

ESTABLISHING A GLOBAL ALGORITHM FOR WATER QUALITY MAPPING FROM MULTI-DATES IMAGES

H. S. Lim, M. Z. MatJafri, K. Abdullah and M. N. A. Bakar

School of Physics

Universiti Sains Malaysia,

11800 Penang

ABSTRACT

The problem of difficulty in obtaining cloud-free scene at the Equatorial region from satellite platforms can be overcome by using airborne imagery. Digital camera was used as a sensor in this study. This technique was cheaper and economical compared with other airborne studies. Digital images were captured at three locations, which were Prai river, Muda river and Merbok river estuaries from a low altitude flying aircraft. Six sets of digital data were captured on five different days. Water samples were collected simultaneously with the airborne image acquisition. The station locations of the water samples were determined using a hand held GPS. Atmospheric correction for multirate images was performed by selecting average digital number of grass as a reference. The digital colour images of the study areas were separated into three bands (red, green and blue) for multi-spectral analysis. The digital numbers were extracted corresponding to the ground-truth location for each band and later used for calibration of the water quality

algorithm. 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. Finally, TSS maps were generated using the proposed calibrated algorithm to the study areas. The data produced a high degree of accuracy. The TSS maps were geometrically corrected and colour-coded for visual interpretation. The result showed that the established global algorithm can be used to generate a TSS map after simple atmospheric correction.

Introduction

Water quality assessment of ocean and inland waters using satellite data has been carried out since the first remote sensing satellite Landsat-MSS has been operational (Thiemann and Kaufmann, 2000). Many researchers used satellite images in their investigations [Allee, et al., (1999), Forster, et al., (1993) and Ritchie, et al., (1990)]. However, in this study we used airborne remote sensing. A digital camera was used as a sensor to capture the images at altitude of 8000 feet. The main objective of the present study is to update our proposed algorithm for mapping total suspended solids in marine environments using digital camera images from previous study (MatJafri, et al., 2002). We also attempted to develop a simple correction technique for the airborne images acquired from different dates, locations, and different flying altitudes. Data from seven image scenes were combined in the present analysis. This study also proposed a cheaper and economical alternative to overcome the problem of obtaining cloud-free scenes in the Equatorial region.

Study Area

In this study, a Kodak DC290 digital camera was used as a sensor and a Cessna 172Q aircraft was used as a platform to capture images of the study areas. The study areas were the Prai, Muda, and Merbok river estuaries, located within latitudes $5^{\circ} 22' N$ to $5^{\circ} 24' N$ and longitudes $100^{\circ} 21' E$ to $100^{\circ} 23' E$; $5^{\circ} 34' N$ to $5^{\circ} 36' N$ and longitudes $100^{\circ} 19' E$ to $100^{\circ} 21' E$; and $5^{\circ} 39' N$ to $5^{\circ} 41' N$ and longitudes $100^{\circ} 20' E$ to $100^{\circ} 24' E$, respectively. The images were captured from the altitude of 3,000 ft on 28 October 2001 and 8,000ft on 9 March 2002 for Prai River estuary, 8,000ft on 20 January 2002 and 9 March 2002 for Muda River estuary, and also 8,000 ft on 5 May 2002, 25 October 2002 and 22 March 2003 for Merbok River estuary. The study areas are shown in Figure 1. Water samples were collected from a small boat within the areas covered by the scenes simultaneously with the airborne image acquisition and later analyzed in the laboratory.



(Source: Microsoft Corp., 2001.)

Figure 1. Study area

Optical model of water

A physical model relating radiance from the water column and the concentrations of the water quality constituents provides the most effective way of analyzing 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, $R(\lambda)$, is given by Kirk (1984) as

$$R(\lambda) = 0.33b(\lambda)/a(\lambda) \quad (1)$$

where

λ = the spectral wavelength

b = the backscattering coefficient

a = the absorption coefficient

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 two water quality components, i.e. chlorophyll, C , and suspended sediment, P , the simultaneous equations for the two channels given by Gallie and Murtha (1992) 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

$b_{bw}(i)$ = backscattering coefficient of water

b_{bc}^* = specific backscattering coefficients of chlorophyll

b_{bp} = specific backscattering coefficients of sediment

$a_w(i)$ = absorption coefficient of water

a_c^* = specific absorption coefficients of chlorophyll

a_p^* = specific absorption coefficients of sediment

C = chlorophyll

P = suspended sediment

Regression Algorithm

TSS concentration can be obtained by solving the two simultaneous equations to get the series of terms R_1 and R_2 that is given as

$$P = a_0 + a_1R_1 + a_2R_2 + a_3R_1R_2 + a_4R_1^2 + a_5R_2^2 + a_6R_1^2R_2 + a_7R_1^2R_2^2 + a_8R_1^2R_2^2 + \dots \quad (3)$$

where a_j , $j = 0, 1, 2, \dots$ are the coefficient for equation (3) that can be solved empirically using multiple regression analysis. This equation can also be extended to the three-band method given as

$$P = e_0 + e_1R_1 + e_2R_2 + e_3R_3 + e_4R_1R_2 + e_5R_1R_3 + e_6R_2R_3 + e_7R_1^2 + e_8R_2^2 + e_9R_3^2 \quad (4)$$

where the coefficient e_j , $j = 0, 1, 2, \dots$ can also be solve empirically.

Data Analysis And Result

Seven sets of the colour images were selected for calibration analysis. Figure 2 shows the images that were used in this study.



(a)



(b)



(c)



(d)



(e)



(f)



(g)

Figure 2. Images of the study areas: (a) the oblique image of the Prai River estuary captured on 28 October 2001 from altitude of 3,000ft, (b) the oblique image of the Muda River estuary captured on 20 January 2002 from altitude of 8,000ft, (c) the vertical image of the Prai River estuary captured on 9 March 2002 from altitude of 8,000ft. (d) the vertical image of the Muda River estuary captured on 9 March 2002 from altitude of 8,000ft, (e) the oblique image of the Merbok River estuary captured on 5 May 2002 from altitude of 8,000ft, (f) the vertical image of the Merbok River estuary captured on 26 October 2002 from altitude of 8,000ft and (g) the vertical image of the Merbok River estuary captured on 22 March 2003 from altitude of 8,000ft.

The colour images were separated into three bands, namely, red, green and blue bands for multispectral analysis. The image of Figure 2(a) was taken at an altitude of 3,000ft, while the rest were taken from altitude of 8,000ft. The image of Figure 2(a), Figure 2(b) and Figure 2(e) were taken obliquely. The view angle correction was first performed to the oblique images to correct for the angular dependence of image brightness. In this study, a contour map of the image brightness was plotted and the view angle effect was removed based on the map. Then, the multi-date data were corrected to remove the difference in atmospheric effects between scenes using radiometric normalization technique. The vertical image of Figure 5(c) was selected as the reference

image and the average brightness of the chosen target; in this case, grass vegetation was noted. We assumed the reflectance of these targets did not change with time. This assumption is in accordance with the methods proposed by Lopez, (1990). The average brightness values of grass in other images were then recorded. The difference from the reference value was used to correct for each scene. All the brightness values of the other five images of Figure 5 (a), (b), (d), (e), (f) and (g) were adjusted using this normalization technique. This normalization technique forced the images to have the same atmospheric conditions and the effects due to different camera altitudes have also been removed. The corrected scenes were then regressed with the sea-truth data to obtain all the coefficients of equation (4) in the proposed multi-date, multi-area, and multi-altitude analysis. Image rectification was performed using second order polynomial transformation equation.

The DN values corresponding to the water sample locations were extracted from all the images. The relationship between TSS and DN of the data set is shown in Figure 3. The coefficients values are listed in Table 1. Figure 4 shows the proposed algorithm produced high correlation coefficient (R) and low root-mean-square (RMS).

The TSS maps were generated using the proposed calibrated algorithm. The generated maps were then filtered by using 5 by 5 pixels average for removing random noise. Finally, the generated TSS maps were colour-code for visual interpretation as shown in Figure 5. This indicates the reliability of the calibrated proposed algorithm for TSS mapping using digital camera imagery.

Table 1. Correlation coefficients of equation (2)

Coefficients	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
Values	43.794	-2.021	-9.964	10.710	0.121	-7.278×10^{-2}	0.279	-1.640×10^{-2}	-0.141	-0.151

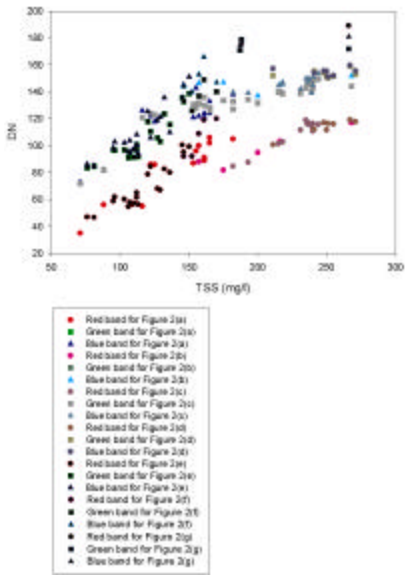


Figure. 3 TSS concentration versus digital number (DN).

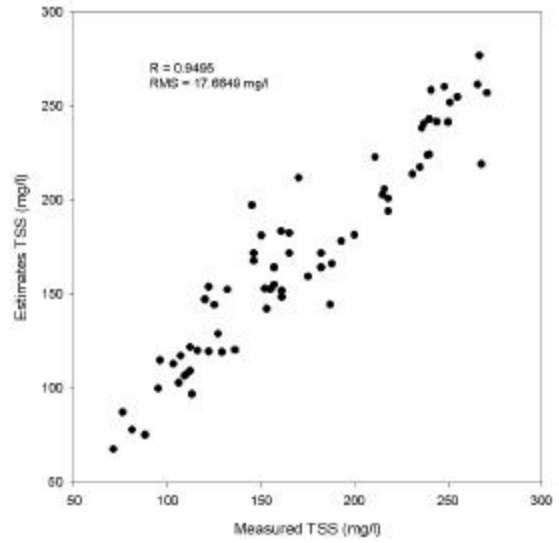
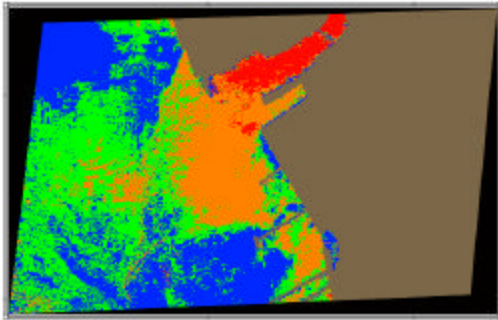
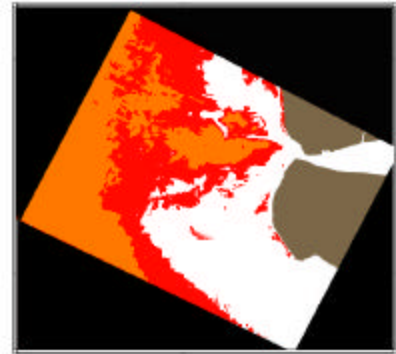


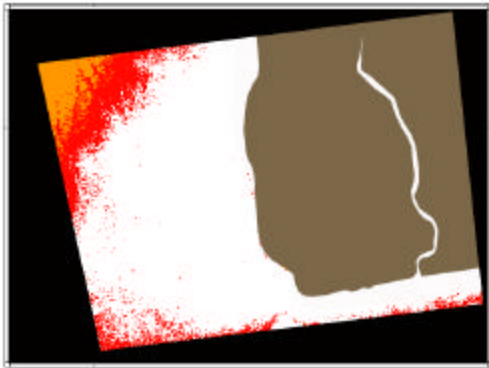
Figure 4. Measured versus estimated TSS concentration



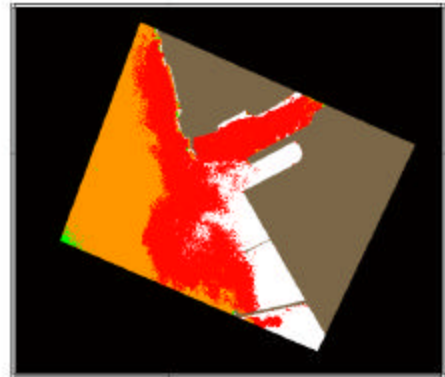
(a)



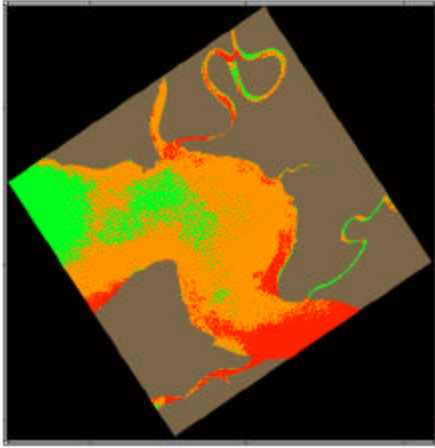
(b)



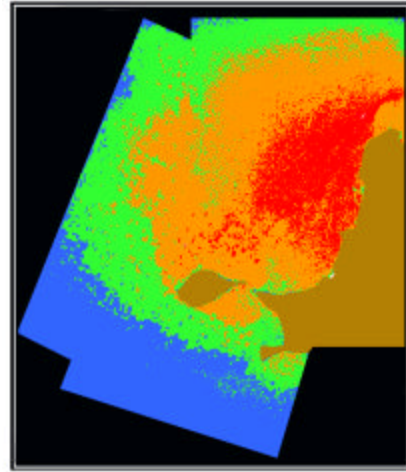
(c)



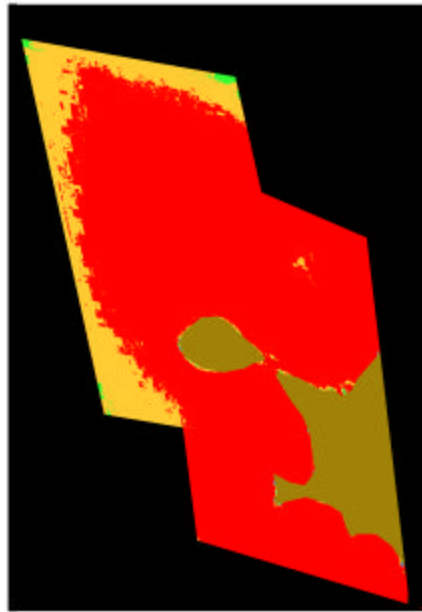
(d)



(e)

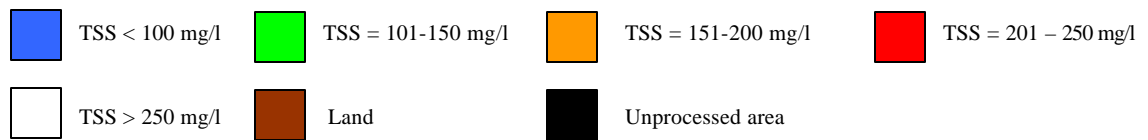


(f)



(g)

Figure 5. TSS map for the study area estimated using the proposed algorithm. Colour code:



Verification analysis

For the verification analysis, sea truth data were divided into two groups, half of the numbers of water samples were radom selected for algorithm calibration and the another half of the numbers of water samples were radom selected for verification analysis. The calibrated algorithm was produced high accuracy with R value of 0.9685 and RSM value of 13.19 mg/l in the verification analysis. Figure 6 shows the relationship of the measured TSS versus estimated TSS concentration for algorithm calibration analysis. Figure 7 shows the relationship of the measured TSS versus estimated TSS concentration for verification analysis.

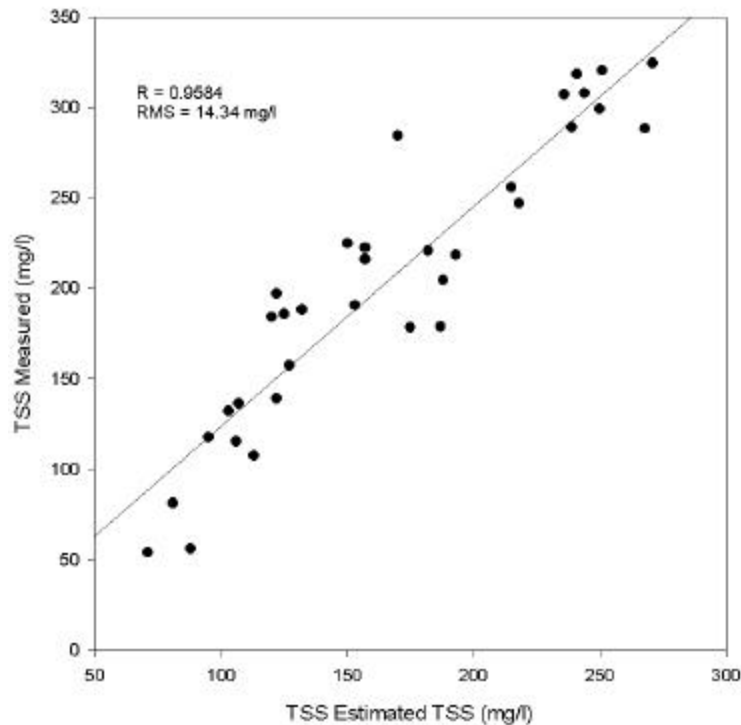


Figure 6. Measured TSS versus estimated TSS concentration for algorithm calibration analysis

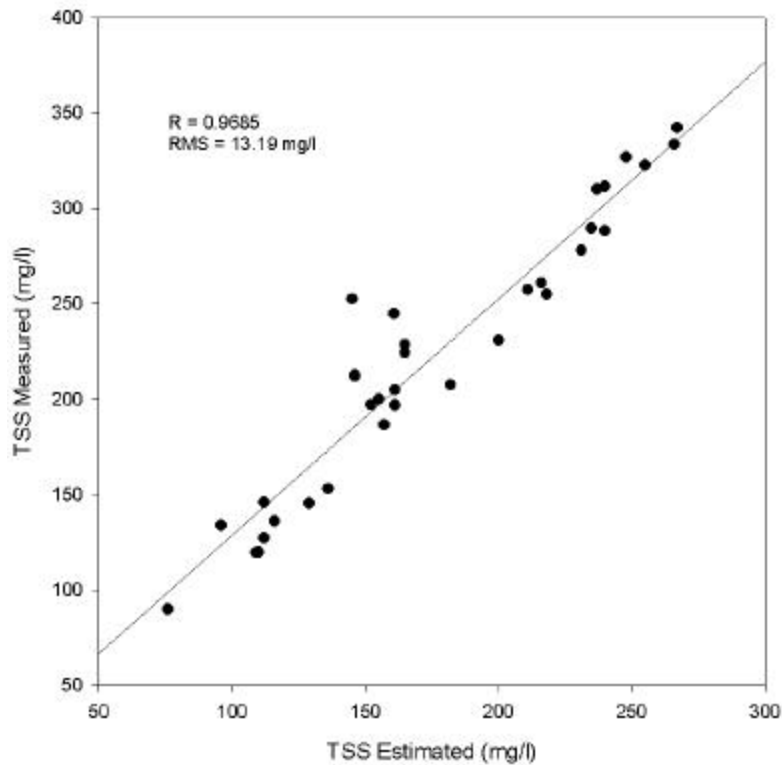


Figure 7. Measured TSS versus estimated TSS concentration for verification analysis

Conclusion

This study gives a cheaper way to overcome the problem of difficulty of obtaining cloud-free scenes at the Equatorial region. Traditional water quality monitoring method based on water sample collection is time consuming and requires a high operating cost. It is good for determined the water pollution for real time. The proposed algorithm is considered superior to other tested algorithms based on the values of the correlation coefficient, $R=0.97$ and root-mean-square error, $RMS=15\text{mg/l}$. This indicates that the TSS maps can be generated using digital camera imagery with the proposed algorithm.

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