Application of THEOS Imagery to Study Chlorophyll-a at the Strait of Penang Island, Malaysia

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Abstract. The water quality significantly influences natural ecosystems, human health, and economic activities. One factor of ecological problems in the world today is overloading of nutrients result in eutrophication. it is essential to have accurate information about the current state of the coastal region. This study explored the potential of using ground based multispectral remote sensing to monitor chlorophyll-a concentrations. The data used in this study includes 2 THEOS (Thailand Earth Observation System) images as well as the nearly simultaneous in-situ data from 24 observation stations on the sea. The study area is Penang strait, Malaysia which is situated within latitudes 5 ° 24'38'' N to 5º 21' 01'' N and longitudes 100 ° 20' 33'' E to 100 ° 22' 49''E. Chlorophyll-a concentrations can be determined by employing an optical model that relates the chlorophyll-a concentrations with the reflectance .Relationships between reflectance bands and reference data were explored the use of linear regressions analysis. The accuracies are measured by correlation coefficient (R^2) and root mean square error (RMSE). The proposed algorithm produced the highest R^2 value and lowest RMSE value. This result showed that the simple nonlinear algorithm was sufficiently accurate to estimate chlorophyll-a concentration over Penang Island, Malaysia. The calibrated algorithm was used to generate water quality maps for all images.

Keywords: satellite remote sensing, chlorophyll-a, Regression analysis, Penang Island

1. Introduction

The quality of surface water in the estuary of streams, lakes, reservoirs and straits is an important environmental worry for it determines the overall health of the coastal ecosystem. A large percentage of the population lives near the coast and depends widely on the use of the region's resources for their life [1].

The condition of the coastal water, which includes the water quality, is principle worry to those who are responsible for managing the region's resources. The surrounding area of the coast is the most developed, industrialized, and populated area. Transformation of the environment, resulting from both human and natural processes, can occur quickly or slowly over many years. Pollution events such as oil spills are right away apparent, while the effect of nonpoint source pollution such as agricultural run-off may exhibit themselves over decades. The water quality significantly influences natural ecosystems, human health, and economic activities [2].

Chlorophyll is a green coloured substance in cells (pigment) that exists in almost all plants, algae, and cyanobacteria. Chlorophyll permits plants to achieve energy from sun and can absorb sun light in the blue portion of the electromagnetic spectrum. It is a weak absorber of green portion of the spectrum; the green colour of plants is due to this phenomenon. The major chlorophyll in plants includes chlorophyll-a which has very strong absorption bands in the visible regions of the spectrum. Chlorophyll-a is typically derived using the blue and green spectral regions [3-6]. The natural fluorescence of chlorophyll-a, that is stimulated by the sun is a good predictor for phytoplankton, even in waters which have varying yellow substance and suspended matter concentrations [7]. Accurate estimates of chlorophyll concentrations are essential for determining the health of the ecosystem [2, 8-10]. Landsat 4 and 5 (TM) sensor have been used often for chl-

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a estimation [11]. Garcia and Caselles in 1990, Lathrop et al. in 1991 [12-13] used blue band, Lathrop and Lillesand [14] used green band of TM sensor to estimate chlorophyll-a. Dall'Olmo and Gitelson proposed a three band algorithm to estimate chlorophyll-a in turbid waters. They showed that the three-band algorithm has the largest effect on the accuracy of chl-a estimation and more sensitive to variations in the bio-optical parameters [15]. For validation data Olszewski *et al.* used regression coefficient (R^2), they found a good value of 0.9 between chlorophyll-a concentration and reflectance ratios [16]. In this research, utility of remote sensing to estimate chlorophyll-a concentrations was investigated. For this purpose the remotely sensed images of THEOS satellite were used and an empirical algorithm was used for estimating chlorophyll-a concentrations.

2. Materials and Method

2.1 Study Area and Methodology

The study area is Penang strait, Malaysia which is situated within latitudes 5° 24'38'' N to 5° 21' 01'' N and longitudes 100° 20' 33'' E to 100° 22' 49''E. Straits of Penang is part of the Indian Ocean and is a channel separating Penang island and mainland Peninsular Malaysia. The mainland is on the eastern side of the channel, while Penang Island is on the western side. It has a maximum depth of 20 m, length of 22 km, and width of 13 km (Fig.1 shows the study area for this project). Specifically, the mainland side of the channel is called Seberang Perai and is a part of the state of Penang. The channel joins the Strait of Malacca, to the north and south.
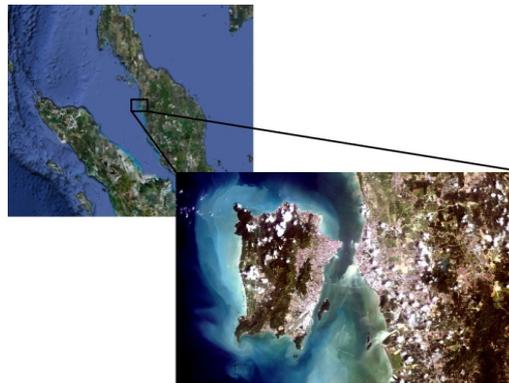

Fig. 1: The study area

In this study, two THEOS images were provided. Table 1 shows the metadata of these images, which includes the dates, sun elevation, and band numbers. Table 2 shows the sensor characteristics for THEOS scene. The spatial resolution of the image pixel is 15 m.

Table 1: Metadata of THEOS Images

Date	Sun azimuth (degree)	Sun elevation (degree)	No.band
12.11.2009	134.340047	57.492245	4
09.02.2010	121.875479	50.585580	4

Table 2. The specification of the satellite THEOS

Band 1 (blue)	0.45-0.52 μm
Band 2 (green)	0.53-0.60 μm
Band 3 (red)	0.62-0.69 μm
Band 4 (near infrared)	0.77-0.90 μm

In-situ data were collected in the Strait of Penang Island in two sites (09 February 2010, 12 November 2009), simultaneously with the THEOS satellite overpasses these areas, water samples collected and their locations were determined by utilizing a hand-held Global Positioning System (GPS). For calculation of

chlorophyll concentration, water samples were taken in all stations. For each site, 12 stations measured clear and turbid waters (Fig. 2).
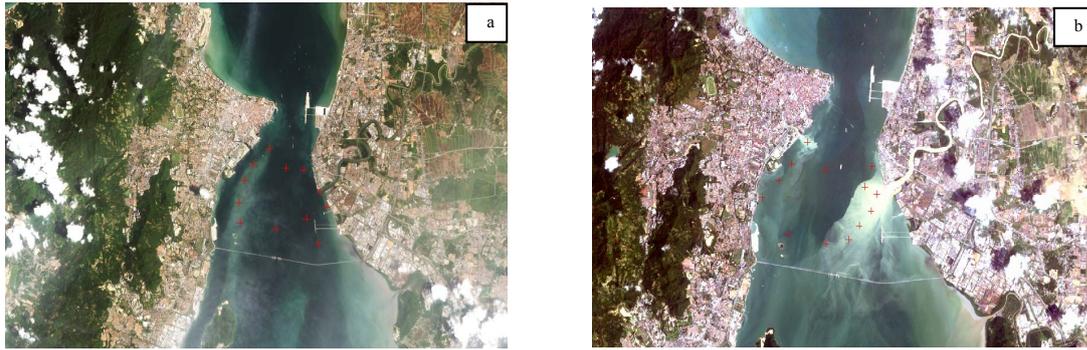

Fig. 2: The raw satellite images and sampling locations acquired on a) 09.02.2010 b) 12.11.2009

2.2 Image processing

Raw remotely sensed image contains some defects and flaws. Pre-processing of the remotely sensed images refers to those operations, which are initial to the main analysis. It includes geometric correction, radiometric correction, masking and filtering. Any remote sensing image will have various geometric distortions. These distortions arise from a variety of factors, including one or more factors such as earth curvature, platform motion, relief displacement, nonlinearity's in scanning motion, the platform altitude, attitude, and velocity, rotation of the Earth [17].To compensate these problems Geometric correction is intended. This process called ground control points (GCPs), that employs identification of geographic features on the image [17-18]. A radiometric correction is the conversion of the digital number (DN) for satellite image to Top of the atmosphere reflectance (R). The PCI Geomatica version 10.3 image processing software was used in all the analyses.

2.3 Statistical Analytical Procedures

The reflectance and surface reference data were analyzed using the SPSS 18.0 statistical. Data plots, correlation matrices, and regression analyses were the initial statistical tools used to investigate the relationships in the data. The statistical parameters for precision of the regression models include the correlation coefficient (R^2) and Root Mean Square Error (RMSE). The square of the correlation coefficient (R^2) shows the proportion of the total variation that can be explained by the regression equation.

Root mean square error (RMSE) is usually used to measure the differences between values estimated by a model and the values actually observed from the thing being estimated. RMSE are also called residuals that can be a good measure of precision. The multiple regression analysis would recognize the relationship between the dependent variable and the independent variables [9]. This is then finally presented as a model as following [19-20]:

$$P = e_o + e_1R_1 + e_2R_2 + e_3R_3 + e_4R_1R_2 + e_5R_1R_3 + e_6R_2R_3 + e_7R_1^2 + e_8R_2^2 + e_9R_3^2 \qquad (1)$$

Where the coefficient ej, j = 0, 1, 2 … can determined empirically from multiple regression analysis.

3. Result and Discussion

Chlorophyll-a for Penang strait was derived using remote sensed images and field sampling simultaneously with THEOS overpass to observe and measure relevant data. Water samples were processed at professional laboratories to measure chlorophyll-a concentrations. Before using regression analysis all data from the two dates were combined to get a more accurate model.

The chlorophyll-a level reading for the strait of Penang on 12.11.2009 and 9.2.2010 showed that the highest value of chlorophyll-a was 12.3 mg/m^3 and the lowest was 2.00 mg/m^3.

The multiple regression analysis was used to compute relationship between chl-a and the THEOS imagery data. The results show a high validation with correlation coefficient and low root mean square error R^2 = 0.952 RMSE = 1.014 for 12.11.2009 and R^2 = 0.836, RMSE = 0.249 for 9.2.2010 after elimination of excluded variables. The algorithm models were achieved for 12.11.2009 and 9.2.2010 as follow, respectively:

Chlorophyll-a = 57.079 (R_1) - 152.775(R_2) – 15.926 (R_3) -28.010 (R_1)^2+129.559(R_2)(R_3) +16.029   (2)

Chlorophyll-a = -281.105(R_1)+20.450(R_2)+1500.713 (R_1)^2 +92.948 (R_3)^2 + 7.426   (3)

The data were corrected for atmospheric effects. The relative atmospheric correction used in this study was sufficient to produce satisfactory results from the combined data of two image dates. The result of multiple regression analysis for the combination of two THEOS imagery and the in-situ chlorophyll-a data are listed in Table 3, which include R^2 and RMSE as well. This regression model included reflectance bands, reflectance bands interaction and reflectance bands square (equation (4)). After modifying and removing insignificant terms ((R_2)^2, (R_3)^2, (R_1)(R_2), (R_1)(R_3)) in equation (5), R^2 = 0.96 and RMSE = 0.69 mg/m^3 were achieved, which show better result than previous model (equation (4)). Fig. 2 shows that the estimated chlorophyll-a achieved by equation (5) is closely to in-situ chlorophyll-a.

Chlorophyll-a = 52.210(R_1) + 4.353(R_2)-11.032(R_3) - 20.387(R_1)^2-12.997(R_2)(R_3)-1.377(R_2)^2 + 5.121(R_3)^2 + 0.398(R_1)(R_2) + 16.477(R_1)(R_3) +0.915   (4)

Chlorophyll-a = 52.210(R_1) + 4.353(R_2) -11.032(R_3) - 20.387(R_1)^2 - 12.997(R_2)(R_3) + 0.915   (5)

Table 3: Multiple regression analysis for two date THEOS imagery and the in-situ chlorophyll-a

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
	(Constant)	.915	2.760		.332	.744
	R1	52.210	43.488	2.721	1.201	.245
	R2	4.353	28.297	.104	.154	.879
	R3	-11.032	6.247	-.949	-1.766	.093
	R1R1	-20.387	34.706	-.628	-.587	.564
	R2R3	-12.997	32.640	-.399	-.398	.695

a. Dependent Variable: chlorophyll

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
	R2R2	-1.377[a]	-.277	.785	-.065	8.606E-5
	R3R3	5.121[a]	.674	.509	.157	3.605E-5
	R1R2	.398[a]	.049	.961	.012	3.258E-5
	R1R3	16.477[a]	2.417	.027	.495	3.470E-5

a. Predictors in the Model: (Constant), R2R3, R1R1, R3, R2, R1

b. Dependent Variable: chlorophyll

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.981[a]	.962	.951	.6965

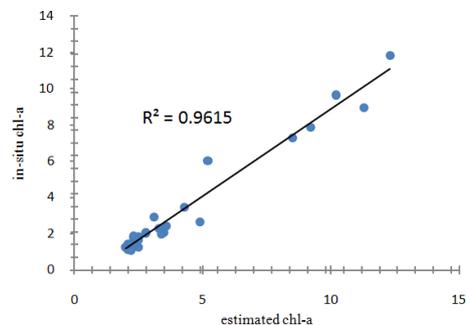a. Predictors: (Constant), R2R3, R1R1, R3, R2, R1

Fig. 3: Comparison of estimated and in-situ values of chlorophyll-a

It is clear that from Fig.3, the data points are distributed relatively close to the straight line that means y≈ x. The results of multiple regression show that in-situ data and remotely sensed data are consistent with an R^2 value of over 0.96. Table 3 shows the value of each coefficient of determination from multiple regression for chlorophyll-a. It is obvious that multiple regression model of chlorophyll-a estimation (calculated values) is satisfactory (Fig.3). The proposed algorithm was used to generate water quality maps. The output maps

provide useful spatial information on water quality distribution patterns in the strait. Fig.4 illustrates chlorophyll maps for the study area generated by using the proposed algorithm..
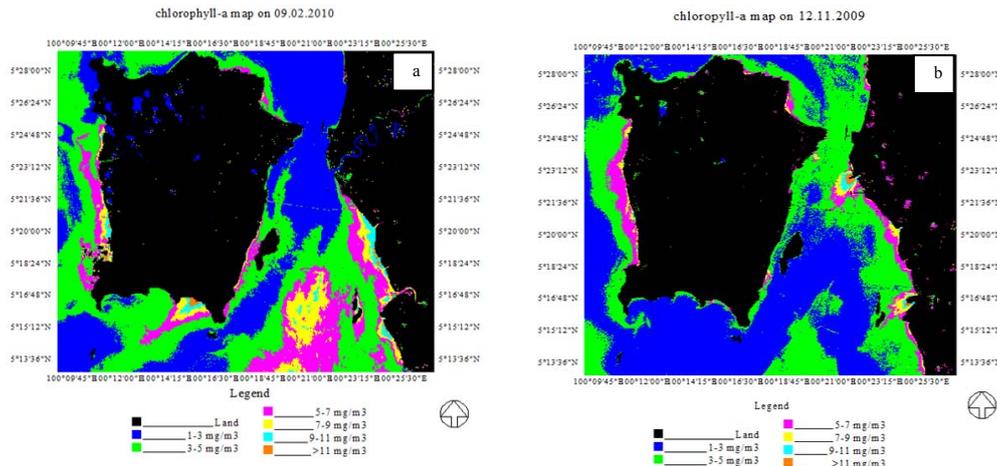

Fig. 4: Map of chlorophyll around Penang Island Malaysia on a) 9.2.2010, b) 12.11.2009

4. Conclusion

The results from the combined data of two image dates give a good correlation between chlorophyll-a determination from satellite remote sensing data and in-situ chlorophyll-a measurements ($R^2 > 0.96$). The obtained results show that THEOS imagery and regression analysis can be used effectively to determine chlorophyll-a levels over Penang Island, Malaysia.

5. Acknowledgements

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