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Evaluating lake eutrophication with enhanced thematic mapper data in Wuhan*

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Abstract By analyzing the enhanced thematic mapper (ETM) images of September 1999, and quality observation data for many consecutive years in several parts of the Donghu Lake in Wuhan, China, the authors discovered a good linear relation between grey scale (GS) abstracted from ETM b5, b7 images and eutrophication level of the lakes, and extended the study to eight other major lakes in the area of Wuhan by using lake eutrophication models. Based on the *in situ* monitoring data, we also evaluated the eutrophication level of the lakes with modified trophic index method brought by M. Aizaki et al. The results of the two methods showed that the most of the lakes were eutrophicated, and even hyper-eutrophicated in some areas. Six of the 8 lakes had very similar trophic state index (TSI) values. Although two of them differed in TSI value, but within an order, while it was different largely from the one by traditional method. The difference of the results between the two methods might have been due to three causative reasons. First, remote sensing technology reflects the overall status of a certain area corresponding to the ETM images in a certain period, but the modified TSI reflects the annual average values of the monitoring spots. Second, the time the ETM images taken is later than that of *in situ* data. Third, ETM images are affected by clouds, water depth, and suspended matter. In short, remote sensing result agreed greatly with the *in situ* monitoring data, indicating that remote sensing technology is feasible and effective for monitoring and evaluating the lake eutrophication in the Wuhan area and it also can be used to evaluate large-scope lake eutrophication.

Key words: lake eutrophication; ETM; remote sensing; Wuhan

1 INTRODUCTION

Increasing eutrophication of lakes in recent years as a result of human impact has become a serious environmental problem in China. Many lakes in the Jianghan Plain, South China, for example, especially near major cities, have been eutrophicated or even hyper-eutrophicated because of fast-growing economy and population. With excessive amount of plant nutrients (primarily phosphorus and nitrogen), domestic sewage, and industrial waste discharged to rivers and lakes in various ways, the balance of nutrients in the water has been broken, which caused over-growth of algae and depletion of dissolved oxygen. The eutrophication impacted adversely on the lake function in water supply, ecosystem activity, fishery, travel industry, and local weather, resulting in very negative influence on sustainable development of the local society and the economy. How to monitor and predict the trophic status of a waterbody timely and accurately is an important mission that scientists should carry out. And it is indispensable for government to take proper measures to reduce the degree of eutrophication.

In the past, studies on lake eutrophication used two methods (Cai, 1997): single-parameter index including character evaluating, parameter evaluating, trophic state index (TSI), and biological character

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index (BCI); and multi-parameter method including function evaluating, statistical method, comprehensive evaluation, and hierarchical analysis (HA). A single-parameter index cannot agree well with the real status although it is easy to use. Multi-parameter approaches can produce more accurate results, but are complicated and need detailed observation data. Many attempts to assess lake trophic levels using sensing technology have been made. Some researchers established a set of statistical models to relate the Landsat data quantitatively to chlorophyll-a concentration and then assessed the trophic levels of waters (Lillesand et al., 1983; Wu et al. 1991; Ekstrand, 1992; Lavery, 1993; She et al., 1996). The objective of this investigation was to examine the usability of remote sensing technology that often applied in geographical studies, for assessing eutrophication levels of the lakes in Wuhan area by using Landsat imagery data, relating the ETM data to freshwaters trophic state index that is considered as a good indicator of trophic status, and applying the method to evaluate many other lakes in a large region.

2 STUDY AREA AND DATA COLLECTION

The Wuhan area is located in the east of the Jianghan Plain in central China, the conjunction of middle reaches of the Changjiang (Yangtze) River and Hanjiang River, 113°41′E–115°05′E, 29°58′N–31°22′N. The total area is 8 467.11 km^2. There are more than a dozen of shallow lakes in the area (Fig.1).

The monitoring data on sub-lake units of Donghu Lake (Fig.1 the inserted) were from a published book: *Ecological Research on Donghu Lake* (Liu, 1992). And the annual average monitoring data of the lakes in Wuhan area were acquired from *Monitoring Results of Lakes and Reservoirs in Hubei Province* (1999) compiled by Environmental Protection Bureau of Hubei Province. The Landsat 7 imagery data were dated in September 1999.

3 EXPERIMENT

3.1 Evaluating lake eutrophication status with *in situ* monitoring data

Many studies (Aizaki et al., 1981; Goda, 1983; Jin et al., 1990; Li et al., 1993) showed good correlation among chemical, physical and biological parameters of eutrophication. Analysis of multiple-year monitoring data on the sub-lakes revealed good relations among chlorophyll-*a* (Chl-*a*), total nitrogen (TN), total phosphorus (TP), and biological oxygen demand (BOD_5). In the study, four monitoring items were chosen as evaluating items: Chl-*a*, TN, TP, BOD_5.

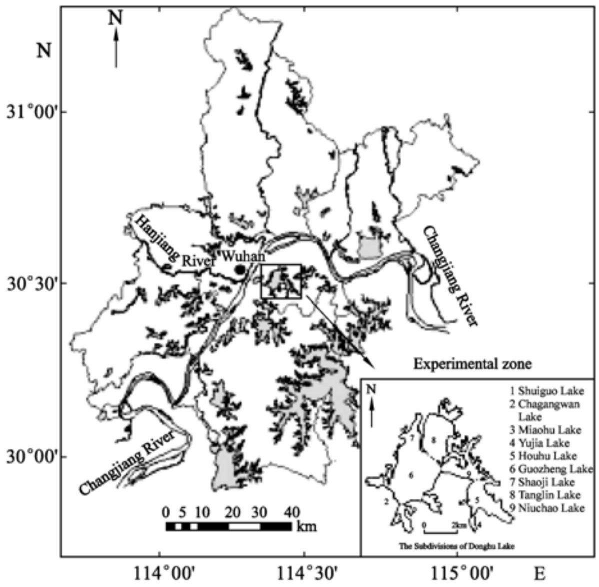

Fig.1 Study area and experimental area

A trophic state index (TSI) is determined based on several biological, chemical and physical indicators, especially the Carlson-type TSI (Carlson, 1977; Walker, 1979; Porcella et al., 1980; Aizaki et al., 1981; Jin et al., 1990; Swanson, 1998), which is the most suitable and acceptable method for evaluating lake eutrophication.

After Carlson (1977) and Aizaki et al., (1981), a modified TSI on scales from 0 to 100 was constructed, based on TP (mg/L of P), TN (mg/L of N), BOD_5 (mg/L), and Chl-*a* (mg/m^3).

The modified trophic state index (TSI_M) is most affected by the Chl-*a* concentration, and ranges from 0 to 100. Supposing TSI_M is 100 at the concentration of 1 000 mg/m^3 and 0 at 0.1 mg/m^3, when Chl-*a* concentration increases by 2.5 times, TSI_M by 10 times correspondently. The result is calculated by:

$$TSI_{M(Chl\text{-}a)}=10*(2.46+\ \ln(Chl\text{-}a)/\ln(2.5)) \quad (1)$$

With Eq.(1), the TSI_M can be related to TN, TP and BOD_5 and determined. The following expressions are used for the calculation with each indicator, respectively:

$$TSI_{M(TN)}=10\times(2.46+(2.150\ 5\ \ln(TN)-3.924\ 2)/\ln(2.5)) \quad (2)$$

$$TSI_{M(TP)}=10\times(2.46+(1.0887\ln(TP)-0.3955)/\ln(2.5)) \quad (3)$$

$$TSI_{M(BOD_5)}=10\times(2.46+(1.3477\ln(BOD_5)-4.715\ 8)/\ln(2.5)) \quad (4)$$

Then the average of $TSI_{M(TN)}$, $TSI_{M(TP)}$ and $TSI_{M(BOD_5)}$ can be calculated as an overall TSI_M value.

$$TSI_{M(AVE)}=(TSI_{M(TN)}+TSI_{M(TP)}+TSI_{M(BOD_5)})/3 \quad (5)$$

According to Carlson (1977) and Xu et al. (2001), the 0–100 scale is divided into 5 levels, each representing a particular trophic state: 0–20 representing oligotrophic, 20–40 mesotrophic, 40–60 meso-eutrophic, 60–80 eutrophic, and 80–100 hyper-eutrophic.

Correlations of Chl-*a* to each TN, TP and BOD_5 (1962-1990) (Liu, 1992) are:

$$\ln(\text{Chl-}a)=2.150\ 5\ln(TN)-3.924\ 2 \quad R^2=0.880\ 4,\ P<0.01$$

$$\ln(\text{Chl-}a)=1.088\ 7\ln(TP)-0.395\ 5 \quad R^2=0.787\ 8,\ P<0.01$$

$$\ln(\text{Chl-}a)=1.347\ 7\ln(BOD_5)-4.715\ 8 \quad R^2=0.882\ 7,\ P<0.01$$

The trophic status of major lakes in Wuhan area are given in Table 1.

Table 1 Eutrophication level of the lakes in Wuhan area*

Lakes in Wuhan Area	TSI_M value based on each parameter			$TSI_{M(AVE)}$	Eutrophication level
	$TSI_{M(TN)}$	$TSI_{M(TP)}$	$TSI_{M(BOD_5)}$		
Tangsun Lake	45.03	52.97	56.25	51.42	Mestro-eutrophic
Liangzi Lake	45.03	60.02	53.46	52.84	Mestro-eutrophic
Futou Lake	47.29	48.82	56.25	50.79	Mestro-eutrophic
Moshui Lake	129.24	85.75	80.80	98.59	Hyper-eutrophic
Dongxi Lake	101.13	73.95	66.77	80.82	Hyper-eutrophic
Zhangdu Lake	42.08	61.39	60.08	54.52	Mestro-eutrophic
Houhu Lake	35.95	62.42	66.07	54.81	Mestro-eutrophic
Hougong Lake	45.30	55.38	58.07	52.92	Mestro-eutrophic

* Data are from "Monitoring Results of Lakes and Reservoirs in Hubei Province (1999)"

Table 2 TSI_M value and grey scale value on each channel image of ETM in sub-lakes of Donghu Lake

Sub-lakes	Channel						
	TSI_M	B1	B2	B3	B4	B5	B7
Chagangwan Lake	72.37	110.7	99.55	75.65	16	9.02	6.9
Miaohu Lake	73.97	90.68	69.44	54.51	11.83	7.59	5.38
Guozheng Lake	66.93	102.96	83.88	60.06	11.23	5.5	3.71
Shaoji Lake	68.92	110.51	92.87	67.25	14.82	7.61	5.38
Yujia Lake	68.36	86.97	70.85	52.55	14.21	7.97	5.38
Shuiguo Lake	57.1	94.39	88.2	60.22	12.61	6.35	4.74
Tanglin Lake	57.04	122.91	109.7	65.03	10.43	5.43	3.63
Houhu Lake	56.73	112.24	92.08	52.34	8.15	5.31	3.32
Niuchao Lake	54.39	107.85	93.18	62.12	10.34	5.46	3.57

3.2 Evaluation model based on ETM Images

It is known that the overall reflectivity of water is low. The reflectivity is relatively high between 0.5–0.7 μm in wavelength. Beyond 0.7 μm, the infrared light is absorbed by water strongly, resulting in very low reflectivity. Therefore, to a water body, the images taken in 1.55–1.75 μm were chosen for better recognition of the boundary of a water body. By analyzing ETM images in seven bands (Table 2), we found that the Band 2 sensors were sensitive to submerged plant, Band 6 sensors were sensitive to hot objects on the ground. However, information on the sensitivity of the Band 6 sensors, and on submerged aquatic vegetation in Band 5 images were few. The water boundary on the ETM Band 5 images was clear enough to distinguish them from other objects. Band 5 is the best band for abstracting the water boundary. When a waterbody is eutrophicated, the Chl-*a* concentration of hydroplankton would show up clearly near infrared wave range (Sun et al, 1997).

First, image geometric correction, image reprojection and noise reduction were applied to ETM images. From the histogram of sub-lake areas on grey images, the mean grey scale (GS) of Donghu Lake divisions was obtained. From the monitoring data of January 1991 to August 1993 (Kuang, 1997), the $TSI_{M\ (AVE)}$ values of sub-lakes were calculated using modified TSI approach. The experimental data in Table 2 show a good linear relation between GS on Bands 5 and 7 images and $TSI_{M\ (AVE)}$ values. The expressions are as follows:

$$TSI_M = 4.459\ 5\ GS_{b5} + 34.131 \quad (R^2=0.656\ 3,\ P=0.008\ 12) \qquad (6)$$

$$TSI_M = 4.915\ GS_{b7} + 41.038 \quad (R^2=0.602\ 1,\ P=0.013\ 97) \qquad (7)$$

Then the GS of the main lakes in the study area was abstracted. Finally, the evaluated results were calculated with Eqs. (6) and (7) (Table 3).

4 RESULTS AND DISCUSSION

Studies on the data in 1960–1970 showed that the TSI_M is an ideal quantitative indicator of lake trophication. So the TSI_M was evaluated as a standard for comparing remote sensing data among different methods.

The histogram of eight lakes (Fig.2) yielded by the two methods shows that six of them have very close TSI values, while the TSIs of other two were different but still within an order and differed largely from the results made with traditional method. For Moshui Lake, as an example, the $TSI_{M(AVE)}$ value was 98.59, while the $TSI_{(b5)}$ and $TSI_{(b7)}$ were 62.63 and 63.94 respectively. The overall values for Dongxi Lake were 80.82, 67.31 and 67.09 for the three ISI_S respectively.

Table 3 Eutrophication assessments of lakes in Wuhan area by remote sensing modeling

Lake	$TSI_{M\ (b5)}$	Trophic state	$TSI_{M\ (b7)}$	Trophic state
Tangsun Lake	53.66	Mestro-eutrophic	54.46	Mestro-eutrophic
Liangzi Lake	46.97	Mestro-eutrophic	46.74	Mestro-eutrophic
Futou Lake	49.87	Mestro-eutrophic	49.74	Mestro-eutrophic
Moshui Lake	62.63	Eutrophic	63.94	Eutrophic
Dongxi Lake	67.31	Eutrophic	67.09	Eutrophic
Zhangdu Lake	60.49	Eutrophic	57.90	Mestro-eutrophic
Houhu Lake	61.38	Eutrophic	60.55	Eutrophic
Hougong Lake	58.48	Mestro-eutrophic	59.67	Mestro-eutrophic

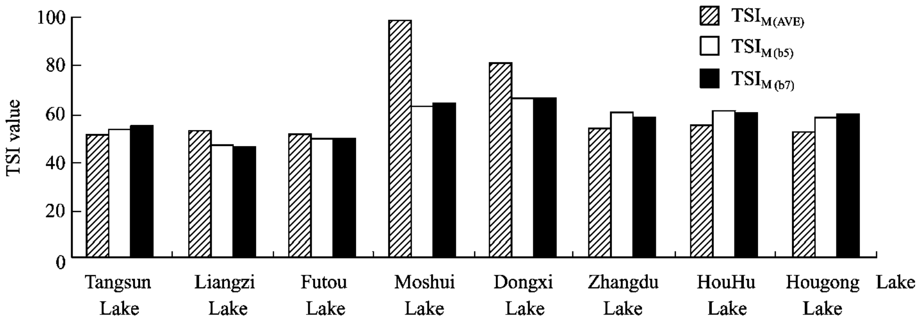

Fig.2 Comparison on the evaluation results between two methods

Three reasons were probably responsible for the difference between the results of the two methods. First, remote sensing technology reflects an overall values of a certain area corresponding to ETM images in a certain period, but modified TSI reflects the annual average values of a monitoring spot. Second, the time when ETM images were taken was later than that of *in situ* data. Third, ETM images are affected by cloud, water depth, and suspended matter, such as sand and hyper-hydrophytes etc. For example, *in situ* data on Moshui Lake and Dongxi Lake, showed that they were in hyper-eutrophic status and that many species had disappeared from the lakes with dramatically increasing Chl-*a* concentration in the water. In the hyper-eutrophic lakes, the correlations between Chl-*a* and TP, TN, and BOD_5 were weak. So the remote sensing values did not agree well with the *in situ* data in Moshui Lake and Dongxi Lake, although, combination of the two methods can often produce quality results indicative of the eutrophication.

5 CONCLUSION

This research shows that remote sensing technique is a good tool for studying lake eutrophication. Three achievements in this work were: (a) the remote sensing results obtained agreed with those by other methods, and the applied model can be modified to match the real work; (b) it can provide information on different trophic status in several areas of a lake by sampling ETM images in grey scale; (c) The method can be also used to evaluate large scale lake eutrophication in much less time and cost.

However, more improvement and *in situ* observation stations are needed and more real time measuring water quality parameters in experimental areas should be established. As weather condition affects the quality and resolution of ETM images then contributes to the accuracy of the model, so that with more improvement, the research would produce better outcome with quality data. In a word, remote sensing technique was proved to be a cost-effective tool in environmental research on eutrophication of the lakes in Wuhan area, and can be also applied in the assessment of lake eutrophication in a large scope.

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