遥感方法应用于湖泊富营养化评价的研究

Study on Application of Remote Sensing to Assessment of Lake Eutrophication

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摘要　利用武汉东湖各子湖多年可靠的地面监测资料和1999年9月Landsat-7的TM各波段的卫星遥感数据，建立了各子湖的营养状态指数与TM各波段图像上灰度值之间的关系模型：一元线性模型、多元回归模型，运用这些模型对武汉各湖泊进行富营养化评价。同时基于地面监测资料，用日本学者相崎守弘提出的修正富营养化指数法对武汉主要湖泊的富营养化程度进行评价。结果显示，武汉湖泊多处于中富营养状态，遥感评价结果与地面监测结果基本一致。指出利用遥感方法进行湖泊水体富营养化监测评价是可行的、有效的，利用该方法可进行大范围的湖泊富营养化调查评价。

关键词：湖泊富营养化　评价　遥感方法

1　引言

我国是一个湖泊众多的国家。武汉等大中城市周边的湖泊，由于城市规模的不断扩大、人口的增长和经济的快速发展，湖泊的富营养化问题愈来愈严重，许多湖泊已接近富营养，有的甚至达到极富营养的程度。湖泊和水库特别是大中城市附近的水体，由于大量生活污水和工业废水的排入，水体易于富营养化。大量营养元素的排入，特别是N、P等营养元素的迅猛增加，破坏了水体原来的营养平衡，造成藻类的大量繁殖，这是水体富营养化的最显著特征。湖泊的富营养化，极大地降低了水体的生态环境、水产养殖、旅游观光、水源供应等多种功能，严重地阻碍了城市经济社会的可持续发展。如何及时准确地了解湖泊富营养化的状况和监测其变化的趋势，对于政府及有关部门制定相应的对策措施，减轻湖泊的富营养化、充分发挥湖泊水体应有的各种功能，均有十分重要的意义。在国内外的湖泊富营养化调查评价中，采用的方法主要有：单一参数评价指数的方法，如特征法、参数法、营养状态指数法和生物指标评价法；多参数的综合评价方法有函数法、统计评分法、模糊综合评判法、层次分析法。本文拟采用遥感与地面监测相结合的方法，既省时省力又可以保证一定的准确度。首先利用地面资料对武汉湖泊的营养状态做出评价，然后利用建立的遥感评价模型对这些湖泊做出营养化评价，最后对比分析评价结果。

2　利用地面监测资料评价

由湖北省环境质量报告书[1)]可知，湖北省湖泊的主要污染物是总氮、总磷和高锰酸盐指数。考虑到高锰酸盐指数的监测数据不全，采用五日生化需氧量作为评价项。选取叶绿素a(Chla)、总磷(TP)、总氮(TN)、以及五日生化需氧量(BOD_5)作为评价水体富营养化程度的关键因子，利用地面监测资料进行评价。国内外大量的研究表明，与湖泊富营养化有关的水质参数之间存在某种相关关系，国内的研究也是如此，Chla与TP、TN、BOD_5之间的相关关系分别为

国家发展计划委员会、国家地质调查局资助项目，编号0799210014。

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1）湖北省环境质量报告书(1996)，1997.

0.84、0.82、0.79[2]。

利用东湖各子湖(水果湖、郭郑湖、庙湖、汤林湖、菱角湖、牛巢湖、后湖、喻家湖、筲箕湖、茶港湾等)多年的地面监测数据,通过相关分析得出叶绿素 a 浓度与总氮、总磷以及五日生化需氧量之间的对数相关关系(见表1)。

引用日本学者相崎守弘提出的修正富营养化指数 TSI_M 法,以叶绿素 a 浓度为基准,分为 0~100 的连续值:假定 $TSI_M=100$ 时,Chla 的浓度为 1 000mg/m³,而 $TSI_M=0$ 时,Chla 的浓度为 0.1mg/m³,且 Chla 浓度每增加 2.5 倍时,对应的 TSI_M 指数值增加 10,其结果可用如下公式表示:

$$TSI_M(\mathrm{Chla}) = 10[2.46 + \ln(\mathrm{Chla})/\ln(2.5)] \quad (1)$$

根据表1中藻类 Chla 与 TN、TP 及 BOD_5 的相关关系,从而可以得到 TN、TP 及 BOD_5 的 TSI_M 指数计算公式:

$$TSI_M(\mathrm{TN})=10\{2.46+[2.1505\ln(\mathrm{TN})-3.9242]/\ln(2.5)\} \quad (2)$$

$$TSI_M(\mathrm{TP})=10\{2.46+[1.0887\ln(\mathrm{TP})-0.3955]/\ln(2.5)\} \quad (3)$$

$$TSI_M(\mathrm{BOD_5})=10\{2.46+[1.3477\ln(\mathrm{BOD_5})-4.7158]/\ln(2.5)\} \quad (4)$$

然后对这 3 项指数求均值得出各湖泊的富营养状态值,即综合评分公式:

$$TSI_M(\mathrm{AVE})=[TSI_M(\mathrm{TN})+TSI_M(\mathrm{TP})+TSI_M(\mathrm{BOD_5})]/3 \quad (5)$$

规定湖泊富营养化程度划分标准:

$TSI_M(\mathrm{AVE})<20$,贫营养;$20 \leqslant TSI_M(\mathrm{AVE})<40$,中营养;$40 \leqslant TSI_M(\mathrm{AVE})<60$,中富营养;$60 \leqslant TSI_M(\mathrm{AVE})<80$,富营养;$TSI_M(\mathrm{AVE}) \geqslant 80$,极富营养。

根据该标准,武汉各主要湖泊的富营养化评价结果[2)]见表2。

表1 Chla 与 TN、TP、BOD_5 的相关关系式
Table 1 Correlative formula between Chla and TN、TP、BOD_5

相关因子	关系式	相关性	解释
ln(Chla)~ln(TN)	$y=2.150\,5x-3.924\,2$	$R^2=0.880\,4$, $P=1.810\,79\times10^{-4}$	y代表ln(Chla),x代表ln(TN)、ln(TP)以及ln(BOD_5);
ln(Chla)~ln(TP)	$y=1.088\,7x-0.395\,5$	$R^2=0.787\,8$, $P=0.001\,4$	
ln(Chla)~ln(BOD_5)	$y=1.347\,7x-4.715\,8$	$R^2=0.882\,7$, $P=1.689\,5\times10^{-4}$	

表2 武汉湖泊营养状态评价结果
Table 2 Assessment result of eutrophication of lakes in Wuhan by *situ* monitoring data

湖泊名称	各单项指数值			综合评分TSI_M(AVE)	富营养化程度
	TSI_M(TN)	TSI_M(TP)	TSI_M(BOD_5)		
武汉东湖	78.86	73.87	68.53	73.87	富营养
武汉沙湖	105.12	76.95	83.03	88.37	极富营养
汉口东西湖	101.13	73.95	66.77	80.82	极富营养
汉阳墨水湖	129.24	85.75	80.80	98.59	极富营养
江夏区汤孙湖	45.03	52.97	56.25	51.42	中富营养
江夏区梁子湖	45.03	60.02	53.46	52.84	中富营养
江夏区斧头湖	47.29	48.82	56.25	50.79	中富营养
汉阳后官湖	45.42	55.70	59.10	53.41	中富营养
新洲区涨渡湖	42.08	61.39	60.08	54.52	中富营养
黄陂区后湖	35.95	62.42	66.07	54.81	中富营养

3 利用遥感的方法评价

由于水体的总体反射率较低,在波长 0.5~0.7μm 处相对较高,0.7μm 以后由于水体对红外光吸收严重,反射率很低。因此对水域变化选用 1.55~1.75μm 的多时域影像较好。TM band5 影像上的水体界限轮廓清晰,与其他地物差别显著,提取水体方便准确。

通过对 TM 各波段影像的分析得知:b_2 对沉水植物较敏感,b_6 对热源较敏感,而 b_5 不易受沉水植物的影响,b_1、b_2、b_3 图片的假彩色合成图反映出的地物与实际地物具有很好的对应关系。当水体富营养化时,浮游植物中的叶绿素对近红外光有明显的"陡坡效应"。

3.1 遥感一元线性模型

在 TM 各波段影像上,对已作出营养状态评价的东湖各子湖的的灰度值进行取样(见表3)。

2)湖北省地面水1999年湖泊水库监测结果统计表,2000.

表 3　武汉东湖各子湖 TSI_M 及 TM 各波段灰度值的实验数据

Table 3　Data of TSI_M and TM image gray degree of subdivision lakes of Lake Donghu in Wuhan

东湖各子湖	TSI_M	b_1	b_2	b_3	b_4	b_5	b_7
茶港湾	72.37	110.7	99.55	75.65	16	9.02	6.9
庙湖	73.97	90.68	69.44	54.51	11.83	7.59	5.38
郭郑湖	66.93	102.96	83.88	60.06	11.23	5.5	3.71
筲箕湖	68.92	110.51	92.87	67.25	14.82	7.61	5.38
喻家湖	68.36	86.97	70.85	52.55	14.21	7.97	5.38
菱角湖	57.1	94.39	88.2	60.22	12.61	6.35	4.74
汤林湖	57.04	122.91	109.7	65.03	10.43	5.43	3.63
后湖	56.73	112.24	92.08	52.34	8.15	5.31	3.32
牛巢湖	54.39	107.85	93.18	62.12	10.34	5.46	3.57

经过分析发现，湖泊的营养状态指数 TSI_M 与 TM b_5 及 b_7 图像的灰度值平均值线性关系很显著。

运用最小二乘法，计算得 TSI_M 与 b_5、b_7 图像的灰度值线性关系式如下：

TSI_M 与 b_5 图像的灰度值关系式为：

$$TSI_M = 4.4595\, b_5 + 34.131 \quad (R^2=0.6563,\ P = 0.00812) \tag{6}$$

TSI_M 与 b_7 图像的灰度值关系式为：

$$TSI_M = 4.915\, b_7 + 41.038 \quad (R^2 = 0.6021,\ P = 0.01397) \tag{7}$$

根据以上建立的一元线性模型(6)、(7)，可分别计算出武汉各湖泊的富营养化指数值(见表 4)。

表 4　武汉湖泊营养化遥感评价结果对照表 1)

Table 4　Contrast between assessment results of eutrophication of lakes by RS in Wuhan

湖库名称	$TSI_M(b_5)$	$TSI_M(b_7)$	$TSI_M(b)$	$TSI_M(\ln b)$
汉口东西湖	67.31	67.09	62.36	62.93
汉阳墨水湖	62.63	63.94	68.61	69.51
江夏区汤孙湖	53.66	54.46	42.58	42.38
江夏区梁子湖	46.97	49.00	43.30	35.68
江夏区斧头湖	49.87	49.74	45.15	36.72
汉阳后官湖	58.48	59.67	50.84	51.61
新洲区涨渡湖	60.49	57.90	52.79	55.62
黄陂区后湖	61.38	60.55	50.79	58.75

1) $TSI_M(b_5)$、$TSI_M(b_7)$、$TSI_M(b)$、$TSI_M(\ln b)$ 分别代表运用(6)、(7)、(8)、(9)式所计算得出的湖泊营养化指数值。

3.2 逐步回归分析

(1) 由表 3 的数据进行多元逐步回归分析得出湖泊的富营养化指数 TSI_M 与各波段上湖泊的灰度值 b_i 之间的回归模型：

$$TSI_M = 31.786 + 0.80314\, b_1 - 0.86626 b_2 + 5.5712 b_7 \tag{8}$$

回归的方差分析如下：F=14.70437，$F(3,5)_{0.01}$=12.1；因为 $F>F(3,5)_{0.01}$，所以这种相关关系特别显著。相关系数 R=0.89819，P=0.00649。

(2) 根据采集的东湖各子湖富营养化指数与各相应湖泊在卫星影像上的灰度值的自然对数数据，作多元逐步回归分析。

建立的线性回归模型如式(9)所示。

$$TSI_M = -40.5901 + 84.65563 \ln b_1 - 73.3874 \ln b_2 + 26.53653 \ln b_7 \tag{9}$$

回归的方差分析如下：F=16.13614，$F(3,5)_{0.01}$=12.1；因为 $F> F(3,5)_{0.01}$，所以这种相关关系特别显著。相关系数 R=0.90638，P=0.00528。

根据以上建立的多元回归模型(8)、(9)可分别计算出武汉各湖泊的富营养化指数值，如表 4 所示。

4 结果与讨论

在所用的遥感模型评价方法中，同时评价的 8 个湖泊中有 6 个湖泊的评价值很接近。与地面监测资料评价结果相比，利用一元回归模型的评价值，除汉阳墨水湖评价结果相差较大外，有 7 个湖泊是很接近的。与地面监测资料评价结果相比，利用多元回归模型的评价结果有 5 个湖泊是一致的，其中汉阳墨水湖相差较大，比地面监测资料评价结果偏低较多；梁子湖和斧头湖的评价值稍偏低。总体而言，评价结果吻合性较好。

导致少数湖泊偏差较大的因素可能有：

(1) 富营养化的评价标准有所不同，级别的划分是一个比较粗糙的范围，不同的划分标准得出的结果会有不同程度的出入；

(2) 地面的监测资料是采样的年平均值，结果与布点的方法及数量范围有关；

(3) 湖泊的灰度采样用的是全湖的灰度平均值、而地面监测采用的是一些代表性的采样点数据，从而

不可避免的会带来一些误差;

(4) TM 图像的获取时间与地面监测的时间有所出入,其结果必然会受到一定的影响;

(5) 反映在TM影像上的地物信息较多,泥沙、水生植物(非藻类)等可能一定程度上对结果产生干扰;

(6) 湖泊的水深和底质等状况对结果也会存在一定的影响。

5 结论

与传统的地面实测相比,卫星遥感技术在湖泊的富营养化监测评价中有明显的优势:

(1) 遥感技术可快速、大范围、周期性的对湖泊的富营养化状态进行监测,也可以进行长年的不同时段不同季节的监测对比,能全面及时地掌握湖泊的富营养化状况;

(2) 遥感技术的大部分工作可在室内计算机上完成,与在地面设立监测网进行人工实测相比,省时省力。在对同一湖泊的不同水域可同时完成营养状态的监测评价。

同时,本文作为实验性研究,也有一些不足和亟待完善的地方;

(1) 本文只是利用一些特征因子对湖泊营养化状态作出了富营养化程度的评价,应该在充分认识湖泊富营养化发生机理的基础上,寻求建立更为合理的评价模型和评价方法;

(2) 除东湖之外,其它湖泊缺少详细的地面同步实测资料,评价模型完全建立在东湖实验区的地面监测数据之上,可能影响了评价模型的代表性。建议今后在更大范围不同区域选择若干个湖泊进行与卫星同步和详细的地面监测资料,特别是叶绿素 a 浓度的监测,以对评价模型进行改进,取得更好的评价结果。

(3) Landsat7 TM 遥感图像的可见光波段的波谱分辨率仍不够高,较难区分浑浊悬浮物对叶绿素的影响,若能利用成像光谱进行评价,预计能取得更理想的结果。在一些图幅中,由于图像局部受天气状况尤其是云雾的影响,评价结果可能与实际情况有出入。这些方面都有待在今后研究中改进。

总之,遥感作为一种新型的湖泊水体富营养化监测手段是经济可行的,适合于大范围的湖泊水体的富营养化监测。

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责任编辑 唐东雄 (收稿日期:2003-10-28)

Practice
Xiamen

Analysis on Effect of Water Pollution in Lake Taihu Basin on Water Quality of Lake Taihu

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The actuality and evolvement reasons of water pollution in Lake Taihu basin were obtained by clearly analyzing the amount of pollutants discharged, monitoring results of water quality, development of industry and agriculture, change of population, amelioration of standard of living, depauperation of the eastern Lake Taihu, change of nutrient in mud and ecological system imbalance. This provided bases for understanding the pollution actuality and formulating countermeasures of pollution prevention in Lake Taihu.

Key words: Lake Taihu basin
Status quo of water pollution
Pollution evolvement
Water quality detection
Ecosystem imbalance
Pollutant discharge
Nutrition change

Study on Target Model of Integrated Water Management for River Basin in China

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In the context of river basin, the characterstics of inter-regional externality of water issues, the characteristics of complicated macro-system of water environment, and the optimization of administrative cost of water management demonstrate the necessity of implementing integrated water management (IWM) in the unit of river basin. According to these characteristics, the target model of IWM should be provided with functions as follows: information functions, including collecting, communicating and publishing information; planning functions, including harmonizing special plans and preparing integrated plans; policy functions, including advising, decision-making, evaluating and feedback; coordination functions, including equalizing benefit and arbitrating conflicts; and implementing key engineering projects directly. Based on the principle of public participation and principle of efficiency and equity, the basic framework of target model of IWM in China is, to establish a State Water Management Committee and some independent river basin committees in the level of main river basins, and in the level of branches and sub-basin, to establish water board popularized in the world.

Key words: Integrated water management
Public participation
Target model

Constructive Perspectives on the Control System of Medical Waste in Shanghai

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So far the medical wastes in Shanghai has not been properly managed. Recently more and more attention has been paid to this issue as the hazard of the wastes polluted the environment heavily. Collection, labeling, transfer, disposal and treatment of medical wastes have been planned, aiming to improve and perfect the existing treatment facilities. The concrete measures were proposed and the state of art situation in Shanghai was also described.

Key words: Medical waste
Control syctem
Shanghai

Study on Application of Remote Sensing to Assessment of Lake Eutrophication

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Through analysis of the Thematic Mapper (TM) images in September, 1999, and reliable monitoring data for many years of several subdivision lakes of Lake Donghu in Wuhan, the authors discovered a good linear relation between the value of grey degree (GD) abstracted from TM band 5, band 7 images and Trophic State Indices (TSI_M) of the lakes, and also established two regression models between TSI_M and the value of GD, and evaluated all the main lakes in Wuhan according to the models. At the same time, based on the *situ* monitoring data, also evaluated the trophic status of lakes in Wuhan by other method "Amended Atrophic Indices" which was brought forward by Japanese scholar Morikiro Aizaki. The evaluated results by remote sensing models and *situ* monitoring data showed that most of lakes were mesotrophic. Some disparity existed between the results by different models. There are three reasons for the difference between the results of the different methods. First remote sensing technology reflects the average values of a certain corresponded with TM images in a certain period, but "Amended Atrophic Indices" reflects the annual average values of the monitoring spots. Second, the time of TM Images is later than that of *situ* monitoring data. And third, TM images are affected by cloud, water depth, suspension, such as sand, hyper-hydrophytes, etc. In a word, the result of remote sensing was almost agreed with the monitoring data. It means that sensing technology is feasible and effective to monitoring and evaluating the lake eutrophication in Wuhan and it can be also used to evaluate lake eutrophication in large scope.

Key words: Lake eutrophication
Remote sensing
Assessment

The *Status Quo* of Waste Electric and Electronic Equipment Recycling Industry in USA

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In recent years, as an emerging industry, waste electric and electronic equipment recycling has been growing up rapidly in the United States. Its economic scope, production capacity, industrial structure and technology were summarized. Meanwhile the background for the industrial development and legislations governing the practice were also presented.

Key words: Waste electric and electronic equipment (WEEE)
Recycling industry
USA

Survey and Analysis on the *Status Quo* of Fine Particulates Pollurtion in Shanghai

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The $PM_{2.5}$ samples were collected at 7 sites during 2000 ~ 2001 in Shanghai and monthly continuous monitoring has been taken separately in Oct. 2000, Jan. 2001, Apr. 2001 and Jul. 2001. The highest $PM_{2.5}$ concentration was 185.9 $\mu g/m^3$ appearing at Baoshan monitoring site, and the lowest was 2.9 $\mu g/m^3$ appearing at Nanhui monitoring site. The annual average of $PM_{2.5}$ concentration was 60.1 $\mu g/m^3$ at 7 monitoring sites in the whole city of Shanghai. Among 7 monitoring sites, it was 65.2 $\mu g/m^3$ at 6 monitoring sites in urban area and 41.3 $\mu g/m^3$ at control site in Nanhui The highest monthly average of $PM_{2.5}$ concentration was 80.2 $\mu g/m^3$ in winter and the lowest was 35.9 $\mu g/m^3$ in summer. $PM_{2.5}$ pollution in Shanghai is quite serious comparing with the US standard (15 $\mu g/m^3$).

Key words: Fine particulate
Environmental quality
Concentration distribution
Shanghai