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## Temporal and Spatial Analysis of COD Concentration in East Dongting Lake by Using of Remotely Sensed Data

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### Abstract

Chemical Oxygen Demand (COD) concentrations in East Dongting Lake (East DTL) were retrieved from multi-temporal TM images. Retrieval results showed that the East DTL was in case II waters in the past several years. Furthermore, COD concentration near the coast is higher than in deep waterway, for the water flows much more rapidly in deep waterway than near the coast. The annual changes of the COD concentration in East DTL increased significantly from 1993 to 1999, but the change from 1999 to 2006 in extremely dry seasons is very small. The retrieval results from remote sensing data compared with in-situ data showed that the empirical and semi-empirical models have high precision in retrieving water quality parameters of a certain range.

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*Keywords:* Remote Sensing; Landsat TM; COD; East Dongting Lake

### 1. Introduction

Dongting Lake is the second largest freshwater lake in China, which plays an important role in anti-drought, flood protection and improves the local ecological environment [1]. Accompanied by the economic development and population growth, large quantities of pollutants and sewage were discharged into the lake, which results the rapid decline of the water quality [2]. More than 20 indicators can be used to monitor water quality. The Chemical Oxygen Demand (COD) can reflect the degree of organic pollution, which is the main indicator to monitor the sewage and residue discharged by paper mills around the lake [3, 4]. Methods for COD concentration determination are Potassium Permanganate Index (COD<sub>Mn</sub>) and Potassium Dichromate Oxidation (COD<sub>Cr</sub>). COD<sub>Cr</sub> is designed for industrial wastewater and sewage monitoring can cause serious secondary water pollution, and it is a time and energy consuming method. Yet, COD<sub>Mn</sub> is applicable to assess the quality of drinking water, surface water, lakes and reservoirs [5, 6].

Generally speaking, traditional method for water quality monitoring only used in-situ and profile sampling data. Remote sensing technology developed rapidly in recent years, it now can provide water

quality information of large area more immediate compared with traditional methods. Methods of water quality monitoring by using of remotely sensed data include empirical and semi-empirical models, artificial neural network model and bio-optical model [7, 8]. Carpenter [9] set up an empirical model based on the Landsat MSS data for chlorophyll concentration monitoring. Baban [10] thought that the best relationship between chlorophyll concentration and DN values is Band3/Band1 (Landsat TM). SeaWiFS data were used by Darecki [11] to monitor water quality at West Coast of Ireland. Zhan [12] and Zhang [13] tried to use artificial neural network model to estimate the concentration of chlorophyll in case II waters and thought that NN4 model is the best one. Lahet [14] proposed a three-component bio-optical model to estimate chlorophyll concentration and which were applied in the mouth area of Ebro River (in Spain). In China, Wang [15] and Wang [16] determined the degree of water pollution based on Band4/Band3 (Landsat TM). Zhang [17] established the relationship between water pollution indicators and DN values from TM 2, 3 and 4. Wang [18] set up an empirical model with Landsat TM data to retrieve a number of indicators for water pollution monitoring. Huang [19] established the COD recognition mode based on TM band 1, 2, 3 and 4.

## 2. Data and research area

Dongting Lake located in the north of Hunan province, south to the middle reaches of the Yangtze River, which extends from approximately 28°30'N and 111°40' E to 30°20'N and 113°10'. Four tributaries named Xiang, Zi, Yuan and Li River flow into it from the south, and three tributaries from the Yangtze River named Songzi, Taiping, and Ouchi mouth flow into it from the north. Dongting Lake includes East, South and West Dongting Lake which covers an area more than 2740km<sup>2</sup>.

Dongting Lake area occupied two scenes of the TM/ETM+ image, the path/row numbers were 123/040 and 124/040, which can not be acquired at one day, so the scene 123/40 were chosen in which East DTL was included. Multi-temporal TM data of October 12, 1993, September 11, 1999 and November 1, 2006 was acquired with good qualities and no clouds. In situ data were collected from environmental monitoring stations include Lujiao (No. 11), East Dongting Lake (No. 12), Yueyang tower (No. 13) and Qilishan hydrological station (No. 14) near the exit of Dongting Lake (Fig.1). The corresponding acquisition dates were September 10, 1993, September 7, 1999 and November 4, 2006, closely to the acquisition dates of remote sensing images. These data will be used in studying the spatial distribution and temporal changes of COD<sub>Mn</sub> in the East DTL.

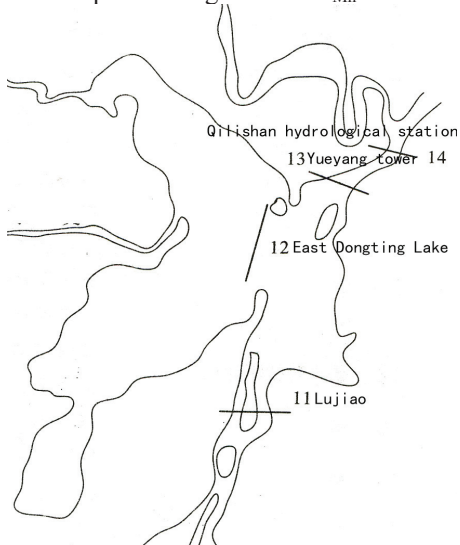


Fig.1 The location of environmental monitoring stations in East DTL

### 3. Method

In the article, the darkest pixel method for radiometric calibration is proposed to remove atmospheric disturbances, and topographic maps with the scale of 1:50000 were used to do the geometric correction.

**Water body extraction.** Mcfeeters [20] proposed a Normalized Difference Water Index (NDWI) to extract water surface, which mixed with a lot non-water area in the final results. For this reason, Xu [21] proposed a Modified Normalized Difference Water Index (MNDWI):

$$MNDWI = (TM_{Green} - TM_{MIR}) / (TM_{Green} + TM_{MIR}) \quad (1)$$

$TM_{Green}$  is green band of TM (TM Band 2);  $TM_{MIR}$  is middle infrared band of TM (TM Band 5). MNDWI values of water surface are higher than 0.

**Retrieve COD<sub>Mn</sub>.** At present, water pollution indicators' retrieval in case II is focused on to set up empirical and semi-empirical models based on Landsat TM / ETM+ data. These models are constructed by selecting best band or combine multispectral bands to estimate water quality parameters with the DN value, radiance, reflectance, band ratio or combinations among bands. Firstly, the following equation is used to convert DN value to spectral radiance [22]:

$$L_{\lambda} = DN \times (L_{max} - L_{min}) / 255 + L_{min} \quad (2)$$

In equation (2),  $L_{\lambda}$  is the spectral radiance of a band,  $DN$  is the grey value of a pixel,  $L_{max}$  and  $L_{min}$  are the spectral radiances for each band corresponding to digital numbers at 0 and 255.

As the water quality parameters have characteristics of logarithmic distribution form, Wang [18] proposed a model with high accuracy to estimate the COD<sub>Mn</sub> concentration in Taihu Lake. The model can estimate COD<sub>Mn</sub> accurately in a certain range between 0 mg · L<sup>-1</sup> and 10mg · L<sup>-1</sup> [23]. The water quality and latitude of Dongting Lake is similar to Taihu Lake, so this model was chosen to estimate COD<sub>Mn</sub> in Dongting Lake [18]:

$$COD_{Mn} = e^{(0.3671+1.2454*\ln(TM2/TM3))} \quad (3)$$

In equation (3), COD<sub>Mn</sub> is Potassium Permanganate Index (mg · L<sup>-1</sup>), TM2 and TM3 are spectral radiances were converted from TM band 2 and band 3.

**Validation.** In situ data were used to estimate the accuracy of remote sensing retrieval results. The indexes include Average Error (AE), Root Mean Square Error (RMSE) and Estimation Accuracy (EA) [24]:

$$AE = \sum_{j=1}^n (\hat{y}_j - y_j) / n \quad (4)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{j=1}^n (y_j - \hat{y}_j)^2} \quad (5)$$

$$EA = (1 - \frac{RMSE}{mean}) \times 100 \quad (6)$$

$y_j$  is in situ data of No. j,  $\hat{y}_j$  is the retrieve value of No. j, mean is the mean value of in situ data.

### 4. Results and analysis

**Water surface changes.** Figure 2 shows the water surface of Dongting Lake (including parts of the Yangtze River) in the autumn of 1993, 1999 and 2006. Total water surface area of East DTL in the

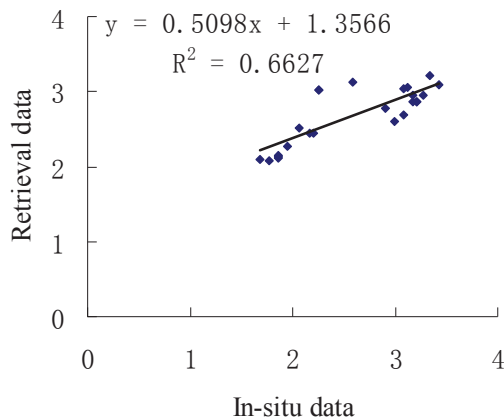
autumn of 1993 was 1424.17 km<sup>2</sup> which was a normal year. In 1999, the water was abundant and the surface area reaches 1741.51km<sup>2</sup>, more than the average area of 1400 km<sup>2</sup>. It is worth mentioning that from the beginning of the century, Dongting Lake extremely affected by severe autumn drought and the Three Gorges Dam. The water surface area of East DTL reduced to 622.27 km<sup>2</sup>, the 44% of its normal area (Table 1). At that time, the water level of Chenglingji was 21.5m, the minimum record in the last 60 years. The main reason is Zi, Yuan, Li River and the surrounding area are sustained drought, and the water level of Yangtze River lower than the entrances of the Songzi, Taiping, and Ouchi mouth, and the water from Yangtze River can not flow into Dongting Lake.

**Table1.** The water surface area of East Dongting Lake

Data	Pixels	Water area[km <sup>2</sup> ]
1993.10.12	1753368	1424.17
1999.09.11	2144056	1741.51
2006.11.01	766227	622.27

**Validation.** Compared with the in-situ data and retrieved results from remote sensing images, AE is 0.08, RMSE is 0.37, and EA is 85%. The correlation coefficient (R) of one- dimensional linear regression equation is higher than 0.8 (Fig.3). The accuracy of the model is satisfactory, and it can efficiently used for water quality monitoring.

**The spatial distribution of COD<sub>Mn</sub>.** Figure 4 shows the regularity of COD distribution in East DTL. Closer to the coast, the higher of COD concentrations. It was mainly due to the sewage output from industrial facilities around Dongting Lake. In the west part of East DTL, the slow velocity of flow lead to the gathering of pollutants thus contributes to the high COD concentration. Water quality in the east part of DTL mainly affected by factories in Yueyang city and Lujiao paper mills. Pollutants from textile, chemical and paper plants mainly included wastewater and suspended particulate matter. Low COD concentration in deep channels of East DTL dues to the water import from South Dongting Lake and the tributaries of Ouchi River accelerate the flow rate of water, which is not fit for the build-up of pollutants.



**Fig.3** The correlation between the retrieval data and In-situ data

**Temporal change of COD<sub>Mn</sub>.** Table 2 shows that in 1993, the water quality of East DTL was in case II ( $>2 \text{ mg}\cdot\text{L}^{-1}$ ,  $<4 \text{ mg}\cdot\text{L}^{-1}$ ), the mean value of COD<sub>Mn</sub> concentration was  $2.59 \text{ mg}\cdot\text{L}^{-1}$ . From 1993 to 1999, water quality of parts of the East DTL belong to case III ( $>4 \text{ mg}\cdot\text{L}^{-1}$ ,  $<6 \text{ mg}\cdot\text{L}^{-1}$ ), the mean COD<sub>Mn</sub>

concentration up to about  $3 \text{ mg}\cdot\text{L}^{-1}$ . Industrial development and population growth had intensified the pollution of lake in this period. From 1999 to 2006,  $\text{COD}_{\text{Mn}}$  concentration had not changed significantly in autumn. It should be noted that this phenomenon only appeared in dry years. Reasons mainly due to the “paper mills closure action” start from 2005 around the Dongting Lake, which have great effects since November 2006. But Luhu Lake in the west of East DTL still suffers from severe pollution.

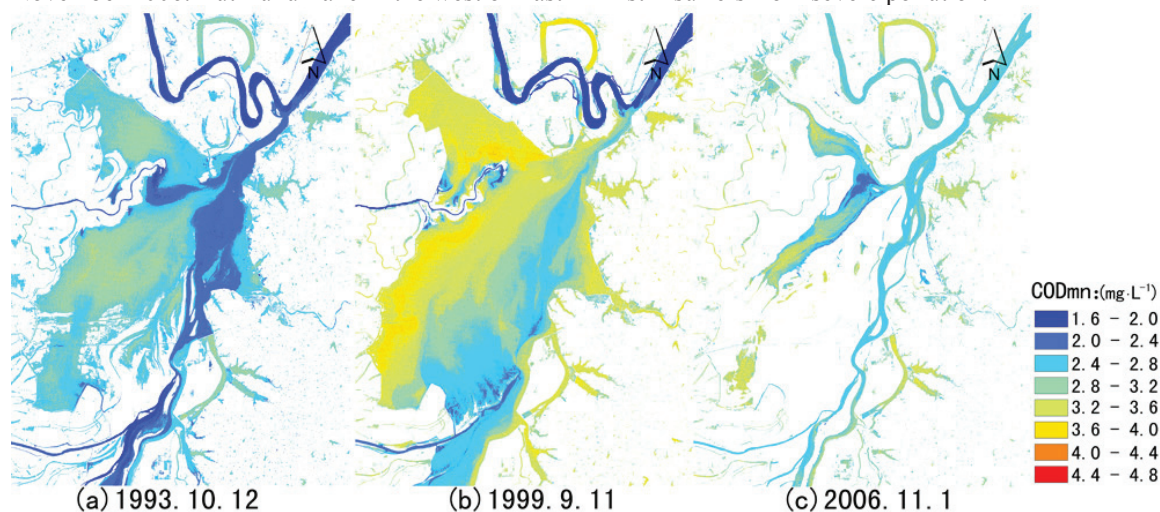


Fig. 4 The distribution of  $\text{COD}_{\text{Mn}}$  in East Dongting Lake

Table 2. Statistics of  $\text{COD}_{\text{Mn}}$  in East Dongting Lake [Unit:  $\text{mg}\cdot\text{L}^{-1}$ ]

Data	Minimum	Maximum	Mean	Standard deviation
1993.10.12	1.69	3.67	2.59	0.34
1999.09.11	1.70	4.45	3.06	0.49
2006.11.01	1.79	4.73	2.90	0.28

## 5. Conclusion and discussion

This paper analyzes the spatial distribution and temporal changes with the empirical model in East Dongting Lake based on Landsat TM/ETM+ data. The results show that the  $\text{COD}_{\text{Mn}}$  concentration in East Dongting Lake belongs to case II. For the spatial distribution, closer to the coastal, the higher of  $\text{COD}_{\text{Mn}}$  concentration. The  $\text{COD}_{\text{Mn}}$  is low at the channel because the water import from South Dongting Lake and the east branch of Ouchi River accelerate the rate of water turnover. For annual changes,  $\text{COD}_{\text{Mn}}$  concentration increased from 1993 to 1999 and increased little from 1999 to 2006 because of the “paper mills closure action”. In addition, remote sensing provides a rapid technological way for collecting water quality parameters in large area. But the accuracy of the empirical and semi-empirical models still need improving. The successive steps and innovative achievements are as follows: (1) The exclusive model used remote sensing data for Dongting Lake needs to be established as soon as possible. The transition from the empirical model and semi-empirical model to the mechanism model merits special attention. (2) The temporal resolution of Landsat TM/ETM+ is too low to reflect dramatic changes in a short time. The Dongting Lake locates in two Landsat TM/ETM+ images and can not obtain high quality images of the entire Dongting Lake at the same time. So the meteorological satellite data could be used to make up this shortcoming in later work.

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