Remote Sensing of Spatial-Temporal Distribution of Suspended Sediment Concentration in East Dongting Lake, China

Mingwu Ou¹, Xi Chen¹, Junjie Zhou¹ 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. Three Landsat 8 OLI scenes acquired from 2016 to 2017 were used to estimate the suspended sediment concentration (SSC) in East Dongting Lake, China. The results show that SSC in East Dongting Lake is generally low, only the SSC of sediment transport channel connecting South Dongting Lake is significantly high, and that in the west of the lake is relatively small. From 2016 to 2017, the average SSC in the eastern channel was 33-120 mg/L, the average SSC in the north branch of the west area was 15-43 mg/L, and the average SSC in the south branch of the west area was 17-46 mg/L. Under the influence of the dilute water of the Yangtze River in flood season, the overall SSC in the lake area is lower than that in non-flood season, and the average SSC is within 40 mg/L. The variation law of SSC in lake area revealed by remote sensing is consistent with the measured data, which verifies the feasibility of this method and provides a new perspective for dynamic tracking and mastering the distribution law and variation trend of suspended sediment in East Dongting Lake.

Keywords: Suspended sediment concentration; remote sensing; East Dongting Lake.

1. Introduction

Suspended sediment is the main influencing factor of lake morphology shaping and grassland evolution, which has a profound influence on environment and sedimentary system [1]. With the construction of Three Gorges Dam and other major water-related projects, the basic hydrological characteristics of East Dongting Lake, such as water level, discharge and SSC, have significantly decreased, and the inflow and sediment of East Dongting Lake have entered a new period [2-3]. Therefore, it is necessary to pay attention to the flux change, spatial distribution pattern, and transport and deposition rule of suspended sediment under the new situation. This not only provides an important analysis basis for regional resource and environment monitoring, but also is the core issue of carrying out resource protection in the Yangtze River Basin.

Traditional lake monitoring methods are time-consuming and laborious, and the monitoring system is not sound, so it is difficult to obtain information comprehensively in a short time. The advantage of remote sensing lies in the frequent and persistent provision of surface feature information, which is a revolutionary change for the traditional observation method based on sparse discrete points. Relevant researchers used remote sensing data of different resolutions and phases to conduct inversion studies on the water quality of East Dongting Lake [4], but the spatial-temporal variation analysis of SSC is relatively seldom, especially the study on spatial differentiation law of SSC. This paper attempts to use...
recent Landsat remote sensing images of East Dongting Lake to quantitatively analyze the spatial distribution law of SSC, and provide a scientific basis for lake governance and protection.

2. Materials and Methods

2.1. Study Area

East Dongting Lake is located in the south of Jingjiang section of the Yangtze River, mainly distributed in Yueyang City, China [5]. The East Dongting Lake plays a key role in ensuring the water security of the Yangtze River basin and the region around lake by receiving the four rivers of Xiangjiang, Zihusi, Yuanjiang and Lishui. The lake area starts from Leishi Mountain, where Dongting Lake meets Xiangjiang River in the south, and reaches Chenglingji in the north to join the Yangtze River. It is about 70 km from north to south and 30 km wide in the east and west. The west side of the lake is bounded by the flood control dike, and the east side is mainly the low hills. Chenglingji Hydrological Station (CHS) is located at the north end of East Dongting Lake, and the intersection of Yangtze River and Dongting Lake. Waterway near CHS is the only outlet for water and sediment from Dongting Lake to enter the Yangtze River (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 [5]; (b) morphology of East Dongting Lake; CHS–Chenglingji Hydrological Station.](image)

2.2. Remote Sensing Data

The spatial resolution of Landsat 8 OLI remote sensing data is 15m, the revisiting period is 16 days, 9 bands, and one scene can completely cover the East Dongting Lake area. Since 2013, the data can be obtained free of charge, and the relevant indicators meet the needs of SSC inversion. In this paper, three Landsat 8 OLI scenes remote sensing data in March 2016, November 2016 and July 2017 are selected to carry out the retrieval of SSC in East Dongting Lake (table 1). The band data of Landsat image are collected from the United States Geological Survey (USGS) website. The images with good data quality, no cloud or little cloud are selected; the changes of flood season and non-flood season are also taken into account.
Table 1. Selected Landsat 8 OLI imagery data.

| No. | Satellite | Instrument | Imaging date | Imaging time | Hydrological period |
|-----|-----------|------------|--------------|--------------|---------------------|
| 1   | LANDSAT-8 | OLI        | 2016/03/01   | 10:56:35     | non-flood           |
| 2   | LANDSAT-8 | OLI        | 2016/11/28   | 10:57:02     | non-flood           |
| 3   | LANDSAT-8 | OLI        | 2017/07/26   | 10:56:37     | flood               |

2.3. Image Processing Method

The preprocessing of remote sensing image data mainly includes geometric correction and atmospheric correction. The basic data of lake information extraction and analysis can be obtained through the above processing methods. Landsat 8 OLI remote sensing data is a Level 1T product after precise geometric correction and terrain correction. The geometric processing accuracy of the product can be obtained from metadata. Atmospheric correction is a very important image preprocessing step in Landsat 8 OLI remote sensing inversion. The accuracy of the results has a great impact on the later retrieval accuracy. Here the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes [6]) atmospheric correction module of ENVI software is used for atmospheric correction to obtain the surface reflectance data.

The spectral characteristics of water in Landsat 8 OLI remote sensing data are obviously different from other surface features, which provide a basis for water extraction. There are many automatic water edge extraction algorithms based on remote sensing images, such as single band method, vegetation index method, spectral relationship method and water index method. In this paper, Normalized Difference Water Index (NDWI) is used to extract the water boundary

\[ NDWI = \frac{(B_{\text{Green}} - B_{\text{NIR}})}{(B_{\text{Green}} + B_{\text{NIR}})} \]  

where \( B_{\text{Green}} \) is the reflectance of the green band; \( B_{\text{NIR}} \) is the reflectance of the near infrared band. Through the ratio calculation of the green band and the near infrared band of Landsat 8 OLI image, the purpose of highlighting the water by suppressing other surface features information to a great extent can be achieved, and the surface water boundary can be extracted quickly and conveniently.

In the field of remote sensing, water bodies can be divided into two categories. Type I water is mainly open sea water, and type II water is mainly inshore and inland water. The water quality inversion model of type I is relatively mature, and there are many types of data sources. The water quality of type II is complex, and there is no unified inversion model at present. In recent years, many studies on quantitative remote sensing inversion of water quality show that the key step is to establish a suitable local model by studying the relationship between water spectral characteristics and surface suspended sediment concentration. In this paper, the retrieval model of SSC in the middle reaches of the Yangtze River is used to extract the information of East Dongting Lake [7]

\[ \ln(\text{SSC}) = 0.290 + 47.02R_1 \]  

where \( R_1 \) is band 4 of Landsat 8 OLI. As a sensitive band of suspended sediment, this band has been confirmed by many research results. Figure 2 shows that there is a good correlation between remote sensing reflectance and SSC. Error analysis shows that the minimum relative error (RE) is 0.9%, the maximum RE is 36.9%, and the average RE is 18.1% in 13 validation results at CHS. It is concluded that the remote sensing inversion model can meet the accuracy requirements of qualitative or semi quantitative.
3. Results and Discussion

Based on the above statistical model and ENVI software platform, the distribution of SSC on March 1, 2016, November 28, 2016 and July 26, 2017 is inversed and calculated, as shown in figure 3.

3.1. Spatial Distribution Characteristics

SSC in the East Dongting Lake is generally low, while the sediment transport channel connecting the South Dongting Lake is significantly high. The results show that on March 1, 2016, the water level of Chenglingji was 21.4 m, the average SSC in the east channel of Dongting Lake was 120 mg/L; the average SSC of the north branch in the west area is about 43 mg/L and that of the south branch is 46 mg/L. On November 28, 2016, the water level of Chenglingji was 21.5 m, the average SSC in the east channel of Dongting Lake was 110 mg/L; the average SSC of the north branch in the west area is 40 mg/L and that of the south branch is 45 mg/L. On July 26, 2017, the water level of Chenglingji was 29.9 m, the average SSC in the east channel of Dongting Lake was 33 mg/L; the average SSC of the north branch in the west area is 15 mg/L and that of the south branch is 17 mg/L.

Figure 2. Regression model of suspended sediment concentration SSC (After [7]).

Figure 3. Distribution of suspended sediment concentration SSC. (a) On March 1, 2016; (b) On November 28, 2016; (c) On July 26, 2017.
3.2. Seasonal Variation Characteristics
On July 26, 2017 (in the flood season), the water area of the lake area was 996 km². Affected by the fresh water from the Yangtze River, the SSC in the lake area was low due to the dilution effect, and the concentration distribution was within 40 mg/L. Due to the influence of topography on suspended solids, the front of mud flat in the middle of the lake increases slightly. The results of March 1, 2016 and November 28, 2016 can represent the distribution pattern of SSC in non-flood season. The results show that the water area in non-flood season is about 1/3 of that in flood season, and the average SSC is 40-120mg/L, which is generally higher than that in flood season. The variation of SSC revealed by remote sensing is consistent with the measured data.

4. Conclusions
Under the ENVI software platform, relevant quantitative remote sensing statistical model is adopted to systematically invert and calculate SSC in 3 Landsat 8 OLI scenes acquired from 2016 to 2017. SSC in East Dongting Lake is generally low; SSC of transport channel connecting south Dongting Lake is significantly high, and that in the west of the lake is relatively low. From 2016 to 2017, the average SSC in the east channel of Dongting Lake between 33-120 mg/L; the average SSC of the north branch in the west area is about 15-43 mg/L and that of the south branch is 17-46 mg/L.

The water area in flood season is greatly affected by the dilute water of the Yangtze River. As a result of water dilution effect, the overall SSC is lower than that in non-flood season, and the average SSC is distributed within 40 mg/L. The variation law of SSC in lake area revealed by remote sensing is consistent with the measured data, which provides a new perspective for dynamic tracking and grasping the distribution law and variation trend of suspended sediment in East Dongting Lake.

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