Monitoring Turbidity in Prai River Estuary Using Digital Camera Imagery

H. S. Lim, M. Z. MatJafri, and K. Abdullah
School of Physics,
Universiti Sains Malaysia,
11800 Penang, Malaysia.
Tel: +604-6533663, Fax: +604-6579150
E-mail: hslim@usm.my, mjafri@usm.my, khirudd@usm.my

***Abstract*- Turbidity distribution in river and coastal waters can be measured with optical remote sensing instruments. In this study, the feasibility of using digital camera imagery for estimating water turbidity using digital camera imagery in the Prai River estuary, Penang, Malaysia, was investigated. Digital camera imagery was acquired on 1st Septembers 2003. The objective of this study is to evaluate the performance of our empirical turbidity retrieval algorithm for water turbidity mapping. Water samples were collected during a 3-hour period simultaneously with the airborne image acquisition above the study area. The colour image was separated into three bands (red, green and blue) for multispectral analysis. The samples were analyzed for turbidity measurement using a handheld turbidity meter. The algorithm used is 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. The three-band algorithm was generated using the three visible bands namely red, green and blue bands. All the in situ data were used for algorithm calibration. The root mean square deviation (RMS) obtained in this study with this empirical algorithm was 1.19 NTU. We used the mosaic digital camera imagery to obtain a bigger study area. The result obtained indicated that reliable estimates of turbidity values for the Prai River estuary, Penang, Malaysia, could be retrieved using this technique.**

***Keywords*- Turbidity, Remote Sensing, NTU, Airborne.**

I. INTRODUCTION

Water quality monitoring is crucial for any effort to produce information in support of water conservation and decision-making. Monitoring normally needs to be carried out as cost-effectively as possible relative to the type of information needed [1]. Traditionally, monitoring of water quality is carried out through shipboard water sampling and laboratory analysis. Such methods are not only labour-intensive, but sampling is also discrete in time and space. Remote sensing offers an alternative method for monitoring water bodies on a large scale [2]. For example, the water quality study [3], algal blooms study [4], mineral mapping [5], plankton blooms study [6], haze study [7], phonological study [8], sediment and volcanic-hoste precious metal systems study [9], sea surface Sun-induced chlorophyll fluorescence [10], rice monitoring study [11], ocean colour and sea-grass study [12], sea surface temperature study [13] and land use study [14]. Remote sensing provides useful information for sediment transportation mapping in the coastal region [15]. Remote sensing can be used for various purposes. Satellite data analysis represents the most suitable method for monitoring natural environments [16]. However, we used digital camera imagery captured from low altitude to overcome the problem of the difficulty in obtaining a cloud free satellite scene at Equatorial region.

Remote sensing techniques have been widely used for water quality studies in coastal regions and in inland lakes [17], [18], [19], [20], [21], [22], [23]. The purpose of the study was to assess the quality of airborne digital images for turbidity measurements of Prai River, Penang. Mostly, satellite data will be used for water quality monitoring, but the major disadvantage of satellite data is that, they cannot see through the clouds. Airborne digital camera imageries were selected in this present study because of several reasons. First, the airborne digital image provides higher spatial resolution data for mapping a small study area. Second, the airborne digital data acquisition can be carried out according to our planned surveys. The satellite observation times are fixed for a particular study area. Third, the digital imagery offers many advantages over film-based cameras. Furthermore, the study areas were located in the equatorial region where the sky is often covered by clouds. Therefore satellite remote sensing, especially for sensing in the visible and infrared regions is difficult. Water quality can be measured in various parameters, e.g. total suspended solids, chlorophyll, Secchi Disk, turbidity and etc. We used turbidity as our water quality parameter in this study. An algorithm was generated the retrieval of turbidity distribution. A normal digital camera, Kodak DC290 was used as a sensor to capture images from a light aircraft, Cessna 172Q, at low altitude of 4400 feet.

II. STUDY AREA

The location of the study area is in the vicinity of the Prai river estuary, Penang. It is situated between latitudes 5º 22' N to 5º 24' N and longitudes 100º 21' E to 100º 23' E (Fig. 1). Images were taken during the flight between 9 a.m to 11 a.m on 1 September 2003. Turbidity readings were measured by using a handheld turbidity meter. Digital camera imagery was captured simultaneously during the acquisition of the water samples. Images were taken from a low altitude flying aircraft at 4400 feet. Water samples locations were determined using a handheld GPS.

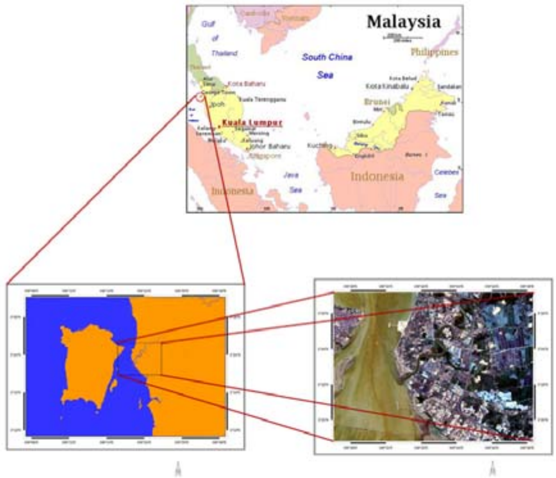

Fig. 1 The study area

III. WATER OPTICAL MODEL

A physical model relating radiance from the water column and the concentrations of the water quality constituents provides the most effective way for analysing remotely sensed data for water quality studies. Reflectance is particularly dependent on inherent optical properties: the absorption coefficient and the backscattering coefficient. The irradiance reflectance just below the water surface, R(λ), is given by

$$R(\lambda) = 0.33 b_b(\lambda) / a(\lambda) \tag{1}$$

where λ is the spectral wavelength, b_b is the backscattering coefficient and a is the absorption coefficient [24]. 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 [25].

For the case of two water quality components, i.e. chlorophyll, C, and suspended sediment, P, the simultaneous equations for the two channels can be expressed as

$$R(\lambda_1) = R_1 = 0.33\frac{(0.5b_{bw}(\lambda_1) + b_{bc}^*(\lambda_1)C + b_{bp}^*(\lambda_1)P)}{(a_w(\lambda_1) + a_c^*(\lambda_1)C + a_p^*(\lambda_1)P)} \quad (2a)$$

$$R(\lambda_2) = R_2 = 0.33\frac{(0.5b_{bw}(\lambda_2) + b_{bc}^*(\lambda_2)C + b_{bp}^*(\lambda_2)P)}{(a_w(\lambda_2) + a_c^*(\lambda_2)C + a_p^*(\lambda_2)P)} \quad (2b)$$

where $b_{bw}(i)$ is the backscattering coefficient of water, b_{bc}*and b_{bp}* are the specific backscattering coefficients of chlorophyll and sediment respectively, $a_w(i)$ is the absorption coefficient of water, a_c*(i) and a_p*(i) are the specific absorption coefficients of chlorophyll and sediment respectively [26].

IV. REGRESSION ALGORITHM

Solving the above simultaneous equations (2a and 2b) for TSS concentration yields the series consisting of the terms R_1 and R_2

$$P = \frac{a_1 + a_2R_1 + a_3R_2 + a_4R_1R_2}{a_5 + a_6R_1 + a_6R_2 + a_7R_1R_2} \quad (3a)$$

$$\Rightarrow \quad P = \frac{A_1 + A_2R_1 + A_3R_2 + A_4R_1R_2}{1 + A_5R_1 + A_6R_2 + A_7R_1R_2} \quad (3b)$$

where a_j, j = 0, 1, 2, … are the functions of the coefficients in equation (3b) which are to be determined empirically using multiple regression analysis. The algorithm can be extended to the three-band method as expected

$$P = \frac{t_1 + t_2R_1 + t_3R_2 + t_4R_3 + t_5R_1R_2 + t_6R_1R_3 + t_7R_2R_3 + ...}{1 + t_8R_1 + t_9R_2 + t_{10}R_3 + t_{11}R_1R_2 + t_{12}R_1R_3 + t_{13}R_2R_3 + ...} \quad (4)$$

The higher order terms in Equation (4) have small values, so, Equation (4) can be approximated as Equation (5) for TSS.

$$P = \frac{e_1 + e_2R_1 + e_3R_2 + e_4R_3}{1 + e_5R_1 + e_6R_2 + e_7R_3} \quad (5)$$

Turbidity is a measurement of the decrease in transparency of stream water as light is scattered by suspended particulate matter [27]. Results from other studies have shown that turbidity measurements may correlate closely with sediment concentrations in streams. Research conducted by other studies showed a simple linear regression between turbidity and sediment measurements [28]. So, Equation (5) can be approximated as Equation (6) for turbidity (Tur).

$$Tur = \frac{e_1 + e_2R_1 + e_3R_2 + e_4R_3}{1 + e_5R_1 + e_6R_2 + e_7R_3} \quad (6)$$

The coefficients e_j, j = 0, 1, 2, … are then empirically determined. This equation is used to relate reflectance values from the image bands to the observed turbidity concentrations. Processing of the digital camera data was carried out as follows. The original digital camera image was georeferenced. The image comprised three visible bands was saved as a *.tiff format image. In this study, we used digital number (DN) instead of reflectance values.

V. DATA ANALYSIS AND RESULTS

Image processing was performed in the School of Physics, Universiti Sains Malaysia using PCI Geomatica 10.1.3 software. The digital camera imagery acquired on 1st September 2003 was high spatial resolution imagery with 480 pixels by

720 lines (Fig. 2). A total of eight digital images were mosaic to obtain a bigger study area (Fig. 3). The mosaic image was separated into three visible wavelength bands assigned as red, green and blue bands for multiband algorithm calibration.

The total number of turbidity measurement points corresponding to the simultaneous airborne data was 15. The mosaic image was rectified based on the image-to-image registration. The second order transformation polynomial was applied to resample the image using the nearest neighborhood method. The RMS error in rectification analysis was below 0.5 pixels. The digital numbers (DN) corresponding to the water locations were extracted for each bands. The DNs value extracted was used for algorithm calibration. The plot of the relationship between the DN's for each channel and the turbidity values is shown in Fig. 4. The accuracy of the generated algorithm was examined based on the correlation coefficient (R), and root mean square deviation, (RMS). Fig. 5 shows the graph of the estimated and measured turbidity values using the generated algorithm.

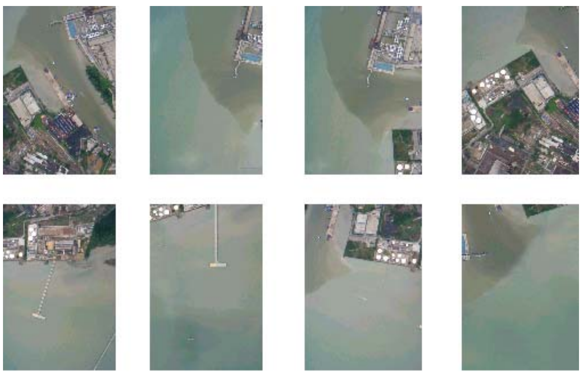

Fig. 2 Raw images used in this study

Fig. 3 The mosaic image and the in situ water samples point

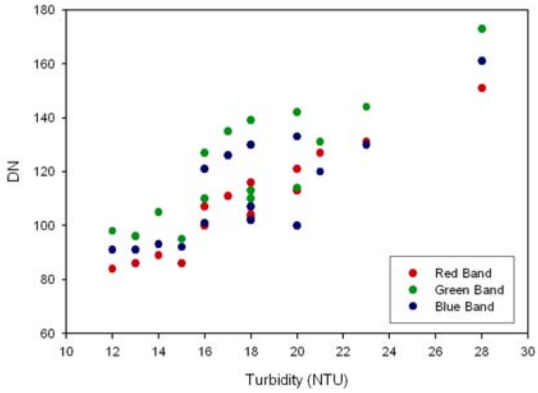

Fig. 4 Graph of digital numbers versus turbidity values

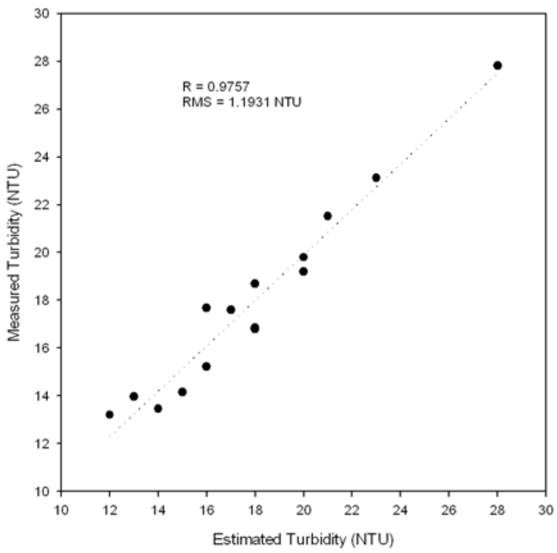

Fig. 5 Relationship between measured and predicted turbidity

The algorithm with three bands inputs, which gave a correlation value of 0.9757 and a standard error of 1.1931 NTU, is given by the following equation for turbidity:

$$Tur = \frac{4.6033 + 0.2398R_1 - 0.4881R_2 + 0.3545R_3}{1 + 0.0053R_1 - 0.0278R_2 + 0.0217R_3} \qquad (6)$$

where R_1, R_2 and R_3 stand for the DNs of the digital camera red, green and blue bands respectively. The proposed algorithm was used to generate a turbidity map. In order to perform image analysis for water areas, the land areas were manually masked using Adobe Photoshop software. To reduce image noise an average filter of 3 by 3 window size was applied to the generated turbidity map. Finally, the turbidity map was colour-coded for visual interpretation (Fig. 6).

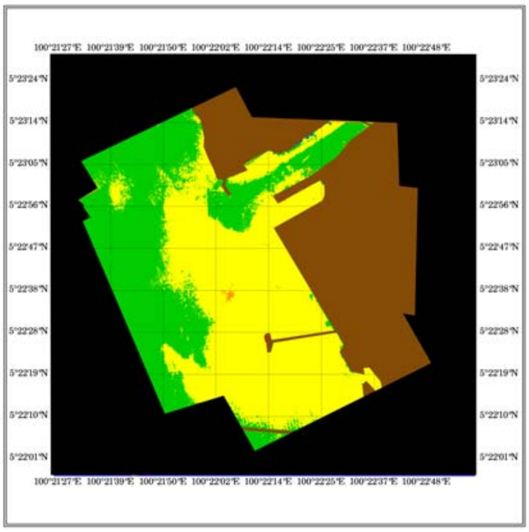

Fig. 6 Map of turbidity near Prai River Estuary [Blue = (< 10 NTU), Green = (10-20) NTU, Orange = (20-30) NTU, yellow = (30-40) NTU, Red = (>40) NTU, Brown = Land and Black = area outside image]

VI. CONCLUSION

This study showed that the generated algorithm produced accurate result for turbidity mapping. A bigger converge of study area can be obtained by mosaic several overlapped images. It also showed that a digital camera could provide useful remotely sensed images for water quality application.

ACKNOWLEDGEMENTS

This project was carried out using the Malaysia Government IRPA grant no.08-02-05-6011, Science Funds and USM short term grants. We would like to thank the technical staff who participated in this project. Thanks are extended to USM for support and encouragement.

REFERENCE

[1] ERKKILA, A. and KALLIOLA, R. (2004) Patterns and dynamics of coastal waters in multi-temporal satellite images: support to water quality monitoring I the Archipelago Sea, Finland. Estuarine, Coastal and Shelf Science, Article In Press.

[2] YEW-HOONG Gin, K., TECK KOH, S., LIN, I.I. and SOON CHAN, E. (2002) Application of spectral signatures and colour rations to estimate chlorophyll in Singapore's coastal waters, Estuarine, Coastal and Shelf Science, 55, 719-728.

[3] Reddy, M. A. (1997). A detailed statistical study on selection of optimum IRS LISS pixel configuration for development of water quality models. International Journal of Remote Sensing, 18(12), 2559−2570.

[4] Lavender, S. J. and Grom, S. B. (2001). The detection and mapping of algal blooms from space. International Journal of Remote Sensing, 22(2−3), 197−201.

[5] Gallie, E. A., Mcardle, S., Rivard, B and Francis, H. (2002). Estimating sulphide ore grade in broken rock using visible/infrared hyperspectral reflectance spectra. International Journal of Remote Sensing, 23(11), 2229−2246.

[6] Svejkovsky, J. and Shdanley, J. (2001). Detection of offshore plankton blooms with AVHRR and SAR imagery. International Journal of Remote Sensing, 22(2−3), 471−485.

[7] Ahmad, A. and Hashim, M., (2000). Determination of haze API from forest fire emission during the 1997 thick haze episode in Malaysia using NAA AVHRR data. Malaysia Journal of Remote Sensing & GIS, 1, 77−84.

[8] Pellikka, P. (2001). Application of vertical skyward wide-angel photography and airborne video data for phonological studies of beach forests in the German Alps. International Journal of Remote Sensing, 22(14), 2675−2700.

[9] Spantz, D. M. (1997). Remote sensing characteristic of the sediment and volcanic-hoste precious metal systems: imagery selection for exploration and development. International Journal of Remote Sensing, 18(7) 1413−1438.

[10] Babin, M., Morel, A. and Gentill, B. (1996). Remote sensing of sea surface Sun-induced chlorophyll fluorescence: consequences of natural variations in the optical characteristic of phytoplankton and the quantum yield of chlorophyll a fluorescence. International Journal of Remote Sensing, 17(12), 2417−2448.

[11] Abu Bakar, S. B., Yusof, S., Chuah, H. T. and Ewe, H. T. (1999). Rice monitoring using Radarsat data. Proc. of The 2nd Malaysia Remote Sensing dan GIS Conference, 26−28.

[12] Hashim, M., Abdullah, A. and Rasib, A. W. (2000). Extracting ocean colour and sea-grass information from remote sensing data: opportunities and limitations. Malaysia Journal of Remote Sensing & GIS, 1, 13−20.

[13] Ferri, R., Pierdicca, N. and Talice, S. (2000). Mapping sea surface temperature from aircraft using a multi-angle technique: an experiment over the Orbetello lagoon. International Journal of Remote Sensing, 21(16), 3003−3021.

[14] Su, Z. (2000). Remote sensing of land use and vegetation for mesoscale hydrological studies. International Journal of Remote Sensing, 21(2), 213−233.

[15] Tassan, S. (1997). A numerical model for the detection of sediment concentration in stratified river plumes using Thematic Mapper data. International Journal of Remote Sensing, 18(12), 2699−2705.

[16] IWASHITA, K., KUDOH, K., FUJII, H. and NISHIKAWA, H. (2004) Satellite analysis for water flow of Lake Inbanuma, Advances In Space Research, 33, 284-289.

[17] EKSTRAND, S., 1992, Landsat TM based quantification of chlorophyll-a during algae blooms in coastal waters. *International Journal of Remote Sensing*, **13**, 1913-1926.

[18] RITCHIE, C. J., COOPER, C. M., and YONG, Q. J., 1987, Using Landsat Multispectral Scanner data to estimate suspended sediments in Moon Lake, Missisippi. *Remote Sensing of Environment*, 23, 65-81.

[19] BABAN, S.M., 1993, Detecting water quality parameters in the Norfolk Broads, U. K., using Landsat imagery. *International Journal of Remote Sensing*, **14**, 1247-1267.

[20] DEKKER, A.G., and PETERS, S.W.M., 1993, The use of Thematic Mapper for the analysis of eutrophic lakes: a case study in the Netherlands. *International Journal of Remote Sensing*, **14**, 799-821.

[21] FORSTER, B.C., XINGWEI, I.S., and BAIDE, X., 1993, Remote sensing of water quality parameters using landsat TM. *International Journal of Remote Sensing*, **14**, 2759-2771.

[22] ALLE, R.J., and JOHNSON, J.E., 1999, Use of satellite imagery to estimate surface chlorophyll-a and Secchi disc depth of Bull Shoals, Arkansas, USA. *International Journal of Remote Sensing*, **20**, 1057-1072.

[23] 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.

[24] 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.

[25] GALLEGOS, C. L., and CORRELD. L., 1990, Modeling spectral diffuse attenuation, absorption and scattering coefficients in a turbid estuary. *Limnology and Oceanography*, 35, 1486-1502.

[26] 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.

[27] Ziegler, Andrew C. 2002. Issues Related to Use of Turbidity Measurements as a Surrogate for Suspended Sediment, Turbidity and Other Sediment Surrogates Workshop, Reno, NV, 30 April - 2 May 2002.

[28] Jessie C. Fink, 2005, The Effects of Urbanization on Baird Creek, Green Bay, WI, MS Thesis, University of Wisconsin Green Bay, May 2005. Available Online: http://www.uwgb.edu/watershed/REPORTS/Thesis/baird_JFink.htm.