

Modeling for Estimation of Algal Bloom in Daecheong Lake Using the Satellite Imagery

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Abstract—Blooms of harmful algae and phycocyanin represent a significant and expanding threat to human health and aquatic resources throughout the South Korea. Algal blooms can be seen in a variety of phenomenon in nature, ranging from massive accumulations of cells that discolor the water, to dilute, inconspicuous, but highly harmful populations. Estimating the distribution and growth of algae in lake systems are particularly important for the personnel of water managements and water supply system. Algae affect the taste and smell which pose considerable filtration problems for the communities using the water system such as Daecheong Lake. Many harmful algal blooms (HABs) have significant economic impacts especially in pisciculture. We developed empirical remote sensing models to estimate Chlorophyll *a* (Chl-*a*) concentrations and cyanobacteria synoptically, over the Daecheong lake using available Landsat TM and ETM+ data. In contrast to previous in situ studies of the cyanobacterial specific pigment such as phycocyanin, we developed remote sensing models capable of directly detecting cyanobacterial biovolume. This distinction is important because Landsat TM and ETM+ data lacks the spectral band information required for optimal phycocyanin detection. Developed model was calibrated and cross-validated with existing in situ measurements from Daecheong lake's Long-Term Water Quality Monitoring Program and Algae Alarm System (AAS). Three lake station measurements taken between 2004 and 2012 were matched with radiometrically converted reflectance data from three spectral bands on the Landsat TM and ETM+ sensor. Step-wise multi-linear regression indicated data from Landsat TM and ETM+ bands 1, 2 and 4 were most significant for predicting Chl-*a* and cyanobacteria biovolume. Based on statistical analysis, the linear models are that included visible band ratios slightly outperformed single band models. The final models captured the extents of cyanobacterial blooms throughout the 2004-2012 study period. The results serve as an added broad area monitoring tool for water resource managers and present new insight into the initiation and propagation of cyanobacterial blooms in Daecheong lake

Keywords—algal bloom; phycocyanin; aquatic resource; chlorophyll *a*; Landsat TM and ETM+

I. INTRODUCTION

Algal bloom in adequate amount is beneficial for aquaculture and wild fisheries operations. However, in some situations algal blooms can have a negative effect, causing severe economic losses to aquaculture, fisheries and tourism operations and having major environmental and human health impacts [1]. Cyanobacteria, a phytoplankton that have a characteristic pigment phycocyanin, can be found in all lake and reservoir ecosystems, ranging from small ponds to lakes. Its presence and volume is important since they are the major toxic blooms producing phytoplankton group in freshwater ecosystems [2]. Such toxins can become a major problem for public health if contaminated water is stored in reservoirs, and used in irrigation, fishing, cultivation and recreational purpose[3] [4].

In present situation with rapidly changing climate, land cover and land use simultaneously with increasing anthropogenic impact on reservoirs and inland aquatic ecosystems, there is an urgent need to improve the effectiveness of algal bloom monitoring methods. The demand of a unified monitoring of inland waters has inspired the formation of Algal Alarm System (AAS), Ministry of Environment in South Korea. The main objective of AAS is to prevent the occurrence of algal bloom phenomenon in advance and protect water bodies from further degradation, which in turn requires monitoring of various biological quality elements for determining the current status of an aquatic body. It has been cautiously operating the algal alarm and danger forecast system for Daecheong Lake from 1996. AAS monitors chlorophyll *a* concentration (Chl *a*), cyanobacterial biomass (CY) and phytoplankton biomass (TBM), the three important ecological parameters that give an overview of phytoplankton state in lakes and reservoirs. The monitoring of satellite imageries and new remote sensing algorithms is an ongoing process; moreover, because of the spatial and temporal variability of algal blooms, it is becoming essential to assess whether standard monitoring and mapping methods could be supported with remote sensing techniques.

The aim of the present study was to investigate and estimate whether spectral resolution of multispectral sensors is adequate for quantitative mapping of algal bloom and whether it is possible to separate potentially harmful blooms of cyanobacteria from waters dominated by algae using Landsat TM and ETM+ satellites.

II. MATERIALS AND METHODS

A. Locations

For this study, cyanobacterial data from Daecheong lake was taken for the present study. Daecheong lake has a major dam and it is slowly developing and forest area. The study area falls in the latitudinal and longitudinal extensions of $36^{\circ}10' - 36^{\circ}31' N$ and $127^{\circ}28' - 127^{\circ}50' E$ on the middle of South Korea. The geographic location of this lake is shown in Figure I. Table I summarizes the location and depth of observation site in Daecheong lakes.

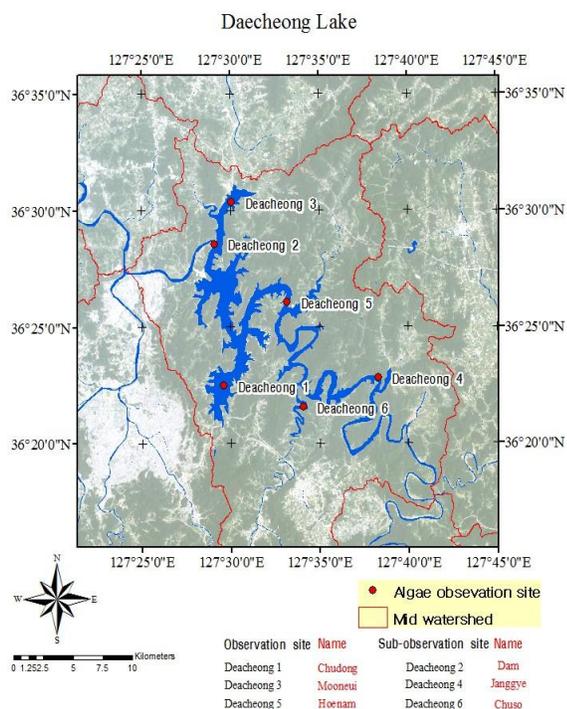


FIGURE I. OBSERVATION SITE MAP OF ALGAL BLOOM IN DAEICHEONG LAKE

TABLE I. LOCATION AND DEPTH OF THE IN-SITU OBSERVATION SITE IN DAEICHEONG LAKE

Code Name	Name	Longitude (DMS)	Latitude (DMS)	Depth (m)
Daecheong 1	Chudong	E 127 ° 29' 37"	N 36 ° 22' 29"	10 ~ 20
Daecheong 3	Mooneui	E 127 ° 30' 04"	N 36 ° 30' 22"	8 ~ 18
Daecheong 5	Hoenam	E 127 ° 33' 12"	N 36 ° 26' 03"	20 ~ 31
Daecheong 2	Dam	E 127 ° 29' 06"	N 36 ° 28' 34"	33 ~ 44
Daecheong 4	Janggye	E 127 ° 38' 19"	N 36 ° 22' 49"	8 ~ 16
Daecheong 6	Chuso	E 127 ° 34' 05"	N 36 ° 21' 33"	4 ~ 16

B. Data description

The existing water quality value was used to assess the present condition of algal bloom. Water samples from each six in-situ observation site (Table I and II) were collected and tested for cyanobacterial species identification and cell count. The Landsat TM and ETM+ satellite imagery was obtained from the U.S. Geological Survey's (USGS) Website for the period of June 2009 to October 2009 (Table III). For water quality, data from Gunkang Environment Agency water quality measurement network for the period of Apr. 2004 to Nov. 2012 was used.

TABLE II. DURATION OF ALGAL BLOOM ALERT IN DAEICHEONG LAKE

Year	In-situ Observation	Criteria of algal bloom (day)		Total duration
		Caution (days)	Warning (days)	
2005	Hoenam	8.2~10.7 (67)	-	67 day
	Choodong	9.1~9.30 (30)		
	Mooneui	9.1~9.30 (30)		
2006	Hoenam	8.4~10.4 (62)	8.4~8.18 (15)	79 day
	Choodong	8.18~10.20 (64)		
	Mooneui	9.7~10.20 (44)		
2007	Hoenam	10.6~10.19 (14)	-	14 day
	Choodong	10.6~10.19 (14)		
2008	Hoenam	7.25~8.8 (15)		15 day
2009	Hoenam	8.6~8.20 (15)	8.21~9.7 (18)	47 day
		9.8~9.21 (14)		

TABLE III. ACQUISITION DATE OF IMAGERY AND IN-SITU

Sensor	Acquisition date	
	Imagery	In-situ
Landsat ETM+	Jun.18,2009	Jun.17,2009
Landsat TM	Jun.26,2009	Jun.24,2009
Landsat ETM+	Aug.21,2009	Aug.19,2009
Landsat ETM+	Oct.24,2009	Oct.21,2009

C. Methodology

By using Landsat TM and ETM+ satellite images and field observation water quality data which can be used to describe the bloom condition in the six observational point, we have developed a multiple regression model for estimation and the observation of the algal blooming phenomenon (Figure II).

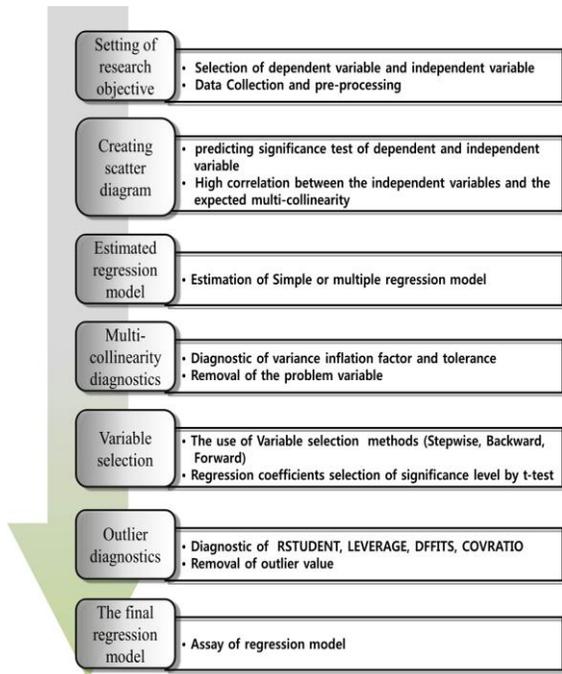


FIGURE II. FLOW CHART OF REGRESSION MODEL

A map of algal blooming phenomenon in the Daechung lake has created by using multiple regression model. The study progress shows as Figure III.

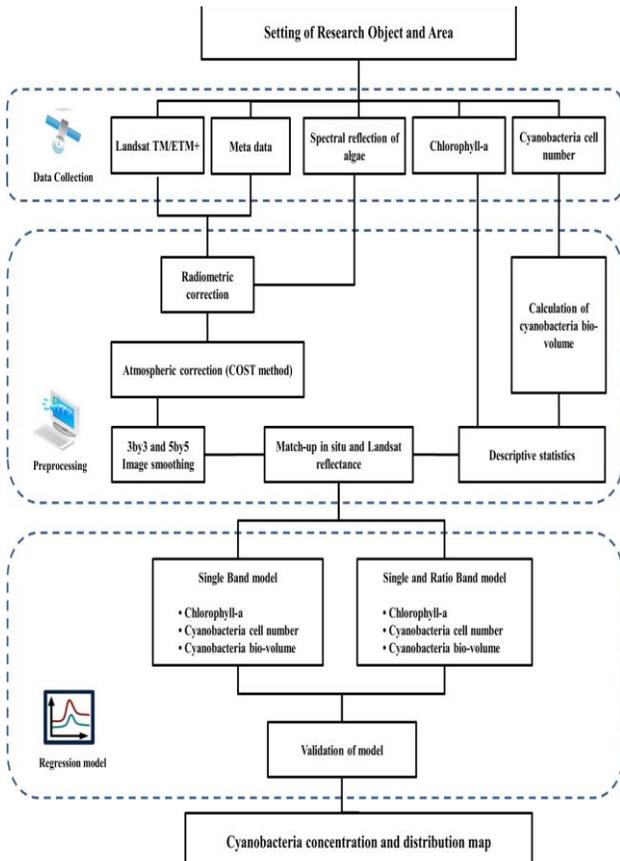


FIGURE III. FLOW CHART OF STUDY PROCESS

III. RESULTS AND DISCUSSION

A. Distributions of Chl.-a and Cyanobacteria

Monthly distribution of Chl.-a (Figure. IV) and cyanobacteria number (Figure. V) measured during the periods of water sampling has been displayed using box plot model.

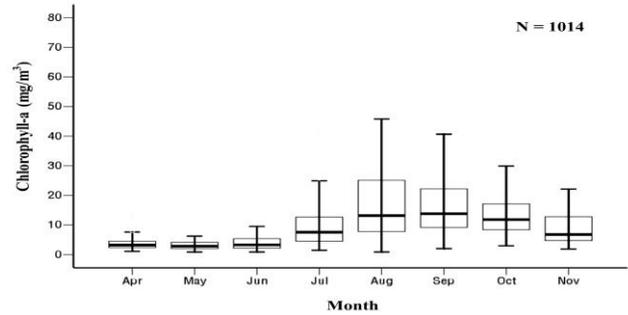


FIGURE IV MONTHLY DISTRIBUTION OF CHL-A

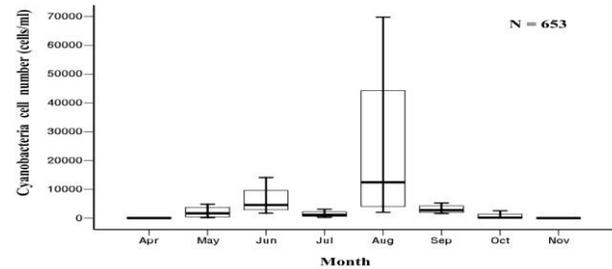


FIGURE V. MONTHLY DISTRIBUTION OF CYANOBACTERIA NUMBER

The results demonstrate a higher concentration of Chl.-a during summer and autumns. Chl.-a increases from the end of July, peak in August and then slowly decrease as autumn progressed. The high temperature and addition of rain water in summer triggers a healthy growth in algal and water bio community. But increasing supply of rain water run-off, water nutrient level also increase and therefore, rise the possibilities of algal bloom. As shown in Figure V, the cyanobacterial number is highest in August and then in June. It was found that the seasonal distribution of cyanobacterial biovolume is a constant cycle which have a strong relationship with solar radiation and water nutrients content. Warm temperatures have a positive effect, inducing an increase in cyanobacteria biomass while cold temperatures lead to a decrease.

B. Distributions of Cyanobacteria Cell Number

The Cyanobacteria Cell Number was estimated based on the dominant species of Daechung Lake during the summer. As given in Table 4, the abundance of cyanobacteria species Anabaena is highest, next Oscillatoria, Microcystis, Aphanizomenon appeared in order. Therefore we used Cyanobacteria Cell Number as a variable in our model in attempt to estimate the possibility of separating cyanobacteria from algal species based on remote sensing reflectance. During our study period maximum Cyanobacteria Cell was recorded 20,000cells/ml in August 2009 at Hoenam.

TABLE IV. DOMINANT SPECIES OF CYANOBACTERIA IN DAECHEONG LAKE

Genus	Anabaena	Microcystis	Aphanizomenon	Oscillatoria
Species	Anabaena spiroides var. crassa	Microcystis aeruginosa	Aphanizomenon flosaquae	Oscillatoria limosa
Mean cell volume ($\mu\text{m}^3/\text{cell}$)	575.2	58.2	17.6	166.3

C. Relationships between Chl.-a and Cyanobacteria Cell Number

Figure VI shows the correlation between the Cyanobacteria Cell Number and the Chl.-a. A high coefficient 0.86, indicate a significant relation between Chl.-a and cyanobacteria.

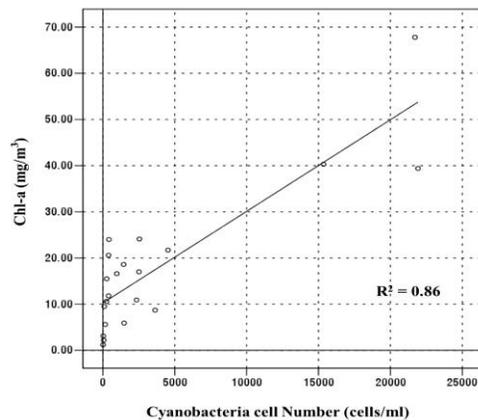


FIGURE VI. RELATIONSHIPS BETWEEN CHL.-A AND CYANOBACTERIA CELL NUMBER AT DAECHEONG LAKE

D. Relationships between Measured and Predicted Cyanobacteria Cell Number

Two Landsat spectral band i.e. Band 2 (0.52-0.60 μm) and Band 4 (0.77-0.90 μm) useful for assessing vegetation and biomass content are used for regression study. Among the several experimental models the best regression models for detecting cyanobacteria cell number is chosen for further study. The final cyanobacteria cell number models based on the band ratio is presented by the following equation:

$$C_{\text{yano}N} = 381287.94(B4) + 12028.277\left(\frac{B2}{B4}\right) + 23370.935\left(\frac{B4}{B2}\right) - 49961.989 \quad (1)$$

Where, $C_{\text{yano}N}$ is cyanobacteria cell number, $B2$ is Band 2 of Landsat, $B4$ is Band 4 of Landsat.

The R^2 value of the regression model is found to be 0.835 with a p value 0.001. Root mean square deviation (RMSD) between observed and predicted cell number is 10.35%, 2269.18cells / ml.

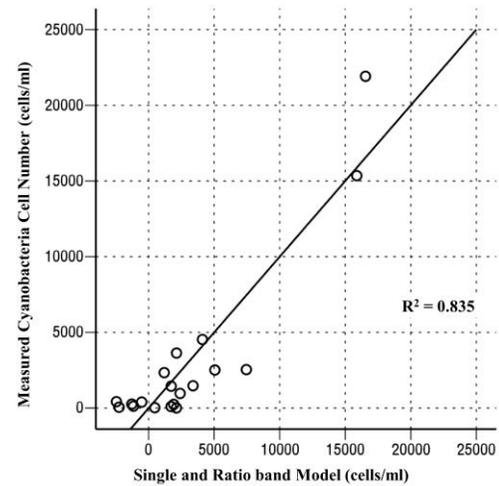


FIGURE VII. RELATIONSHIPS BETWEEN MEASURED AND PREDICTED CYANOBACTERIA CELL NUMBER AT DAECHEONG LAKE

E. Distribution map of Cyanobacteria Cell Number

Figure VII shows the distribution map of the Cyanobacteria Cell Number in September 30, 2006 at Daechung Lake. The study established the possibility of using multispectral sensors like Landsat for mapping of cyanobacteria in lake waters. Addition of other spectral band and their ratio can increase the efficiency of the present model, hence should be included as potential option for modification in further study.

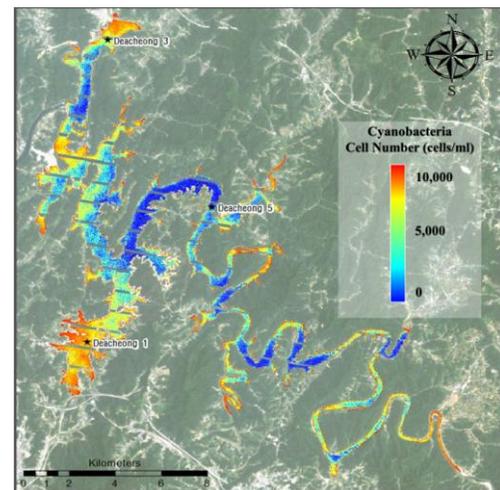


FIGURE VIII. DISTRIBUTION MAP OF CYANOBACTERIA CELL NUMBER IN SEP. 30, 2006

IV. CONCLUSIONS

Although there is limitations still exist in current applications, the present study shows that remote sensing can play a significant role in estimating algal blooms in lakes with large geographical areas. There is no doubt that an effective monitoring and detecting system of algal blooms through remote sensing requires the coupling of powerful strategies and a comprehensive understanding of the biological mechanisms behind the formation of algal blooms in lakes. Still the method is expected to provide a valuable opportunity to investigate the

factors that are important in determining the development and distribution of algal bloom in large water systems.

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