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Remote sensing quantitative monitoring of chlorophyll a concentration in Taihu Lake based on measured spectrum of water surface

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Abstract. In order to solve the regional and seasonal limitations of the algorithm, the database is introduced into the chlorophyll a concentration inversion. Usually, the inherent optical quantity of different water bodies in different seasons is obtained through a large number of field experiments and laboratory analysis, and stored in the database, and the index is established according to water body, season and inherent optical quantity. The main content of this paper is to quantitatively monitor the concentration, distribution and evolution of chlorophyll a in turbid and eutrophic water bodies such as Taihu Lake by remote sensing. The research of inversion method and strategy based on measured spectrum of water surface provides theoretical and methodological support for its application in remote sensing images. The data obtained in this paper mainly include: water quality parameters, apparent optical quantity and inherent optical quantity of Taihu Lake. The results show that the correlation coefficient R2=0.936, which is linear and sensitive to high-value areas. This result not only reflects the feasibility of the ratio index model for chlorophyll content inversion, but also shows that the absolute error is basically below 23 mg/m3, and the inversion result is relatively stable.

Keywords: Measured spectrum of water surface, Taihu Lake, Chlorophyll a concentration

1. Introduction

In recent years, with the rapid increase of population and the sustained and rapid development of economy, the influence of human activities in this area has become more and more severe, and the natural resources have been severely damaged. Especially, industrial and agricultural wastewater and domestic sewage are discharged into the lake almost untreated, which causes serious pollution to Taihu Lake and changes the ecological environment. Chlorophyll concentration in water is the index of plankton distribution and the most basic index to measure the primary productivity and eutrophication of water body [1]. Using remote sensing method to monitor water quality parameters has the advantages of wide monitoring range, high speed, low cost and convenience for long-term dynamic monitoring [2-4]. A lot of research achievements have been made in monitoring the chlorophyll concentration of water by using the measured spectral data of water surface, and various empirical or semi-empirical correlation models of algae chlorophyll concentration inversion and multiple algorithms for estimating the chlorophyll content of oceans, lakes and rivers have been determined [5~ 8].
Chlorophyll A is the most important pigment related to photosynthesis. Chlorophyll A absorbs most of red light and blue light but reflects green light, so chlorophyll is green. It is the sensitivity to light that makes water bodies with different chlorophyll a content show different colors, and the color characteristics caused by chlorophyll a pigment can be well captured by optical remote sensors [9]. The main content of this paper is to quantitatively monitor the concentration, distribution and evolution of chlorophyll a in turbid and eutrophic water bodies such as Taihu Lake by remote sensing. Based on the measured spectral data of water surface and synchronous chemical analysis data of water quality, this paper studies the mechanism and model of spectral measurement and quantitative remote sensing inversion of chlorophyll a in inland waters, which has certain reference and guiding significance for the band setting of sensors.

2. Basic principles and methods of hyperspectral measurement of water bodies

The transmission of light in water is mainly affected by the absorption and scattering of water components. The reflectivity curve of pure water in visible light band is close to linear, and the reflectivity gradually decreases with the increase of wavelength. In the near infrared band, the reflectivity of pure water surface is close to zero because of the large absorption coefficient of water. The bottom of the water may be rocky or sandy, and may be partially or completely covered with various benthos such as algae and mollusks [10]. All these factors are the underwater effects that affect the water color observation of remote sensors. Therefore, in order to quantitatively invert the concentrations of water components or water quality parameters, it is necessary to effectively extract the water-leaving radiation from the water signal obtained by the sensor, so as to obtain our ideal results.

In order to solve the regional and seasonal limitations of the algorithm, the database is introduced into the chlorophyll a concentration inversion. Usually, the inherent optical quantity of different water bodies in different seasons is obtained through a large number of field experiments and laboratory analysis, and stored in the database, and the index is established according to water body, season and inherent optical quantity. The foundation of the optical quantity database and the empirical model database is that the water quality of the same water body is single, and the optical characteristics of the same water body in the same season are the same. The database of inherent optical quantity of water body and the empirical model database also need to be constantly updated, which leads to a large workload of field experiments and water body sampling. Therefore, it is difficult to solve the applicability of the algorithm by the method of inherent optical quantity database and empirical model database.

For the field measurement, the influence of atmospheric scattering signal can be ignored. It is worth noting that at present, in many spectral measurements of water bodies carried out in China, the measurements are made vertically down the ship's side, and the so-called "water reflectivity" is obtained by comparing the measured value L_t of the water body target with the measured value L_p of the upper standard plate, that is:

$$\rho_t = \frac{L_t}{L_p} \tag{1}$$

Where L_t is the signal measured in the water body, and L_p is the signal converted to 100% reflectivity plate. And mistakenly adopt long integration time and automatic integration time adjustment for "accurately" measuring very low water signal; It is also considered that the strict radiation calibration of the instrument can be avoided because of the ratio.

3. Data acquisition and analysis

3.1 Data acquisition

The measured spectral data of water surface is a common data source of water color remote sensing, which provides reliable measured data support for the inversion algorithm of water color remote sensing. The research of inversion method and strategy based on measured spectrum of water surface provides theoretical and methodological support for its application in remote sensing images.

Data acquisition is the foundation of the establishment and accuracy verification of water quality inversion method. The data obtained in this paper mainly include: water quality parameters, apparent optical quantity and inherent optical quantity of Taihu Lake. The main parameter of spectral measurement of water surface is remote sensing reflectivity. At present, it is one of the most commonly used apparent optical quantities of water body in optical remote sensing, and it is also an important input parameter for water quality parameter inversion. Two factors should be considered in the observation geometry of water body brightness measurement: one is to avoid the influence of hull shadow and reflection, and the other is to avoid the influence of the specular reflection (i.e. flare) of direct sunlight on water surface.

The water surface reflection spectrum data is measured by the fixed-point measurement method under the Beidou satellite navigation. The water surface of Taihu Lake was measured in three ways (vertical water surface, 45 ° tilt with vertical water surface and 45 ° sky with vertical water surface upward normal) and the vertical reflection spectrum of reference plate. In addition, relevant information (time, measurement sample content, measurement point record number, latitude and longitude, weather, etc.) is recorded for each measurement site.

Chlorophyll is an important photosynthetic pigment in plant photosynthesis. It converts sunlight into energy, exists in chloroplasts in plant cells, reflects green light and absorbs red and blue light, making plants appear green. The routine monitoring method is colorimetry. The sample was filtered, ground, centrifuged, fixed to volume, then placed on a spectrophotometer, and analyzed with a 1cm optical path cuvette.

3.2 Data processing and analysis

Before the analysis, the calculated remote sensing reflectivity of water body is mainly normalized and first-order differential smoothing. The normalization of remote sensing reflectance data of water body is to use the average reflectance of water body in 420-750nm band as the normalization point, and divide the remote sensing reflectance value calculated at each wavelength by the reflectance value of the normalization point to obtain the normalized reflectance value of each wavelength [11]. The formula for normalization processing of remote sensing reflectance data of water body is:

$$R_N(\lambda_i) = \frac{R(\lambda_i)}{\frac{1}{n}\sum_{i=420}^{750} R(\lambda_i)} \tag{2}$$

Where: $R_N(\lambda_i)$ is the normalized remote sensing reflectance of water body, $R(\lambda_i)$ is the original calculated remote sensing reflectance of water body, and n is the number of bands between 420--750am.

The total incident irradiance $E_d(0^+)$ of water surface can be obtained by measuring the reflection of standard gray plate, and the formula is:

$$E_d(0^+) = L_p * \pi / \rho_p \tag{3}$$

Where, L_p is the measured value of standard gray board; ρ_p For the reflection ratio of standard gray plate, we choose 30% gray plate which has been strictly calibrated.
The measurement of chlorophyll a concentration goes through the following steps: filtering water samples, extracting chlorophyll a, measuring absorbance, quality control, and calculating chlorophyll a concentration. First, clean the filter with pure water, then assemble the filter device, and use the receiving bottle cleaned by pure water to receive the filtered liquid. Take a soaked and cleaned filter membrane, put it in the middle of the filter, and try to keep the filter membrane in a horizontal position. The cleaner the water body is, the larger the volume of filtered water sample will be, and with the increase of filtered water sample volume, the filtration time will also increase greatly. Therefore, it is necessary to find a balance between the filtration volume and filtration time.
Calculate the chlorophyll a concentration according to the following formula:

$$C_{chla} = 27.9V_{\text{ethanol}}[(E_{665} - E_{750}) - (A_{665} - A_{750})]/V_{\text{sample}} \quad (4)$$

In which, C_{chla} is chlorophyll a concentration (mg/m3), V_{ethanol} is the volume (mL) of the extract after constant volume, and V_{sample} is the volume of water sample before filtration (L).

4. Analysis and discussion of results

The estimation of chlorophyll a concentration by the traditional ratio and differential method can only be carried out in a single environment and time, which is greatly influenced by the region and time, which challenges the applicability and universality of the model. This paper quotes the mature mixed spectral analysis model in geological industry, and tries to apply it in the field of water environment.
Since there is no high concentration chlorophyll a in the experimental area covered by Hypeiorn, the reflectivity of the high concentration chlorophyll a area measured in the past is directly used as the end-member reflectivity curve of chlorophyll a. Figure 1 shows the reflectivity of two end-member components.

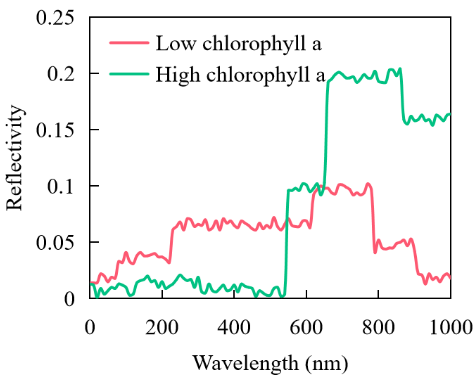

Figure 1 Chlorophyll a and end-member reflectance components of water body

The results of mixed spectral decomposition show that the contrast of chlorophyll a concentration level is better than that of ratio analysis and differential analysis, and the details of chlorophyll a concentration distribution are clearer. In addition, it is worth noting that the concentration estimation of ratio and differential treatment results is low, which is mainly due to the influence of the reflection peak near 700nm moving to the long wave direction with the increase of chlorophyll a concentration.
In order to further verify the results of equivalent off-water reflectivity, this paper uses the above analysis data and measured data as the main data source to construct a ratio index model for the inversion of chlorophyll concentration in water body, and analyzes the measured chlorophyll content in water body, and obtains the inversion result of chlorophyll content in water body based on ratio index (Figure 2).

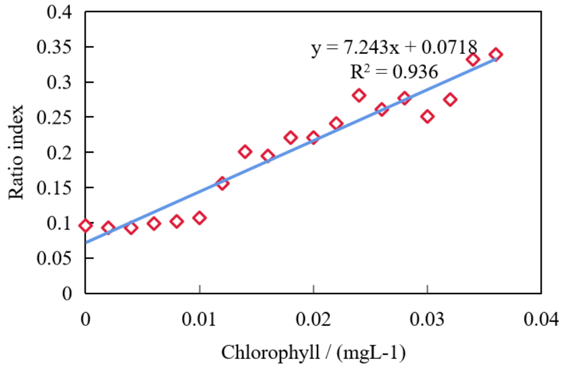

Figure 2 Inversion result of chlorophyll content ratio index

It can be seen that the inversion of chlorophyll is feasible, with the correlation coefficient R^2=0.936, which is linear and sensitive to high-value areas. This result not only reflects the feasibility of the ratio index model to retrieve the chlorophyll content, but also verifies the research result of this paper, that is, the channel response function can be used to establish the equivalent off-water reflectivity based on the satellite-borne data.
The inversion strategy based on soft classification inverses the chlorophyll a concentration of all 88 stations in Taihu Lake. The inversion results are shown in Figure 3 below.

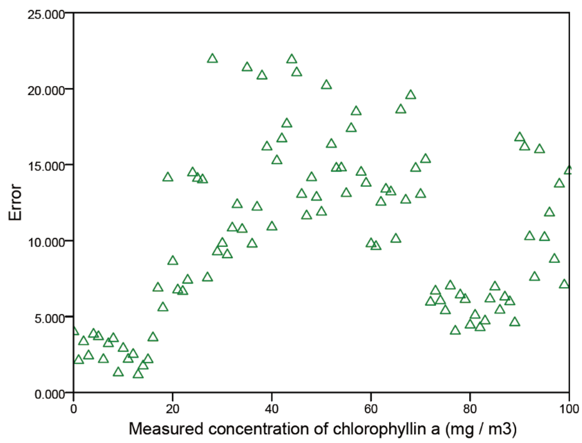

Figure 3 Error distribution of soft classification inversion strategy

It can be found from the figure that the inversion results are basically distributed near the 1:1 line, and there are no stations that deviate from the 1:1 line seriously, indicating that the soft classification inversion strategy is generally stable, and the phenomenon of abnormal values is small. In addition, with the change of chlorophyll a concentration, the inversion results of soft classification are not obviously larger or smaller.

Further analyze the error distribution of soft classification inversion results. The absolute error is basically below 23 mg/m^3, and there is no point where the absolute error value deviates greatly, so the inversion result is relatively stable. The absolute error value also increases to some extent with the increase of chlorophyll a concentration, but the increasing rate is far less than that of chlorophyll a concentration, which accords with the law of absolute error distribution.

5. Conclusions

Chlorophyll concentration in water is the index of plankton distribution and the most basic index to measure the primary productivity and eutrophication of water. Using remote sensing method to monitor water quality parameters has the advantages of wide monitoring range, high speed, low cost and convenience for long-term dynamic monitoring. The research of inversion method and strategy based on measured spectrum of water surface provides theoretical and methodological support for its application in remote sensing images. Data acquisition is the foundation of the establishment and accuracy verification of water quality inversion method. The data obtained in this paper mainly include: water quality parameters, apparent optical quantity and inherent optical quantity of Taihu Lake. The results of mixed spectral decomposition show that the contrast of chlorophyll a concentration level is better than that of ratio analysis and differential analysis, and the details of chlorophyll a concentration distribution are more clearly displayed. In addition, it is worth noting that the concentration estimation of ratio and differential treatment results is low. The inversion of chlorophyll is feasible, with the correlation coefficient R2=0.936, which is linear and sensitive to high-value areas. This result not only reflects the feasibility of ratio index model for chlorophyll content inversion. The absolute error is basically below 23 mg/m3, and there is no point where the absolute error value deviates greatly, so the inversion result is relatively stable.

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