Remote Sensing Retrieval and Evaluation of Chlorophyll-a Concentration in East Dongting Lake, China

Xi Chen¹, Mingwu Ou¹, Jia Shi¹ and Ying Li²*
¹ Hunan Dongting Lake Water Conservancy Affairs Center, China
² Zhejiang University of Water Resources and Electric Power, 583 Xuelin Road, 310010 Hangzhou, China
Email: liying@zjweu.edu.cn

Abstract. Using Landsat 8 OLI remote sensing images in November 2016, October 2017 and December 2017, relevant quantitative remote sensing statistical models were adopted under the ENVI software platform to invert and evaluate the chlorophyll-a (Chl-a) concentration in East Dongting Lake, China. The results show that from 2016 to 2017, the maximum concentration of Chl-a was 28 mg/m³, with an average of 16 mg/m³. The water temperature is relatively high in summer, and the photosynthesis of algae is enhanced, which is conducive to the growth and reproduction of algae. The concentration is relatively high in flood season, and the non-flood season is relatively low. In the northwest of East Dongting Lake, there is no free exchange of water with the shore, and the water in the lake has a relatively low purification capacity for pollutants; Chl-a concentration in this region is higher than that in other regions, while the water in the channel connecting South Dongting Lake has strong fluidity with low concentration. In the flood season of July 2017, the trophic state index (TSI) value of the west inshore side of the lake can reach 60-70, and there is a problem of water bloom. The TSI of non-flood season is 40-50. The degree of eutrophication has decreased recently, which should be related to the overall management of water environment.

Keywords: Chlorophyll a; eutrophication; remote sensing; East Dongting Lake.

1. Introduction
Lake eutrophication is a global ecological and environmental issue. The concentration of Chl-a in water reflects the distribution of phytoplankton and is one of the most important parameters to evaluate the primary productivity (biomass of aquatic plants) and eutrophication degree of water [1]. Compared with traditional lake water quality monitoring, remote sensing technology provides a long-term, rapid and effective way to monitor the water environment. Meanwhile, large-scale observation also makes up for the shortage of prototype observation sample points, so it has obvious advantages in the quantitative estimation and evaluation of Chl-a [2-3]. At present, a variety of remote sensing data (LANDSAT MSS, MODIS, etc.) and various Airborne Hyperspectral Data (AVIRIS, CASI, etc.) are widely used in water quality remote sensing monitoring.

Various methods have been used to investigate remote sensing retrieval and evaluation of Chl-a concentration in lake waters. Zheng et al [4] proposed an empirical band-ratio algorithm for estimating diffuse attenuation coefficient patterns from Landsat 8 OLI imagery of Dongting Lake. Wu et al [5] also developed a statistical model to estimate suspended particulate matter concentrations in the same area with remote sensing images. In this paper, Landsat 8 OLI remote sensing data source from 2016 to 2017 was used to carry out remote sensing inversion and evaluation of Chl-a concentration in East
Dongting Lake, to provide scientific basis for the management of eutrophication in lake.

2. Materials and Methods

2.1. Study Area
East Dongting Lake, located in Yueyang City, Hunan Province (figure 1), is located in the south of Jingjiang section of the Yangtze River [6]. East Dongting Lake plays a key role in ensuring the water security of the Yangtze River basin and the region around the lake by receiving the four rivers of Xiangjiang, Zishui, Yuanjiang and Lishui. Historically, East Dongting Lake was a small body of water near Junshan Mountain. Due to the continuous evolution of the relationship between rivers and lakes, Dongting Lake expanded southward under the action of the Yangtze River flood, and sediment accumulation formed the lake wetland landscape. In recent years, with the rapid development of economy in Dongting Lake area, pollution from various aspects, such as industry, urban resident, agricultural production, aquaculture and etc., poses a serious threat to the ecological environment of Dongting Lake.

![Figure 1. Location of the study area. (a) Diagram of Dongting Lake. SZ – Songzi; HD – Hudu; OUC – Ouchi; LS – Lishui; YJ – Yuanjiang; ZS – Zishui; XJ – Xiangjiang [6]; (b) morphology of East Dongting Lake.](image)

2.2. Remote Sensing Data and Processing
The Landsat 8 OLI image of the United States is selected as the data source for the analysis, with a total of 3 scenes (see table 1) to carry out the research on the remote sensing inversion of the East Dongting Lake. The spatial resolution of Landsat 8 OLI remote sensing data is 15 m, the revisiting period is 16 days, 9 bands, and one scene can completely cover the East Dongting Lake area. Since its launch in 2013, the data can be obtained free of charge, and the relevant indicators meet the needs of water quality inversion. All band data of Landsat images are collected from USGS website. Most of the data are Level 1T products after precise geometric correction and terrain correction, and the geometric processing accuracy of products can be obtained from metadata. Atmospheric correction is a very important image preprocessing stage in Landsat 8 remote sensing inversion. The accuracy of the results has a great impact on the later retrieval accuracy. Atmospheric calibration is carried out on ENVI software platform, and the calibration model adopts FLAASH atmospheric correction module [7].
Table 1. Selected Landsat 8 OLI imagery data.

| No. | Satellite  | Instrument | Imaging date | Imaging time | Hydrological period |
|-----|------------|------------|--------------|--------------|---------------------|
| 1   | LANDSAT-8  | OLI        | 2016/11/28   | 10:57:02     | non-flood           |
| 2   | LANDSAT-8  | OLI        | 2017/07/26   | 10:56:37     | flood               |
| 3   | LANDSAT-8  | OLI        | 2017/12/17   | 10:56:53     | non-flood           |

2.3. Evaluation Index of Water Eutrophication

According to the eutrophication state of Dongting Lake, the eutrophication state index is calculated. This study made full use of the TSI method constructed by Carlson [8], and used the content of Chl-a to reflect the nutrient state index of the lake

\[ TSI(CHL)=9.18\ln(chl)+30.6 \]  (1)

where TSI (CHL) is the trophic status index, Chl is the Chl-a concentration. The relationship between TSI and Chl-a concentration is shown in table 2.

Table 2. Relationship between TSI and Chl-a concentration.

| TSI value | <30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | >80 |
|-----------|-----|-------|-------|-------|-------|-------|-----|
| Chl-a (mg/m³) | <0.95 | 0.95-2.6 | 2.6-7.3 | 7.3-20 | 20-56 | 56-155 | >155 |

3. Results and Discussion

3.1. Temporal and Spatial Variation of Chl-a Concentration

Based on the above statistical model and ENVI software platform, the remote sensing distribution maps of Chl-a in East Dongting Lake in November 2016, July 2017 and December 2017 are illustrated, as shown in figure 2. It can be seen from the figure that the overall Chl-a concentration in East Dongting Lake is low and does not change much, with the maximum concentration of 28 mg/m³, and the average Chl-a concentration in the lake area is 16 mg/m³ in three time phases. On the whole, the flood season concentration was higher in the year, such as July 2017, while the Chl-a concentration was lower in December 2017 in the non-flood season. The higher Chl-a concentration in flood season is mainly due to the relatively high water temperature during this period, the enhanced photosynthesis of algae, which is conducive to the growth and reproduction of algae. From the perspective of space, the Chl-a concentration in the northwest of East Dongting Lake is higher than that in other regions; Due to the poor water exchange, the purification capacity of lake water to pollutants is relatively low, while the water in the channel connecting South Dongting Lake has strong fluidity with low concentration. According to the data of field sampling [9], the Chl-a concentration of Dongting Lake in different years and seasons is between 4.9 mg/m³ and 22.3 mg/m³. The remote sensing monitoring data is basically consistent with the measured data, which verifies the feasibility of the remote sensing inversion method.
3.2. Water Eutrophication Assessment

According to the results of Chl-a concentration remote sensing model, Carlson TSI method was used to evaluate the lake water trophic status with Chl-a concentration as the index (figure 3). The results show that in the non-flood season, the TSI of East Dongting Lake in November 2016 and December 2017 was 40-50, which was in the range of eutrophication to mesotrophication. In the flood season, the TSI values of the west inshore side of the lake area in July 2017 can reach 60-70, and there is a problem of water bloom. In terms of interannual variation trend, the water nutrition index of East Dongting Lake in December 2017 was lower than that in December 2016. Since 2016, Dongting Lake has implemented comprehensive water environment treatment, and carried out "five special actions" including ditch dredging, livestock and poultry breeding pollution treatment, purse seine breeding cleaning, inshore garbage cleaning, and key industrial pollution source eliminating. These actions supervised and rectified the problems of water quality decline and ecological damage caused by illegal sand mining, aquaculture and fishing in key lakes and reservoirs.

Figure 3. Eutrophication assessment of water body in different time phases. (a) On November 28, 2016; (b) On July 26, 2017; (c) On December 17, 2017.
4. Conclusions

Based on ENVI software platform, the quantitative remote sensing statistical model was used to evaluate the Chl-a concentration of East Dongting Lake in different seasons and years from 2016 to 2017. The results show that the maximum Chl-a concentration was 28 mg/m$^3$, with an average of 16 mg/m$^3$ during the analysis period. In summer, the water temperature is relatively high; the photosynthesis of algae is enhanced, which is conducive to the growth and reproduction of algae. The Chl-a concentration is higher in the flood season and lower in the non-flood season.

The water exchange between the northwest of East Dongting Lake and the shore is not free, the purification ability of the lake water for pollutants is relatively low, and the Chl-a concentration in this area is higher than that in other areas; while the channel connecting South Dongting Lake has strong fluidity with low concentration. In the flood season in July 2017, the distribution of TSI values of the west shore side of the lake area could reach 60-70, and there was a bloom problem. In the non-flood season in November 2016 and December 2017, the trophic index TSI of East Dongting Lake was 40-50, which was in the range of eutrophication degree. In terms of the annual change trend, the eutrophication degree of water decreased from 2016 to 2017, which is related to the recent comprehensive environmental arrangement in the lake area.

References

[1] Nazeer M, Nichol J E 2016 Development and application of a remote sensing-based Chlorophyll-a concentration prediction model for complex coastal waters of Hong Kong Journal of Hydrology 532: 80–89.
[2] Lins R C, Martinez J M, Motta Marques D D, Cirilo J A, Fragoso C R 2017 Assessment of chlorophyll-a remote sensing algorithms in a productive tropical estuarine-lagoon system Remote Sensing 9: 516. doi:10.3390/rs9060516.
[3] Yang B, Liu Y, Ou F, Yuan M 2011 Temporal and spatial analysis of COD concentration in East Dongting Lake by using of remotely sensed data Procedia Environmental Sciences 10: 2703–2708.
[4] Zheng Z, Ren J, Li Y, Huang C, Liu G, Du C, Lyu, H 2016 Remote sensing of diffuse attenuation coefficient patterns from Landsat 8 OLI imagery of turbid inland waters: A case study of Dongting Lake Science of the Total Environment 573: 39–54.
[5] Wu G, Cui L, Liu, L, Chen F, Fei T, Liu Y 2015 Statistical model development and estimation of suspended particulate matter concentrations with Landsat 8 OLI images of Dongting Lake, China International Journal of Remote Sensing 36(1): 343–360.
[6] Yuan Y, Zeng G, Liang J, Li X, Li Z, Zhang C, Huang L, Lai X, Lu L, Wu H, Yu X 2014 Effects of landscape structure, habitat and human disturbance on birds: A case study in East Dongting Lake wetland Ecological Engineering 67: 67–75.
[7] Yuan J, Niu Z 2008 Evaluation of atmospheric correction using FLAASH Proceeding of International Workshop on Earth Observation and Remote Sensing Application (EORSA) - Beijing, China: 1–6. doi:10.1109/eorsa.2008.4620341.
[8] Carlson R E 1977 A trophic state index for lakes Limnology and Oceanography 22: 361-369.
[9] Bai R 2019 Inversion of Chlorophyll a Concentration and Evaluation of Water Eutrophication Status in East Dongting Lake based on LIBSVM Changsha: Central South University of Forestry and Technology.