using two bands and observed Chl.a are shown in Table 3 and Table 4, respectively. Thus, the correlation coefficients of [670 nm] (VN7) (r=-0.54), [443 nm/565 nm] (VN3/VN6) (r=-0.52), and Chl.a were the highest. Scatter plots of these are shown in Figure 6. Neither correlation that equalled the relationships of Figure 5(b) was obtained. On the other hand, the relationship between LCI obtained from Equation (7) and observed Chl.a is shown in Figure 7. The correlation coefficient (r=0.52) of Chl.a estimation using LCI for SGLI is equal to the method using a single band and the ratio of the band. However, when the area average in the lake was mutually plotted, a very high correlation was obtained as shown in Figure 8. Figure 9 shows the relation between average LCI and Chl.a in the lake calculated by using the MODIS data. Both relationships obtained a very high correlation. It was verified that average Chl.a could be monitored in the lake from LCI like Equation (7) if the band of SGLI was used from this.

Table 3. Correlation coefficient of reflectance of SGLI single band and Chl.a

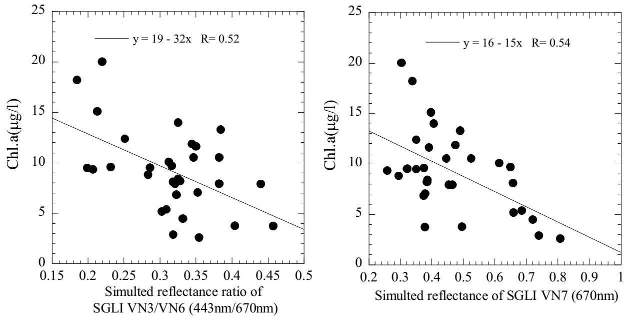
Band	VN2	VN3	VN4	VN5
r	-0.32	-0.50	-0.48	-0.17
Band	VN6	VN7	VN9	VN10
r	-0.06	**-0.54**	0.05	0.09

n=32

Table 4. Correlation coefficient matrix of the reflectance ratio of SGLI two bands and observed Chl.a

	VN3	VN4	VN5	VN6	VN7	VN9
VN2	0.12	-0.14	-0.26	-0.33	0.03	-0.04
VN3	-	-0.33	-0.46	**-0.52**	0.02	-0.09
VN4		-	-0.48	-0.49	0.32	-0.03
VN5			-	-0.18	0.46	0.03
VN6				-	0.47	0.09
VN7					-	-0.09
VN9						-

n=32



(a) Single band model

(b) Two band model

Figure 6. Relationship between the simulated SGLI reflectance or reflectance ratio, which has the highest correlation coefficient with Chl.a and observed Chl.a

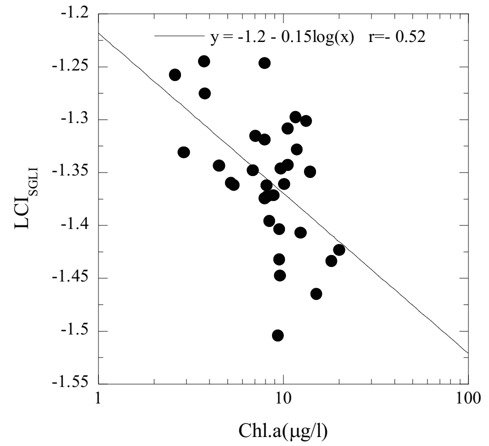


Figure 7. Relationship between simulated LCI for SGLI using Equation (7) and observed Chl.a.

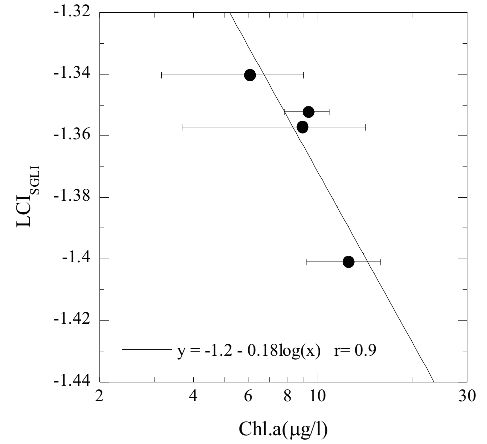


Figure 8. Relationship between area average LCI for SGLI using Equation (7) and area average Chl.a in Lake Kojima

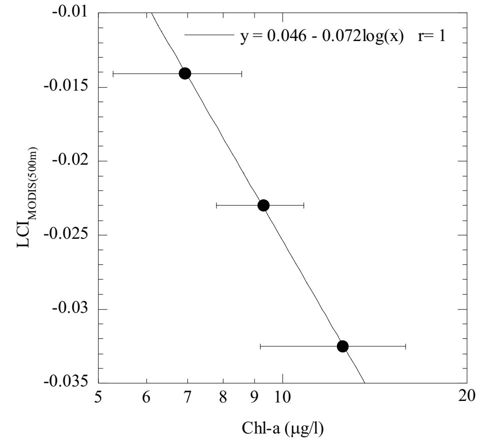


Figure 9. Relationship between area average LCI from MODIS with 500-m resolution using Equation (7) and area average Chl.a in Lake Kojima

4. CONCLUSION

In this study, some Chl.a estimation techniques such as the single-band model, two-band model, and the LCI model using a data set in Lake Kojima are tested for the determination material of a SGLI Chl.a model in Case II area. As a result, even when some models were applied, the correlation with observed Chl.a was about r=0.5. However, the correlation of the area average in the lake was very high (r=0.9 or more). Therefore, we recommend incorporation of this technique for routine monitoring of water quality using hyper-spectral sensor data such as Hyperion or SGLI in coastal and large estuarine waters like Lake Kojima in the future.

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REFERENCES

Frouin, R., Deschamps, P., Gross-Colzy, L., Murakami, H., and Nakajima, T., 2006. Retrieval of chlorophyll-a concentration via linear combination of ADEOS-II Global Imager data, *Journal of Oceanography*, 62, pp.331-337.

Igarashi, T., Imaoka, K., Kachi, M., Fujii, H., Murakami, H., Hori, M., Ono, A., Tanaka, K., Ito, N., Nakagawa, K., 2009. The perspective of Global Change Observation Mission, *Journal of The Remote Sensing Society, Japan*, 29(5), pp.665-674.

Gitelson, A. A., Schalles, J. F., Hladik, C. M., 2007. Remote chlorophyll-a retrieval in turbid, productivite estuaries: Chesapeak Bay case study, *Remote Sensing of Environment*, 109, pp.464-472.

Miyazaki, K., Takano, H., Yasuoka, Y., 1991. Satellite mapping of water quality in the Lake Kojima and its surrounding water area by Landsat TM data, *Journal of The Remote Sensing Society, Japan*, 11(2), pp.191-193.

Oki, K. and Yasuoka, Y., 1996. Estimation of chlorophyll-a concentration in rich chlorophyll water area from near-infrared and red spectral signature, *Journal of The Remote Sensing Society, Japan*, 16(4), pp.1-9.

Takano, H, Yamamoto, J., Saito, N. Nakagawa, S., 2007. Studies on Purification of Lake Kojima - Water Quality of Lake Kojima in 2006 -, *Annual Report of Okayama Prefectural Institute for Environmental Science and Public Health*, 31, pp.33-40.

Thiemann, S. and Kaufmann, H., 2002. Lake water quality monitoring using hyperspectral airborne data - a semiempirical multisensor and multitemporal approach for the Mecklenburg Lake District, Germany, *Remote Sensing of Environment*, 81, pp.228-237.

Sakuno, Y. and Matsunaga, T., 2008. Evaluation of the estimation accuracy of high chlorophyll-a concentration in brackish lake using spectral reflectance data, *Committee of Environmental Engineering Japan Society of Civil Engineering*, 45, pp.113-119.