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Performance Comparison of Band Ratio and Derivative Ratio Algorithms in Chlorophyll-A Estimation using Hyperspectral Data

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Abstract: Water body management is essential to provide quality water to the requirement of drinking, agriculture and industries. Estimation of water quality in dams, lakes, rivers is paramount activity in quality control. As phytoplankton concentration is based on the physical and chemical state of the water, it is a good indicator and its concentration represents water quality. As Chlorophyll-a(Chl-a) is a color pigment that exists in phytoplankton, estimation of Chl-a concentration provides the phytoplankton concentration. The conventional Chl-a measurement that includes sample collection Chl-a extraction to chemicals and testing at lab takes long time and has lengthy procedure. Measuring the reflectance by remote sensing methods provides Chl-a concentration in near real time. Many reflectance based algorithms like Band ratio, three band model, four band model and first order derivative based algorithms like derivative data and derivative ratio methods are developed to estimate Chl-a concentration. The reflectance of the Chl-a in red region is less as its absorption is more but it has no effect in Near Infrared region. The ratio of these two bands provides chlorophyll concentration. Similarly the derivative ratio in this region also reflects the Chl-a concentration. In this study, the performance of two band ratio methods of reflective and derivative were compared using high spectral resolution data acquired using in-situ spectroradiometer at Madiwala lake, Bangalore. Correlation study on these estimated values with measured values was conducted and Pearson correlation coefficient and determination coefficient were calculated. Relation between the reflectance, derivative values with chlorophyll-a concentration was established through regression study.

Keywords: *Chlorophyll-a, Spectroradiometer, Hyperspectral, Derivative*

1. Introduction

The importance of water body management is being realized due to the increased water requirement and the deterioration of water bodies due to natural disasters and human activities like industrial revolution, increase in population and change in life style. The water body management includes controlling the quality of water i.e. different organic and inorganic constituents should be within the specified limits. As growth and health of phytoplankton is controlled the physical state and available chemical constituents in the water body, it is a good indicator of water. As Chlorophyll-a is a color pigment that exists in phytoplankton, estimation of Chlorophyll-a concentration provides the phytoplankton concentration and water quality (Gitelson 1992). The conventional method of chlorophyll measurement is by collecting water from various locations of the water body and extracting the chlorophyll in laboratory. The modern method is based on the remote sensed reflectance spectrum of the chl-a and different algorithms to estimate the chlorophyll concentration. This method provides results relatively faster and without consuming costly chemicals. Different remote sensing methods are in-situ measurement by spectroradiometer, Ariel survey and satellite remote sensing. While in-situ measurement by spectroradiometer provides atmospheric interference free data, it needs somebody to sail into water for measurement. Arial remote sensing provides good resolution data in terms of spectral and spatial but it is expensive. The satellite remote sensing provide moderate spatial resolution, systematic coverage in less expensive. While many satellites provide moderate spatial resolution data in multispectral bands, hyperspectral imagers provide very good spectral information in hundreds of narrow spectral bands. In the case of Ocean remote sensing, As the reflectance of the Ocean (Case- 1 water) is dominated by chl-a, the estimation is easy and done by bands of any spectral region. Many algorithms are developed for case-I water and they provide very good results in chlorophyll estimation. As the case-II water bodies like lakes, rivers, coastal waters have many constituents (Chl-a, Colored Dissolved Organic Matter (CDOM), Particulate matter, suspended sediments) that contribute to the water reflectance, many algorithms used in the case-I waters are not suitable to Case-II water. As the effect of Colored Dissolved Organic Matter (CDOM) is more in the blue region and it decreases with increase in wavelength, become less and constant in RED-Near Infrared (NIR) region, many new algorithms are being developed in this region to estimate chlorophyll-a concentration.

The spectroradiometer has been used to collect the spectral reflectance in many studies (Huang 2010; Cheng 2013). It provides data in hundreds of bands with high spectral resolution in the order of nanometer.

Among many methods used to estimate the Chl-a concentrations, the two band reflectance ratio algorithms are simple, efficient, utilizing Red and NIR region spectral bands to estimate Chl-a concentration (Han 1997; Moses 2012; Huang 2014).

The derivative models are powerful and enhance minute fluctuation and separate related absorption features. Derivative spectroscopy is used to eliminate background signal and to resolve overlapping features. In satellite remote sensing, derivative method reduces the effect of atmosphere (Philpot 1991). First order derivative (Rundquist et al. 1996; Han 2005), and derivative ratio model(Tsai and philpot 1998) are used to estimate the Chl-a concentration.

2. Methods and Material

2.1 Study Area

The study area, Madiwala Lake is located at 12.9226° N, 77.6174°E and situated in southern Bangalore. The image of the study area is provided in the figures 1 as obtained by Resourcesat-2 (Courtesy: NRSC-Bhuvan 2D maps).

Figure 1 *Study Area and sample locations*

The study area was selected based on the Chl-a variation and Human accessibility. The south-west part of this lake is a recreational place with boating facility and other part of the lake is covered with vegetation. The depth of the lake varies from five to fifteen meters and average depth of the lake is approximately ten meters. The area cover of the lake is about three sq-km. The water source for this lake is rainwater from surrounding areas. The Study area is illustrated in the figure.1.

The study involves measuring spectral reflectance of the water body using a hyperspectral spectroradiometer. The water samples were also collected at all sample collection locations immediately after the spectral reflectance measurement.

2.2 Spectroradiometer Data

In-situ spectral reflectance measurements were carried out by ASD field spectroradiometer (Analytical Spectral Devices, Boulder, CO, USA) which gives the output in the spectral resolution of one nm. The above water radiance at each location was measured from a boat. Measurements were carried out on eastern side of the boat to avoid the shadow of the boat and the person holding the probe. During the measurement, the probe was held approximately half a meter above the water surface, nearly 0.5 m away from the boat by hand and directed vertically down towards water. After moving to the new location, boat was stopped for two minutes before making measurements to settle the ripples and waves. For every measurement, the instrument was collecting the radiance 25 times and averaging to produce the samples. The dark current values at each band were measured and subtracted from measured radiance values. This procedure was followed for measurement of water radiance as well as reference plate (Lambertian reflector) radiance. During the measurement of reference plate radiance, the plate was kept parallel to the water surface in sun light and the measurement probe was held normal to the surface. For having same illumination conditions, the reference measurements were carried out immediately after the water upwelling radiance measurement at each location.

The latitude and longitude information of sample collection locations were recorded using a GPS system for future reference. In this study, the secchi depth was measured using secchi disk to ensure that the optical depth is less than actual lake depth. This avoids the bottom floor reflection reaching the spectrophotometer. The disk is lowered vertically into the water until it disappears from view. This depth of disappearance is called secchi depth. The fieldwork was carried out between 9.30 AM and 11.00 AM local time to avoid the sun glint. At each sampling location, both water leaving radiance and reference radiance were measured without time gap. The view of the lake and the spectroradiometer measurement setup is shown in figure 2.

Figure 2 *A view of the lake and the spectroradiometer*

The remote sensing reflectance spectra from the spectroradiometer was calculated using equation-1 (Rundquist 1996; Han 1997)

$$R_{rs}(\lambda)_{meas} = \frac{L_w(\lambda)}{L_{cal}(\lambda)} * R_{cal}(\lambda) \quad (1)$$

Where $L_w(\lambda)$, $L_{cal}(\lambda)$ and $R_{cal}(\lambda)$ are water leaving radiance, scattered radiance by reference plate and reflectance factor of panel respectively. Here, it is assumed that the illumination conditions during the target and reference measurements are same. The data selection and reflectance calculation activities were carried out using ASD ViewSpecPro software package. Extracted reflectance values were plotted using MATLAB. The reflectance of water at different wavelengths is shown in Figure.3

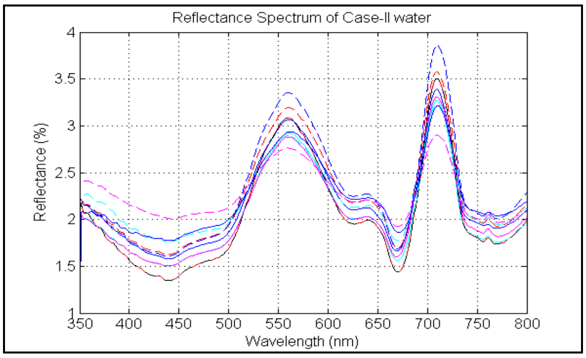

Figure 3 *Reflectance (%) Vs Wavelength at different locations*

The reflectance spectra magnitudes in the blue wavelength region of 400 to 450 nm are relatively lower than the green wavelength range (500–600) due to the high absorption of water, phytoplankton and dissolved organic matter in this region. The maximum absorption observed is at 440 nm. The reflectance spectra show a clear reflectance peak in the green region between 550 nm and 570 nm. This is due to high reflectance from algal biomass and backscattering by inorganic suspended sediments (Han and Rundquist, 1994). After 570 nm the reflectance comes down steadily upto 670 nm and this minimum reflectance is caused by combined effect of chlorophyll and water absorption. A slight reflectance trough around 620 nm formed by the secondary absorption peak by phycocyanin (Simis et al. 2005). A second reflectance trough around 675 nm corresponds to the red Chla absorption. After this, the reflection steadily increases up to the region around 700 nm (NIR) and this high reflectance is due to combined effect of Fluorescence of Chl-a(Nelille & Gower 1977), minimum absorption water, and high scattering of algal-cells (Han & Rundquist 1997). After this, the reflection decreases due to the absorption of water.

2.3 Derivative Data

As the derivative data amplifies even small variation, noise also will be amplified. This was avoided by smoothing the reflectance data with a mean filter with a window size of five before derivative calculation. The derivative values are calculated from the smoothened spectral reflectance data using following equation (Demetriades-shah, 1990; Huang 2014).

$$\text{Where, } R'_{\lambda n} = \frac{R_{\lambda n+1} - R_{\lambda n-1}}{\lambda_{(n+1)} - \lambda_{(n-1)}} \quad (2)$$

Where $R'_{\lambda n}$ is first derivative of reflectance in band λ_n, $R_{\lambda n+1}$, $R_{\lambda n-1}$ are the reflectance at λ_{n+1} and λ_{n-1}. The first order derivative values provide the rate of change of reflection with respect to wavelength (dR(λ)/(dλ). This is the slope of the reflective spectrum at wavelength λ. The derivative spectrum derived from reflectance data using equation (4) is shown in the figure 4.

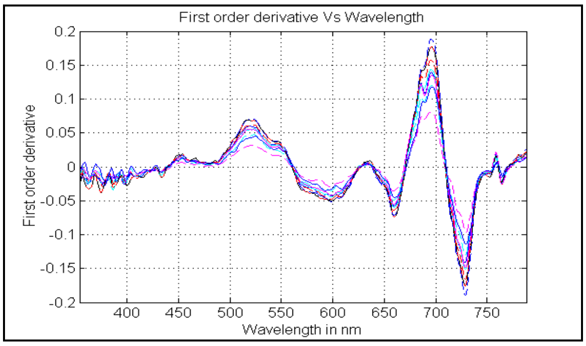

Figure 4 *Derivative values Vs Wavelength at different locations*

2.4. Water Sample Collection and Chl-a Measurement

Water samples of one liter in volume were collected immediately after spectroradiometer measurements at same locations. They were kept in aluminum foil bags to avoid photochemical breakdown of the chlorophyll, stored in an icebox, and taken to the laboratory for Chl-a concentration measurement. Chlorophyll-a was concentrated by filtering a known volume of water through a membrane filter (0.4 μm pore size). The pigments were extracted from concentrated sample (filter) to a solution of acetone (90%). The chlorophyll *a* concentration was determined by measuring the absorbance (optical density - OD) of the extract at various wavelengths (750nm, 663nm, 645nm and 630 nm) using a spectrophotometer. The absorbance at 750 nm was subtracted from the 630, 647, and 664 nm values for turbidity correction and the Chl-a calculated by equation-2 (Jeffrey 1975, Arar 1997)

$$Chl - a = \frac{S*[11.85(a_{664}) - 1.54(a_{667}) - 0.08(a_{630})}{V} \quad (3)$$

Where,

S = volume of acetone used for the extraction (ml)
V = volume of water filtered (L)
a664, a647 and a630 are the absorbance values
L = cell path length (cm)

3. Analysis and Results

3.1 Correlation Study

Correlation study is carried out to estimate the correlation between the measured Chl-a values and estimated Chl-a values using reflectance or derivative data. The bands that provide maximum correlation with chlorophyll measured values are selected for further study.

3.1.1 Reflectance ratio correlation

The reflectance ratio is two band model derived from three band model by eliminating the second term. The two band ratio is given in equation 4. (Dall'olmo 2005).

$$R_{rs}^{-1}(\lambda 1) R_{rs}(\lambda 2) \propto a_{chla}(\lambda 1) \quad (4)$$

Where R_{rs} is the reflectance value, λ1 is the first wavelength and λ2 is the second wavelength which shall be in the spectral range of > 730 nm and $a_{chla}(\lambda 1)$ is the absorption due to chlorophyll-a at λ1 and directly proportional to chlorophyll concentration. During the analysis we found that the spectral band ratio of 725nm and 577nm (R725/R577) gave maximum correlation (R^2 = 0.894) with the measured Chl-a values. The correlation values of various band combinations are given in figure 5.

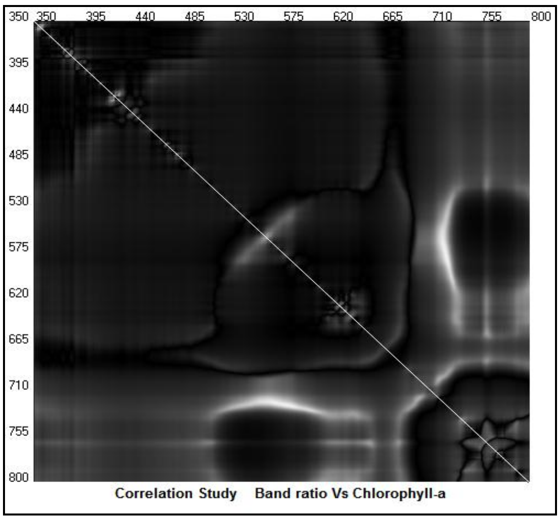

Figure 5 *Correlation of band ratio with measured Chl-a values*

3.1.2 Derivative Ratio correlation

First order Derivative ratio values of different band combinations were correlated with the measured values to estimate the chlorophyll concentration. In this method the highest correlation (R^2 = 0.862) was achieved with the derivative values of wavelengths 598 nm and 732nm. The correlation values obtained with various band combinations are given in figure 6.

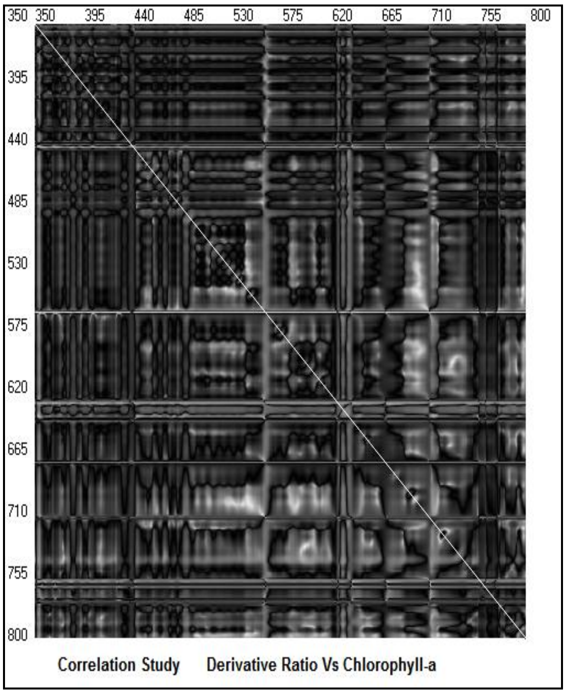

Figure 6 *Correlation of derivative ratio with measured Chl-a values*

Table 1 *Comparison of the performance of algorithms*

Method	R2	RMSE
Band Ratio	0.876	0.3499
Derivative Ratio	0.86	0.3713

3.2 Regression Study

3.2.1 Reflectance ratio Regression

Linear regression process fits the observed Chl-a concentration with linear combination of independent variables (reflectance values or derivative ratio at a particular wavelength). The output of the study is a linear equation with the form as given in equation (5)

$$Cchl\text{-}a = ax + b \quad (5)$$

where *C*chl-a is Chl-a concentration (µg/L), *a* and *b* are the regression coefficients, and *x* is the reflectance ratio or derivative ratio at a specific wavelength. The regression study was carried out using MATLAB software.

The regression study on the reflectance ratio values and measured chlorophyll values was carried out and the relation between the ratio and chlorophyll concentration was established. The equation, R^2 values and RMSE are provided in the figure.7

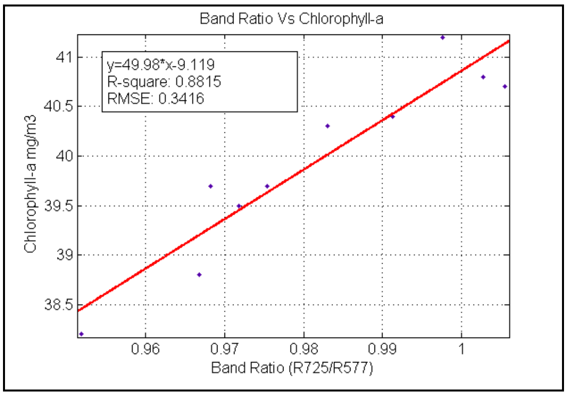

***Figure 7** Relation between Band ratio and measured Chlorophyll- a values*

3.2.2 Derivative Ratio Regression

Regression study between the derivative ratio values and measured values was conducted and the equation relates the chlorophyll and derivative ratio was computed. The values are provided in the figure.8

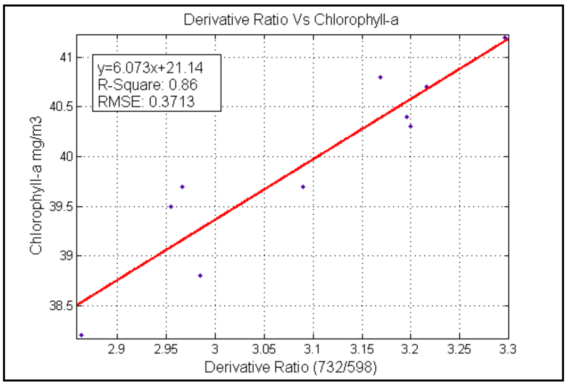

***Figure 8** Relation between Derivative ratio and measured Chlorophyll- a values*

4. Conclusion

The in situ spectroradiometer data of a turbid water body was collected at ten different locations. Derivatives were computed from the reflectance data after smoothing. The chlorophyll values were measured by collecting sample water and measuring at lab. Correlation study on the band ratio data and derivative ratio with measured values was conducted. The performance of reflective band ratio and derivative ratio methods in estimation of chlorophyll was compared. In the Madiwala lake water the performance of the band ratio is slightly better than the derivative ratio algorithm.

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