Assessing Spatiotemporal Variations of Chlorophyll-a with Satellite Images and modeling Technique: A Case Study of Paldang in Korea

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Abstract: This study illustrates a concept how satellite images can overcome the limitation of the water quality monitoring in terms of the gaps in time and in-situ sampling. Unfortunately, there is no way to resolve the issues but the water quality modeling technique can be partially compensate for the limiations of time and sampling. However, this approach still has a limitation in setting up boundary conditions in modeling.

Keywords: water quality, satellite image, modeling, chlorophyll-a

1. Introduction

Water bodies such as lakes, impoundments, and rivers are being changed responding to pollutant loading discharged from the surface water runoff or groundwater discharge. Especially, nutrients from agricultural land and waste water or chemicals by human activities pollute water resources and significantly influence on the aquatic ecosystem. With the development of chemistry, water quality has been periodically monitored for water bodies with field sampling. However, the sampling approach is not appropriate for the representative quality of a whole water body and does not provide enough information for the spatial distribution of contamination. Remote sensing often used for water quality monitoring as well but it always requires field samples corresponding to the exact time of satellite image capture, which is very difficult. Scientists often use computer modeling to anticipate future water quality based on the real world parameters and provide useful information for a specific time domain that can be arbitrary setup. However, modeling is lack of real world information and provides rough results since its coarse spatial resolution.

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Here, we attempted to use the advantages of each method for understanding the spatiotemporal variations of chlorophyll-a as an indicator of nutrient loading into Lake Paldang located in South Korea.

Table 1 Pros and cons of the methods of field sampling, computer modeling, and remote sensing

Method	Properties
Field Sampling	- Accurate - Time consuming - Relatively expensive - Not periodical. - No spatial distribution. - Discontinuous
Computer Modeling	- Results can be accurately obtained for anytime of interest with a given real-world dataset. - Not ground truth but a mathematical approximation. - Spatial resolution is too coarse.
Remote Sensing	- Fast and cost effective for large area - Snapshot of the ground truth - Distributed - Weather and time dependent - Sampling data required.

2. Method

The conceptual methodology for estimating Chl-a is illustrated in Figure 1. Field sampling is usually conducted periodic basis but often useless for Chl-a extraction from satellite images because sampling does not coincide at the time of satellite image capture, which means sampling results can be representative only for the time of sampling. Also, satellite collects images periodically but images are often failed to be collected depending on weather condition. However, if sampling data is used to estimate the Chl-a content at the time of satellite data collection, modeling can provide relatively accurate reference for satellite image analysis for the Chl-a content.

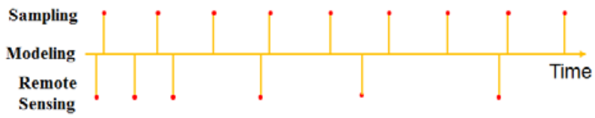

Figure 1 Conceptual combination of the datasets from field sampling, modeling result, and remote sensing imagery

Here, we input datasets of water sampling results from Ministry of Environment for boundary condition of computer model and measured the model sensitivity. Then the Chl-a contents at the time of satellite images collection was extracted from the modeling result and the estimation of the Chl-a content was derived from Landsat 7 images for three years.

There were problems with associating the Chl-a contents from modeling and satellite images so we assume that the maximum Chl-a content from satellite image was filtered with one sigma value of the distribution of Chl-a contents in the whole image and matched with a linear regression like Figure 2.

Note that the model we have run for Chl-a was GEMSS (Generalized Environmental Modeling System for Surface), which was often used to estimate the water quality like PO4-, NH3, TN (total nitrogen), BOD (Bio-Oxidation Demand), TP, NO3, Chl-a, DO, etc.

For satellite images, Chl-a is typically sensitive to band 3 (inversely proportional) and band 1 is least responsive to Chl-a (Figure 3). So simple ratio of band 3 to band 1 was used for this study.

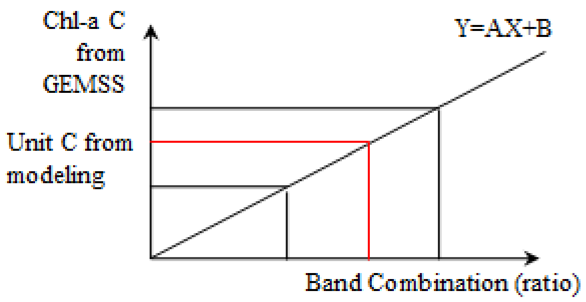

Figure 2 Conceptual Chl-a matching with regression

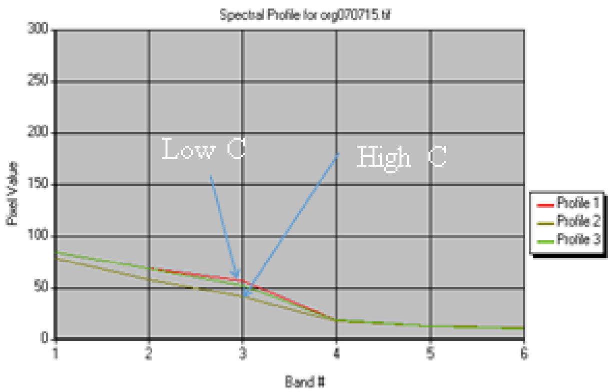

Figure 3 Contrast of band 2 and band 3 of ETM+

3. Results

3.1 Model Sensitivity

The model sensitivity can be considered to be reliable with Pearson coefficient = 0.823, $P < 0.05$ and bias = 1.1468 overall (Figure 4).

3.2 Linear Regression

Relationship between sampling data at meshed cells in the GEMSS model and corresponding average values to the cells was associated for linear regression as shown in Figure 5 and $y=2.1x+1$ was the equation representing the relationship. The actual results of GEMSS at 1:55PM on July 15, 2007, for example, was illustrated in Figure 7. The Southern branch of Paldang Reservoir takes large inflow of the high concentration of Chl-a.

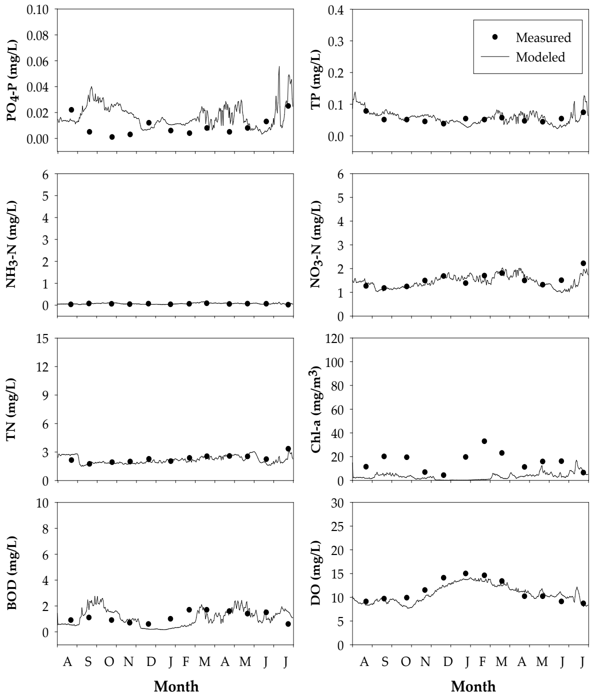

Figure 4 The model sensitivity results that shows a reliable accuracy

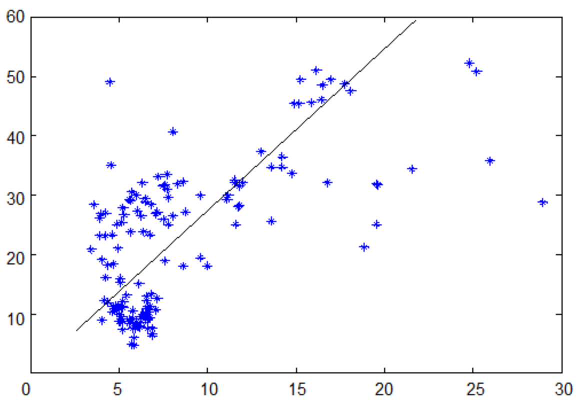

Figure 5 Linear regression for sampling vs. images datasets

Figure 7 shows the Chl-a concentration retrieved from Landsat 7. Interestingly, the results of both Chl-a concentration provided the similar spatial distribution pattern within a range of 4 to 110 mg/cm^3. However, the eastern branch of the reservoir showed a large difference.

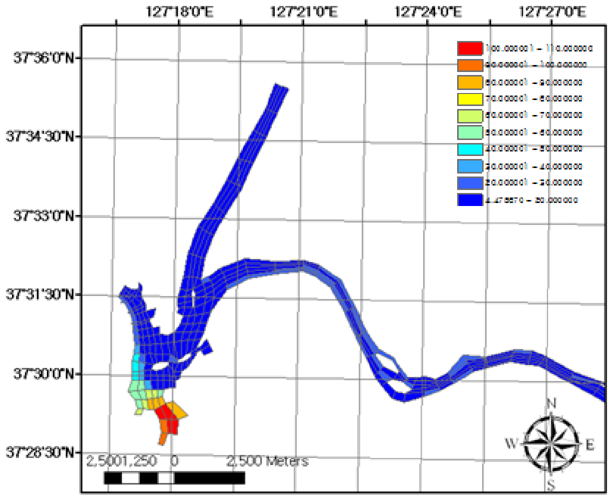

Figure 6 Chl-a concentration from GEMSS

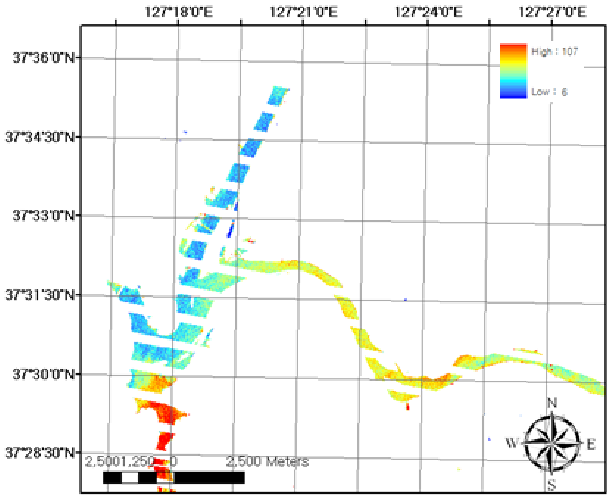

Figure 7 Chl-a concentration from EMT+

4. Discussion

We conducted very simplified experiment for measuring the Chl-a concentration with modeling and remote sensing. However, the concentration of Chl-a was determined by the modeling result so there is always uncertainty even with the linear fitting since we used statistical approach rather than more scientific one. Also, it was difficult to define the effective water depth with this approach because the Chl-a concentration from images is always different depending on the turbidity of water. In some cases, it was reported that the sediment matrix in water seem to be more influential to the reflectance for band 3 so measuring exact concentration of Chl-a is very challenging. Lastly, we only tested this approach to a dynamic water system which is frequently includes large amount of sediment and the sediment includeing Chl-a can be radically changed so that additional segregation method of the Chl-a should be considered.

References

Tyler, A. N., Svab, E., Preston, T., Presing, M. and Kovacs W. A., 2006. Remote sensing of the water quality of shallow lakes: a mixture mdolling approach to quantifying phytoplankton in water characterized hy high-suspended sediment. International Journal of Remote Sensing, 27, 1521-1537.

Kolluru, V., Buchak, E., and Brinkmann, P., 2003. Hydrodynamic modeling of coastal LNG cooling water discharge, J. Energy Eng. 129, 16-31.