The 2nd International Conference on Earth Observation for Global Changes (EOGC 2009)

May 25 - 29, 2009

Chengdu Yinhe Dynasty Hotel

Chengdu, Sichuan, China

Final Program

Organizers

Local Organizers

Water total suspended solids (TSS) Mapping Using Landsat TM data over Penang Island, Malaysia

H. S. Lim*, M. Z. MatJafri, K. Abdullah, N. Mohd. Saleh, H. T. Teh and M. R. Mustapha @ Rosli
School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia.

ABSTRACT

Environmental monitoring through the method of traditional ship sampling is time consuming and requires a high survey cost. The aim of this study was to test the applicability of Landsat TM image for water quality determination based on the water optical properties over Penang Island, Malaysia. The algorithm was developed based on the reflectance model, which is a function of the inherent optical properties of water and this in turn can be related to the concentration of its constituents. Water samples were collected during the time of image acquisition and their locations were determined using a handheld GPS. The digital numbers for each band corresponding to the sea-truth locations were extracted and then converted into radiance values and reflectance values. The reflectance values were used for calibration of the water quality algorithm. The efficiency of the proposed algorithm was investigated based on the observations of correlation coefficient (R) and root-mean-square deviations (RMS) with the sea-truth data. The proposed algorithm produced the highest R value and lowest RMS value was used to generate the TSS map. The TSS map was colour-code and geometric correction was performed. This study indicates that TSS mapping can be carried out using Landsat TM data over Penang, Malaysia.

Keywords: Landsat TM, TSS.

1. INTRODUCTION

Environmental pollution is of increasing concern nowadays because all the daily activities of man are related to the environment. Water pollution problem becomes increasingly critical in this present-day, whether in the developed or developing countries. Suspended matter deposited in reservoirs reduces their storage capacity and suspended material reduces the light penetration in water thus minimising the fish production (Choubey, 1998). Suspended sediments causes problems in water bodies and to some extent indicates pollution and erosion in an area. Remote sensing is widely used for many scientific applications. Remote sensing technique can overcome the problems. Water quality mapping by using remote sensing data provides better result at a relatively cheaper cost (Weatherbee and Kleamas, 1998). Remote sensing is a useful and advanced technique for mapping water quality. Determination of water quality parameters using regression algorithm technique has been adopted by many workers [Dekker, et al., (2002), Tassan, (1993) and Doxaran, et al., (2002)].

The standard traditional mapping and monitoring techniques have already become too expensive compared to the information achieved for environmental use. A solution could be to optimize our efforts and more frequently base our surveillance on remote sensing techniques to improve the information content and limit the cost (Ostlund 2001). Remote sensing offers potentially a significant source of information and methods are being developed for operational large-scale monitoring of water quality (Koponen et al. 2002). Water quality parameter used in this study is the Total Suspended Solids (TSS).

Various models have been used to correlate water quality with remote sensing measurements. An empirical calibration approach that uses regression analysis has been widely quoted in the literature (Forster et al. 1993). The regression models rely on simultaneous measurements of ground data and the remote sensing observations. Such a calibrated algorithm is site specific because it depends on the type of water constituent involved in the calibration analysis. The use of an algorithm which does not require complementary ground data has been demonstrated by Hakvoort et al. (2002).

*hslim@usm.my; phone 604-6533663; fax 604-6579150; www.usm.my/phy

In this study, satellite scene from Landsat TM was used for water quality mapping around Penang Island, Malaysia. This study indicates the possibility of using Landsat TM image for monitoring coastal water quality. Multi-spectral algorithms were used to determine the TSS concentration on the surface of seawater. The proposed algorithm was used to generate the water quality map. Finally, the digital image was geometrically corrected to produce a water quality map.

2. STUDY AREA

The study area is the Penang Island, Malaysia within latitudes 5° 12' N to 5° 30' N and longitudes 100° 09' E to 100o 26' E. The map of the region is shown in Figure 1. The satellite image was acquired on 24 February 2007. Water samples were collected simultaneously with the airborne images acquisition from a small boat. The sampling locations were determined using a handheld GPS. Water samples were analysed in the laboratory to determine the TSS by using the standard method as suggested by Strickland and Parson (1972).

Fig. 1. Study area.

3. OPTICAL MODEL OF WATER

A new algorithm was developed for detecting and mapping water pollution from the digital camera images. The algorithm used was based on the reflectance model which is a function of the inherent optical properties of water and this in turn can be related to the concentration of its constituents.

A physical model relating radiance from the water column to the concentrations of the water's constituents provides the most effective way to analyze remotely sensed data for water quality studies. Remote sensing reflectance, R, is related to the irradiance reflectance just beneath the water surface, R_{ird} [Doxaran et al., 2002] and is calculated as:

$$R = \frac{(1-\rho)(1-\sigma)R_{ird}}{n^2(1-rR)Q} \quad (1)$$

where ρ = internal Fresnel reflectance

σ = air-water Fresnel reflection at the interface

r = water-air reflection

n = refractive index (1.34)

Q = π

Equation (1), according to Doxaran et al., 2002, can be approximated as

$$R = 0.182\frac{R_{ird}}{Q} \quad (2)$$

For estuaries water, backscatter is much less significant than absorption [Gohin et al., 2002]. Therefore, the irradiance reflectance just below the water surface [Morel and Prieur, 1977), Siddorn et al. (2001) and Kirk (1984)] is:

$$R_{ird} = 0.33\frac{b}{a} \quad (3)$$

where

b = backscattering coefficient

a = absorption coefficient

Then equation (2) can be simplified to

$$R = c\frac{b}{Qa} \quad (4)$$

where c = constant

The inherent optical properties are determined by the contents of the water. The contributions of the individual components to the overall properties are strictly additive [Gallegos and Correl, 1990].

For a case involving a simple water quality component, suspended sediment, P, the equation can be expressed as [Gallegos and Correl, 1990]

$$a(\lambda) = a_w(\lambda) + a_p(\lambda) \quad (5)$$

The absorption of pure seawater is practically the same as the pure water in the visible region (400□-700nm). Absorption by dissolved salts is known to be negligible in this region [Gallegos and Correl, 1990]. The absorption related to each substance is expressed as the product of its concentration, P (non-chlorophyllous particles) and its corresponding specific absorption coefficients $a_p^*(\lambda)$.

Therefore the total absorption

$$a(\lambda) = a_w(\lambda) + a_p^*(\lambda)P \quad (6)$$

Similarly for the back-scattering coefficients [Prieur and Sathyendranath, 1981]

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda)) \quad (7)$$

where $b_{bw}(\lambda)$and $b_{bp}(\lambda)$, are the back-scattering coefficients of water and suspended matter respectively. Then

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}^*(\lambda)P \quad (8)$$

The symbol * denotes specific coefficients. The magnitude of $b_{bw}(\lambda)$ is $0.5b_w(\lambda)$ because the molecular volume-scattering function of pure sea water, $b_w(\lambda)$, is symmetrical [Gallie and Murtha, 1992].

For a case involving water quality component, suspended sediment, P, the equation can be expressed as [Gallie and Murtha, 1992]

$$R(\lambda) = R = 0.33\frac{(0.5b_{bw}(\lambda) + b_{bp}^*(\lambda)P)}{(a_w(\lambda) + a_p^*(\lambda)P)} \quad (9)$$

where

$b_{bw}(\lambda)$ = backscattering coefficient
$a_w(\lambda)$ = absorption coefficient
a_p* = sediment specific absorption coefficient
P = suspended sediment

TSS concentration can be obtained by solving Equation (9)

$$P=\frac{1-\dfrac{a_w R}{0.165 b_{bw}}}{-\dfrac{0.33 b_{bp}^{*}}{0.165 b_{bw}}+\dfrac{a_p^{*}}{0.165 b_{bw}} R} \quad (10)$$

4. REGRESSION ALGORITHM

We have to know two parameters (the backscattering and absorption coefficients) to solve Equation 10. But these parameters were not available from this study area. So we used regression technique to solve the equation. From Equation 10, we can simplify the regression model as shown by Equation 11 for TSS.

$$P=\frac{1+a_0 R}{a_1+a_2 R} \quad (11)$$

where the coefficient a_j, j = 0, 1 and 2 are the functions related to the coefficients used in equations (10) which are to be determined empirically from regression analysis. This equation is used to relate reflectance values from the image bands to the observed TSS concentrations.

5. DATA ANALYSIS AND RESULTS

A Landsat TM satellite scene of the study area captured on 24 February 2007 was used in the present investigation. Figure 2 show the raw Landsat TM satellite scene. All image-processing tasks were carried out using PCI Geomatica version 10.1.3 digital image processing software at the School of Physics, Universiti Sains Malaysia (USM).

Fig. 2. Raw satellite image.

The digital numbers (DN) for each band corresponding to the sea-truth locations were determined. The satellite image was then geometrically corrected by second order polynomial equation using the nearest neighbor method. Digital numbers for each band corresponding to the sea-truth data collected simultaneously with the digital images acquisition were determined for later use in the algorithm calibration analysis. The DNs values extracted using the window size of 3 by 3 was used due to the higher correlation coefficient (R) with the sea-truth data. The extracted DN values were converted into irradiance values and then converted into reflectance values. First, radiance was calculated from DN by:

L_i=a*DN_i+c

where L is radiance; i is the spectral band; a is the spectral band gain; and b is the spectral band offset.

The gain and offset values are unique for each spectral band acquired by a particular sensor. Then, the signal in each band and at each pixel was converted to At-Sensor Spectral Reflectance values using the following equation:

$$R_i = \frac{\pi L_i d^2}{ESun_i Sin\theta}$$

where R is the unitless planetary reflectance; i is the spectral band; L is radiance; d is the Earth-Sun distance; Esun is mean the solar atmospheric irradiance; and θ is solar zenith angle in degree. This correction compensated for different sun angles at different acquisition dates. The At-Sensor Spectral Reflectance is then corrected for atmospheric effects using ATCOR2 in the PCI Geomatica version 10.1.3 image processing software. In this study, Landsat TM 5 signals were used as independent variables in our calibration regression analysis.

A good result was produced by the proposed model, which achieved the correlation coefficient of about 0.88 and low RMS value of 7.6 mg/l. A map of the chlorophyll parameter was then generated using the calibrated proposed algorithm. Then the generated chlorophyll map was geometrically corrected using the cubic convolution method to produce a smoother map. The generated map was filtered using 3 by 3 pixels averaged to remove random noise and then colour-coded for visual interpretation as shown in Figure 3. The local distribution pattern is shown on the generated TSS map. Higher concentration areas are distributed near the river mouths and the shallow southern region of the channel. The plumes in the river mouths were created by river discharges. In the shallow water, the turbidity might be caused by bottom resuspension due to waves and wind actions. The concentration seems to be relatively lower in the deeper part of the sea.

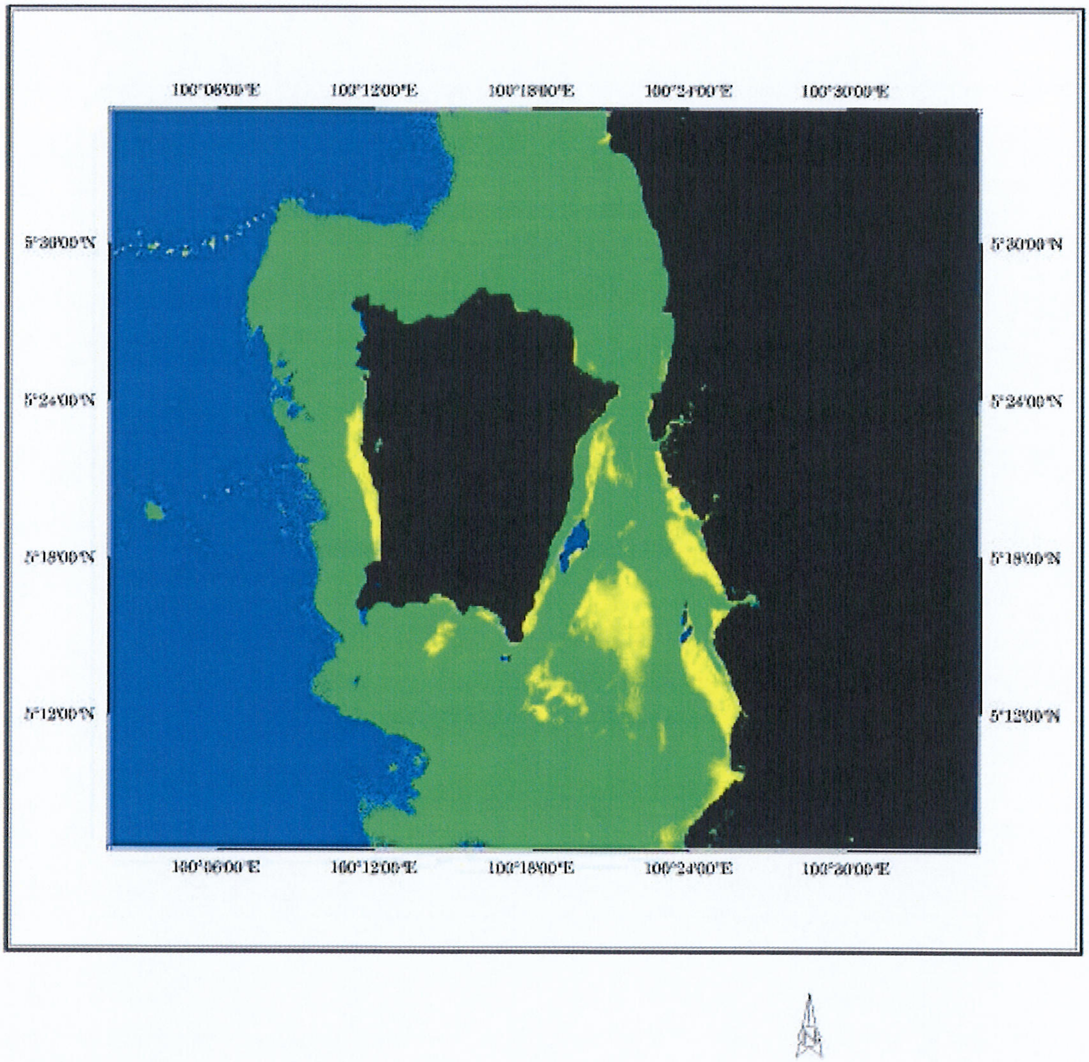

Fig. 3. Map of TSS around Penang Island, Malaysia (Blue < 50 mg/l, Green = (50-10) mg/l, Yellow = (100-150) mg/l, Orange = (150-200) mg/l, Red = (>200) mg/l and Black = Water and cloud area)

6. CONCLUSION

Landsat TM can provide a useful tool for water quality mapping around Penang Island. The application of the developed algorithm for mapping of TSS using the present data set produced reliable and accurate result. The feasibility of applying the present technique for operational use has to be further validated. Therefore more data will be required for this verification analysis.

ACKNOWLEDGEMENTS

This project was carried out using the Science Fund and USM short term grants. We would like to thank the technical staff that participated in this project. Thanks are extended to USM for support and encouragement.

REFERENCES

[1] Baban, S. M. J. 1993, *Detecting water quality parameters in the Norfolk Broads, U.K., using Landsat imagery.* International Journal of Remote Sensing, 14(7), 1247-1267.

[2] Choubey, V. K., 1998, Laboratory experiment, field and remotely sensed data analysis for the assessment of suspended solids concentration and secchi depth of the reservoir surface water. International Journal of Remote Sensing, 19, 3349-3360.

[3] Dekker, A. G. and Peters, S. W. 1993. *The use of the Thematic Mapper for the analysis of eutrophic lakes: a case study in the Netherlandsd.* International Journal of Remote Sensing, 14(5), 799-821.

[4] Doxaran, D., Froidefond, J. M., Lavender, S. and Castaing, P., 2002, Spectral signature of highly turbid waters application with SPOT data to quantify suspended particulate matter concentrations. *Remote Sensing of Environment*, 81, 149–161.

[5] Forster, B., Xu, B. D. and Sha, X. W. 1993, *Satellite remote sensing of pollution and its distribution in near-coastal waters.* Asian-Pacific Remote Sensing Jounal, 6(1), 1-10.

[6] Gallegos, C.L. and Correl, D. L., 1990, Modeling spectral diffuse attenuation, absorption and scattering coefficients in a turbid estuary. Limnology and Oceanography, 35, 1486–1502.

[7] Gallie, E.A. and Murtha, P.A., 1992, Specific absorption and backscattering spectra for suspended minerals and chlorophyll-a in Chilko Lake, British Columbia. Remote Sensing of Environment, 39, 103–118.

[8] Gohin, F., Druon, J. N. and Lampert, L., 2002, A five channel chlorophyll concentration algorithm applied to SeaWiFS data processed by SeaDAS in coastal waters. International Journal of Remote Sensing, 23(8), 1639–1661.

[9] Hakvoort, H., De Haan, J., Jordan, R., Vos, R., Peters, S. and Rijkeboer, M., 2002, Towards airborne remote sensing of water quality in the Netherlands – validation and error analysis. ISPRS Journal of Photogrammetry & Remote Sensing, 57, 171-183.

[10] Kirk, J. T. O., 1984, Dependence of relationship between inherent and apparent optical properties of water on solar altitude. Limnology and Oceanography, 29, 350–356.

[11] Koponen, S., Pulliainen, J., Kallio, K. and Hallikainen, M. 2002. Lake water quality classification with airborne hyperspectral spectrometer and simulated MERIS data. Remote Sensing of Environment, 79, 51-59.

[12] Morel, A. and Prieur, L., 1977, Analysis of variation of ocean color. Limnology and Oceanography, 22, 709 – 722.

[13] Ostlund, C., Flink, P., Strombeck, N., Pierson, D. and Lindell, T., 2001, Mapping of the water quality of lake Erken, Sweden, from imaging spectrometry and Landsat Thematic mapper. *The Science of The Total Environment*, 268, 139-154.

[14] Prieur, L. and Sathyendranath, S., 1981, An optical classification of coastal and oceanic waters based on the specific spectral absorption curves of phytoplankton pigments, dissolved organic matter and other particulate materials, Limnology and Oceanography, 26, pp. 671-698.

[15] Siddorn, J. R., Bowers, D. G. and Hoguane, A. M., 2001, Detecting the Zambezi river plume using observed optical Properties. Marine Pollution Bulletin, 42(10), 942–950.

[16] Strickland, J. D. H. and Parsons, T. R., 1972, A practical handbook of seawater analysis.

[17] Tassan, S. (1993). An improved in-water algorithm for the determination of chlorophyll and suspended sediment concentration from Thematic Mapper data in coastal waters. International Journal of Remote Sensing, 14(6), 1221–1229.

[18] Weatherbee, O. and Kleamas, V. (1998). *Coastal Courier - News about the coastal ecosystem health project*. [online]. http://www.ocean.udel.edu/publications/Newsletter/coastal/1998/Coastal98.pdf.