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Using remote sensed data and GIS technique to estimate surface chlorophy11-a of Chaohu Lake

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Abstract— The thematic mapper (TM) images from Landsat-V satellite are characterized by a short acquired period (16 days per cycle), and high spatial and spectral resolution. It is cheap and convenient to establish a dynamic monitoring system for water quality in large lakes by combining TM image data and measured data with a chemical method. In this paper the TM image digitized and GIS technology have been used to acquire digital remote sensing data. At the time the TM image were taken, samples of chlorophyll-a from the surface water of Chaohu Lake were collected and analyzed. Comparing the TM image digitized data with the measured chlorophyll-a data, the relationships have been found and quantitative models have been established . Applying the model as supported by a GIS, the map of chlorophyll-a distribution in the surface of Chaohu Lake has been produced . The average concentration of surface chlorophyll-a of Chaohu Lake is calculated.

Keywords: chlorophyll-a; Chaohu Lake; remote sensing.

INTRODUCTION

The blooming of algae , especially *Microcystis* , is the main characteristics of eutrophication in Chaohu Lake (Yin , 1989) . For this reason , the concentration of chlorophylla in the surface water of Chaohu Lake is an important indicator for the eutrophication assessment (Wang , 1985) . The conventional estimating methods require huge work hours with numerous samples and analysis in the field and laboratory, which is time consuming, costly and can not meet the needs of dynamical monitoring chlorophyll-a in large lakes. Thus it is necessary to find a new method for solving the problem, and applying remote sensing technology may be a potential solution.

Many researchers have published studies on applying remote sensed data to monitor oceanic chlorophyll (Clark, 1970; Tassan, 1980; Kullenberg, 1980; Smith, 1982), and some quantitative models have been found. Bakata and Jerome (1981) have established a model called the "lake optical water quality model "for multicomponents of water , which has been the theoretical basis for further work . In addition , Shu Shouyong *et al* . (1989) have come up with a statistic model for estimating chlorophyll-a using TM data , which was then used to develop a special instrument for measuring chlorophyll-a directly in the field . Meanwhile , Tian Guoliang *et al* . (1988) used remote sensed data from a ground spectrometer to estimate the content of chlorophyll in lakes . In our study , the TM image digitized data have been used to find a more convenient and cheaper way to dynamically estimating the surface chlorophyll-a in Chaohu Lake .

DATA ACQUISITION

Remote sensed data requirement

TM images Band 3 and Band 4 on August 11, 1987 and in scale of 1: 1000000 were obtained from Beijing satellite ground station. The images were digitized into Dipix image processing system by a scanner at the Institute of Remote Sensing, Beijing University. The density of the re-sampled image pixels was 1728 × 1728. Because the re-sampled image covers only an area of about 50 × 50 km² on the original image, the resulting pixel size is almost the same as that of original image. Supported by the Dipix system and a geographic information system (GIS)

Table 1 The mean lightness values of images TM3 and TM4, and the concentrations of surface chlorophyll-a at the sampling sites of Chaohu Lake

Sample No.	TM4	TM3	Chl.-a mg/m³	Sample No.	TM4	TM3	Chl.-a mg/m³
1	213.00	66.00	13.65	17	190.00	91.00	4.10
2	211.00	50.00	16.02	19	150.00	117.00	1.37
3	212.00	83.00	12.29	20	160.00	90.00	2.73
4	209.00	74.00	10.92	21	178.00	86.00	4.16
5	184.00	103.00	2.72	22	147.00	112.00	1.37
6	223.00	77.00	12.29	23	241.00	16.00	57.33
7	185.00	101.00	2.73	24	131.00	121.00	1.37
8	197.00	79.00	6.38	25	103.00	111.00	2.73
9	189.00	97.00	5.46	26	180.00	87.00	8.29
10	151.00	73.00	13.65	27	217.00	68.00	6.38
11	172.00	98.00	4.10	28	215.00	59.00	16.38
12	149.00	103.00	2.73	29	233.00	34.00	49.14
13	201.00	83.00	5.46	30	178.00	76.00	2.73
14	204.00	81.00	6.38	31	216.00	59.00	4.10
15	189.00	113.00	1.37	32	201.00	42.00	38.22
16	245.00	20.00	49.14	34	171.00	66.00	4.09

developed by the Institute of Remote Sensing , Beijing University , the image digitized data have been corrected linearly according to different grey levels and the average value of lightness on the real data sampling points have been calculated , as listed in Table 1.

Field data requirement

The chlorophyll-a samples from the top water of Chaohu Lake (depth less than 0.5 m) were collected during the period dating from August 10 to 12, 1987, which is corresponding with the approximate receiving time of the TM image. The sampling sites have been shown on the sampling map (Fig. 1). Chlorophyll-a was analyzed by the conventional method with filtration, extraction and spectrometric analysis by other scientists (Tu, 1990) and the resulting data are listed in Table 1. It should be noted that because of wind action and surface turbulence on August 12, 1987, the samples collected on that day (samples No. 30 – 34 in Table 1) may be greatly different from the samples collected at the time the TM images were received.

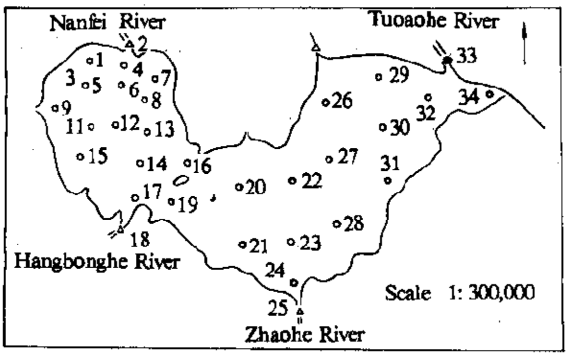

Fig. 1 Sampling sites of chlorophyll-a in Chaohu Lake

RESULTS

From TM3 image of Chaohu Lake, the variation in chlorophyll-a content and its distribution in the lake can be identified clearly. The TM4 image also shows a good view of the distribution of chlorophyll-a. The key aim of this study is to establish a quantitative model to describe the relationship between the brightness of the images and chlorophyll-a concentration. Some researchers have suggested different models based on diverse approximations to the theory of radiation transfer (Lu, 1981). Because of diversification of components in natural water bodies and limitations of spatial and spectral resolution of remote sensors, up to now no widely acceptable theoretical model has yet been found. In practical investigations, most researchers preferred statistical methods for establishing their own regression models for particular water bodies (Tian, 1988).

Comparing the remote sensed data with the field data, some relationships between them can be obtained (Fig. 2 and Fig. 3). From Fig. 2, the relationship between brightness of the TM3 image (TM3) and concentration of chlorophyll-a (C) can be approximately represented by a hyperbolic function:

$$C = K/\mathrm{TM3} + a \ . \qquad (1)$$

From Fig. 2, the relationship between the brightness of the TM4 image (TM4) and concentration of chlorophyll-a (C) can be given by a parabolic function as follows:

$$C = K\ (\mathrm{TM4} - h)^2$$

$$\text{or} \quad C = K \times \mathrm{TM4} - 2 \times h \times K \times \mathrm{TM4} + kh^2 \ . \qquad (2)$$

Combining Equations (1) and (2), and unify the coefficients, the third equation can be obtained:

$$C = a - a1/\mathrm{TM3} + a2 \times \mathrm{TM4} + a3 \times \mathrm{TM4}^2 \ . \qquad (3)$$

Equation (3) looks almost the same form as the model proposed by Khorram (1981). The difference between them is that Khorram's model came from the OCS (Ocean Color Scanner) data used different spectral bands.

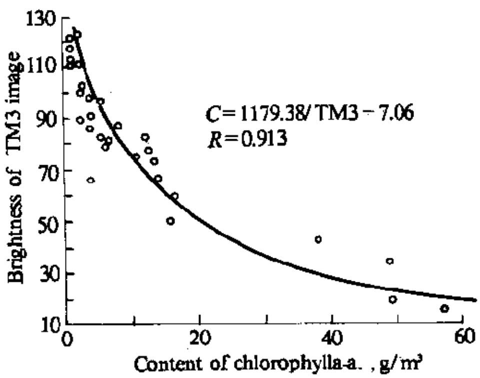

Fig. 2 Relationship between brightness of TM3 image and concentration of chlorophyll-a in Chaohu Lake

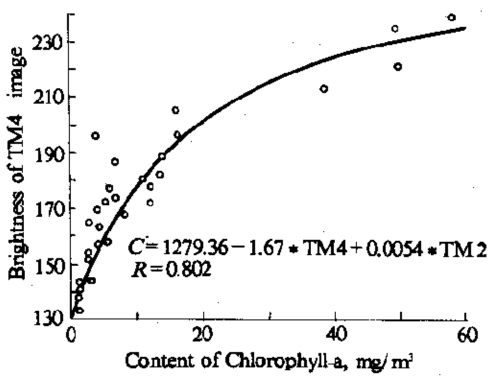

Fig. 3 Relationship between brightness of TM4 image and concentration of chlorophyll-a Chaohu Lake

The coefficients of the equations given above have been estimated by regression analysis. The regressed results have been listed in Table 2. In order to compare with previous models proposed by other authors, two other models are also listed below:

$$\ln C = a + b \times \ln\ (\mathrm{TM4}/\mathrm{TM3}), \quad \text{(Kullenberg, 1980)}, \qquad (4)$$

$$\ln C = a + b \times TM3\ (TM4), \qquad (\text{Shu, 1989}). \qquad (5)$$

The regressed results for these equations are shown in Table 2, where r is the correlation, coefficient and δ_i is average relative error of the regressed results. $\bar{\delta}$ is calculated by following formula:

$$\bar{\delta}_i = 1/n \sum_{i=1}^{n} \delta_i \quad ,$$

$$\delta_i = (Y - \hat{Y}) / \hat{Y} \times 100\% \quad ,$$

where δ_i : relative error for data i : $\bar{\delta}_i$: average relative error; Y : regressed value i : $\hat{Y}$: measured data i; n : number of data .

Table 2 The regression results of six equations

Eq. No.	Models	r	$\bar{\delta}_i$, %
Eq. (1)	$C=1179.38 \times TM3 - 7.06$	0.914	62.3
Eq. (2)	$C=1279.36 - 1.67TM4 + 0.054TM4$	0.802	93.5
Eq. (3)	$C=15.76 + 981.66 \times 1/TM3 - 0.315TM4 + 0.00108TM4^2$	0.94	32.6
Eq. (4)	$\ln C=0.41 + 1.53\ln\ (TM4/TM3)$	0.878	44.18
Eq. (5)	$\ln C= -2.74 + 0.024TM4$	0.737	58.83
Eq. (6)	$\ln C=4.71 - 0.036TM3$	0.905	56. 5

Note: By F-test, six equations are all significant at the test level $\alpha = 0.05$.

All six equations listed in Table 2 show significant regressed results. Among them, the Equation (3) has shown the highest r value and the lowest $\bar{\delta}_i$ value, indicating that it has a regression accuracy much better than others. So the Equation (3) is the best choice of the models for estimating surface chlorophyll-a of Chaohu Lake.

Among the single parameter equations (Equations(1), (2) and (3)), the better one for estimating the concentration of surface chlorophyll-a is the equation containing TM3 (Table 2). It suggests that at Chaohu Lake the absorption of TM3 by surface chloprophyll-a is a more sensitive measure of the change in concentration than back scattering of TM4.

Further consideration of Equation (3) from Fig. 4 and Table 3 shows that Equation (3) yields a relatively poor accuracy in the lower concentration of surface chlorophyll-a, i. e. $C < 5$ mg/m^3, the $\bar{\delta}_i$ reaches to 53.36%, and gives a good accuracy in higher concentration of chlorophyll-a , over 5 mg/m^3, the $\bar{\delta}_i$ is only 15.2%. Therefore under the condition of higher surface chlorophyll-a content , the accuracy of Equation (3) is good enough to monitor the surface chlorophyll-a of Chaohu Lake .

It is not clear why the regressed accuracy of Equation (3) is relatively poor in low chlorophyll-a concentration, probably the presence of color materials such as suspended matter, non-chlorophyll particles and yellow materials have a disturbing effect on the radiation received by remote sensors.

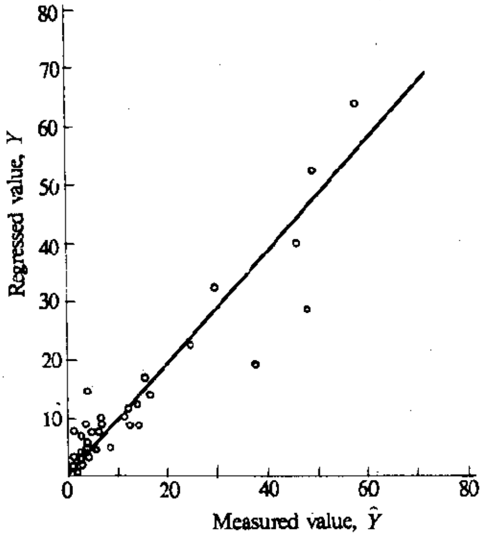

Fig. 4 Comparison of measured value with regressed value for chlorophyll-a on the surface water of Chaohu Lake

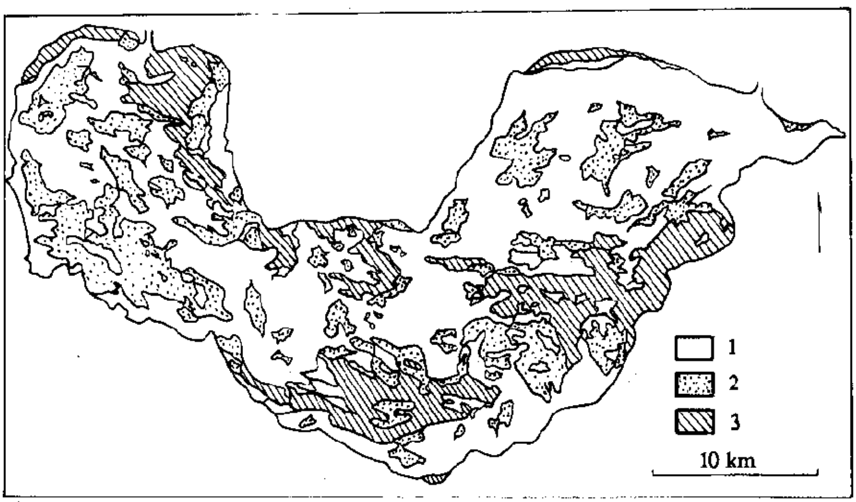

Fig. 5 Regressed chlorophyll-a content in chaohu Lake with TM3 and TM4 image analysis on August 11, 1987
1. < 10 mg/m^3 23% area 2. 10−35 mg/m^3 41% area 3. >35mg/m^3 36% area

Table 3 The comparison of measured data with data regressed by the /Equation (3) for surface chlorophyll-a of Chaohu Lake

No. of samples	Measured value Y	Calculated value Y	r	No. of samples	Measured value Y	Calculated value Y	r
1	13.65	12.39	0.092	17	4.10	5.55	0.354
2	16.02	16.86	0.053	19	1.37	1.10	0.201
3	12.29	9.20	0.252	20	2.73	3.80	0.393
4	10.92	10.22	0.064	21	4.10	5.20	0.268
5	2.72	3.77	0. 385	22	1.37	1.45	0.062
6	12.29	11.48	0.039	23	57.33	63.76	0.112
7	2.73	4.04	0.479	24	1.37	1.05	0.234
8	6.38	7.91	0.239	25	2.73	3.54	0.298
9	5.46	4.79	0.122	26	8.19	5.21	0.364
10	13.65	6.16	0.549	27	6.83	12.55	0.837
11	4.10	3.43	0.164	28	16.38	14.45	0.118
12	2.73	2.23	0.184	29*	49.14	29.71	0.395
13	5.46	7.76	0.422	30*	2.73	6.70	1.454
14	6.83	8.42	0.233	31*	4.10	14.60	2.564
15	1.37	3.36	1.452	32*	38.22	19.31	0.495
16	49.14	52.32	0.065	34*	4.09	8.23	1.012
$\bar{\delta}_i$ (Tot al) =32.6% $\bar{\delta}_i$ (C>5 mg/m^3) 15.2% $\bar{\delta}_i$ (C<5 mg/m^3) =53.36%							

* The data of samples on August 12, 1987 are not used in calculation.

Using Equation (3) and supported by the Dipix image processing system and the GIS system, the distribution map of surface chlorophyll-a concentration over the whole of Chaohu Lake has been obtained (Fig. 5).

The average concentration of chlorophyll-a for whole Chaohu Lake is calculated by the following formula:

$$C = 1/n\sum_{i=1}^{n} Ci$$

where C_i is concentration of surface chlorophyll-a calculated from Equation (3) for pixel i on the image, n is the number of pixels of the total Chaohu Lake area on the image, C the average concentration is calcutated as 19.6 mg/m^3.

Because of the *Microcystis* floats on the surface of Chaohu Lake, its accumulation and dispersion on the surface of water depends heavily on wind condition. On a windy day, *Microcystis* can float from one place to another rapidly. An attempt has been made to look for the relation between the distribution of chlorophyll-a and sources of pollution. Unfortunately no discernible relation has been found. This was likely being caused by strong wind. On the other hand, due to the large area of Chaohu Lake, the conventional sampling method make it impossible to collected samples synchronously. Usually one run of sampling work took more than three days. This was a major problem for chlorophyll-a monitoring at Chaohu Lake. The method used here have solved the problem because the every pixel on the TM images is taken at the same time. The average concentration estimated by the method can represent the concentration of surface chlorophyll-a at a particular time.

DISCUSSIONS

Evaluation of quality of the TM image digitized data

In general, only the computer compatible tape (CCT) data can give a linear relation with the irradiance of targets. The brightness of images or the transmissivity of images are of linear relation to irradiance of targets only under the condition where the contrast index (r) of the film is equal to 1. Unfortunately in most cases, r is not equal to 1 because its value depends on many factors such as the properties of film and film processing conditions. For this reason, it is difficult to compare the image digitized data with each other. The linear correction method used in the present work is to increase the comparable quality of the data. If more than two images taken at different time have to be used, some new methods with be needed to correct the unlinear problems. One of the methods proposed here is that some special targets which radiation does not change with time can be chosen as reference correction points. Different images can be corrected by comparing with them.

Cost-benefit efficiency

The total expense of the research including image acquisition, image processing and information extraction (without field work) is about five hundreds US dollars. If a lake to be studied corresponds with one TM image, the expense of monitoring the lake four times per year is about two thousands US dollars, which is cheap enough for a local lake monitoring station, especially doing it in China.

Some factors influencing the accuracy of the estimating

Yellow substance and chlorophyll-a are both important materials in determining the color of natural lake water. The previous study (Ji, 1984) has shown that both of them can be easily differentiated from one another by studying the spectra of their radiation in red and infrared (TM3 and TM4 band). So by using the models of TM3 and TM4 as used in the research, the influence of the yellow substances is negligible. In addition, non-chlorophyll suspended matters may be another important influencing factor in estimating chlorophyll-a. That is because they are mainly composed of quartz, feldspar and clay minerals which reflect TM4 wavelength strongly, in contrast to chlorophyll-a which absorb TM4 wavelength sharply. If there is a lot of non-chlorophyll suspended matters in the top water, the chlorophyll information on the TM3 and TM4 images could be strongly disturbed by them. In order to solve the problem, it is necessary to establish a multi-components optical water quality models. Of cause, that needs to be investigated in the further. Another influence factor is atmospheric condition. In the research no atmospheric corrections were considered on the assumption that the area of Chaohu Lake is small enough that the atmospheric condition above it can be considered constant.

CONCLUSIONS

1. The TM image digitized data can be used to estimate the concentration of chlorophyll-a of Chaohu Lake. From the information extracted from the images the distribution map of chlorophyll-a in Chaohu Lake can be produced and the average concentration of chlorophyll-a at the time the image was taken can be easily estimated by using the models and GIS system. Because of all the information can be obtained synchronously, dynamically and rapidly, the method used here would be a considerably improved way to estimate dynamically chlorophyll-a at Chaohu Lake.

2. The best model of estimating chlorophyll-a is the Equation (3).

Under higher concentration of chlorophyll-a ($C > 5$ mg/m^3), the model has the regression average relative error $\bar{\delta}_i$ is 15.2%, which is quite sufficient to monitor the chlorophyll-a content of the surface water of Chaohu Lake.

3. The TM3 image digitized data is more sensitive to the change in chlorophyll-a than the TM4 image digitized data for Chaohu Lake. If the single image data has to be used, the TM3 image would be a better choice.

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