CHLOROPHYLL-A MAPPING FROM THE MODERATE RESOLUTION IMAGING SPECTRORADIOMETER DATA IN THE SOUTH CHINA SEA

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Abstract: The amount of chlorophyll-a depends on the amount of algae and can also be used as an indicator of phytoplankton abundance and biomass in coastal water. The concentration of chlorophyll-a also could be a general measure of water quality. A series of Moderate Resolution Imaging Spectroradiometer (MODIS) data acquired on different dates were used in this study since chlorophyll-a concentration change over time. In this study, four different algorithms had been chosen to extract chlorophyll-a concentration from MODIS data in the South China Sea. MODIS data acquired on 13 June 2001 was used to derive the coefficients in the algorithm since ground- truth data is available. The accuracy of these algorithms was also assessed by comparing the correlation between measured and calculated chlorophyll-a values. The best algorithm is the Gordon's algorithm with a R^2 value of 0.735. Thus, Gordon's algorithm was used to obtain chlorophyll-a distribution during the north east, south west and inter- monsoon periods in 2003 and 2004. The results show that during the north east monsoon and south west monsoon periods, the chlorophyll-a concentration is between 0.1-1.5 mg m^{-3}, while the chlorophyll-a concentration during the inter- monsoon period is between 0.1-1.0 mg m^{-3}.

Keywords: MODIS, Chlorophyll-a, Monsoon.

1.0 Introduction

Chlorophyll-a is a green pigment that is present in all plant life and is necessary for photosynthesis. The amount of chlorophyll-a present in water depends on the amount of algae and can also be used as an indicator of phytoplankton abundance and biomass in coastal water. It is natural for chlorophyll-a levels to change over time. An increase of chlorophyll-a concentration can reflect an increase in nutrient loads and increasing trends can indicate eutrophication of aquatic ecosystems (Setiarto and Suradi, 1999). Normally, the chlorophyll-a concentration is higher in coastal areas than in the offshore areas. However, there are also some areas in the offshore areas that contain high chlorophyll-a concentrations and this may be caused by strong currents that carry the chlorophyll-a from the coastal areas. Besides this, the monsoon winds could also significantly affect the chlorophyll-a distribution; or upwelling which brings cool, nutrient- rich water from the ocean depths to the surface (Abbott and Barksdale, 1995).

Chlorophyll-a mapping over ocean areas is important in the fishing industry. However, it is not easy to monitor chlorophyll-a distribution over a large area continuously based on the conventional water sampling. This traditional chlorophyll-a sampling is very time consuming,

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expensive and only can be done for a small area. Due to these limitations, the sample size cannot be large enough to cover the entire water body. Remote sensing techniques from satellite data can overcome this problem. Remote sensing data that will be used in this study is multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) data. MODIS belongs to a new generation of sensors that collect data across a wide spectral range with moderate spatial resolution (250m-1km). The relatively good resolution and daily overpasses due to wide swath make MODIS suitable for chlorophyll-a monitoring over the South China Sea.

2.0 Objectives of Study

The main objectives of the study are:

i) To identify suitable algorithms to extract chlorophyll-a concentration from the MODIS data and to determine chlorophyll-a from these algorithms.

ii) To assess the accuracy of the algorithms by comparing satellite- derived chlorophyll-a with ground truth data.

iii) To map the distribution of chlorophyll-a concentration over the South China Sea by using the best algorithm.

This study is based on the literature review of chlorophyll-a studies from satellite data. The suitable algorithm and spectral bands of the MODIS data are used in the determination of chlorophyll-a and mapping of chlorophyll-a in the South China Sea.

3.0 Study Area

The study area covers a major portion of the South China Sea (Figure 1).

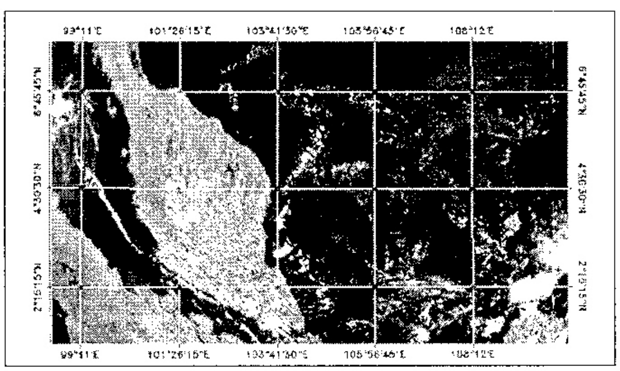


Figure 1: MODIS image (8 June 2003) over South China Sea.

The area undergoes 3 seasons namely the north- east monsoon, the south- west monsoon and an inter- monsoon period. The area is also an important area that contributes to the fishing industry in Malaysia.

4.0 Methodology

The methodology used in the study is as shown in Figure 2.

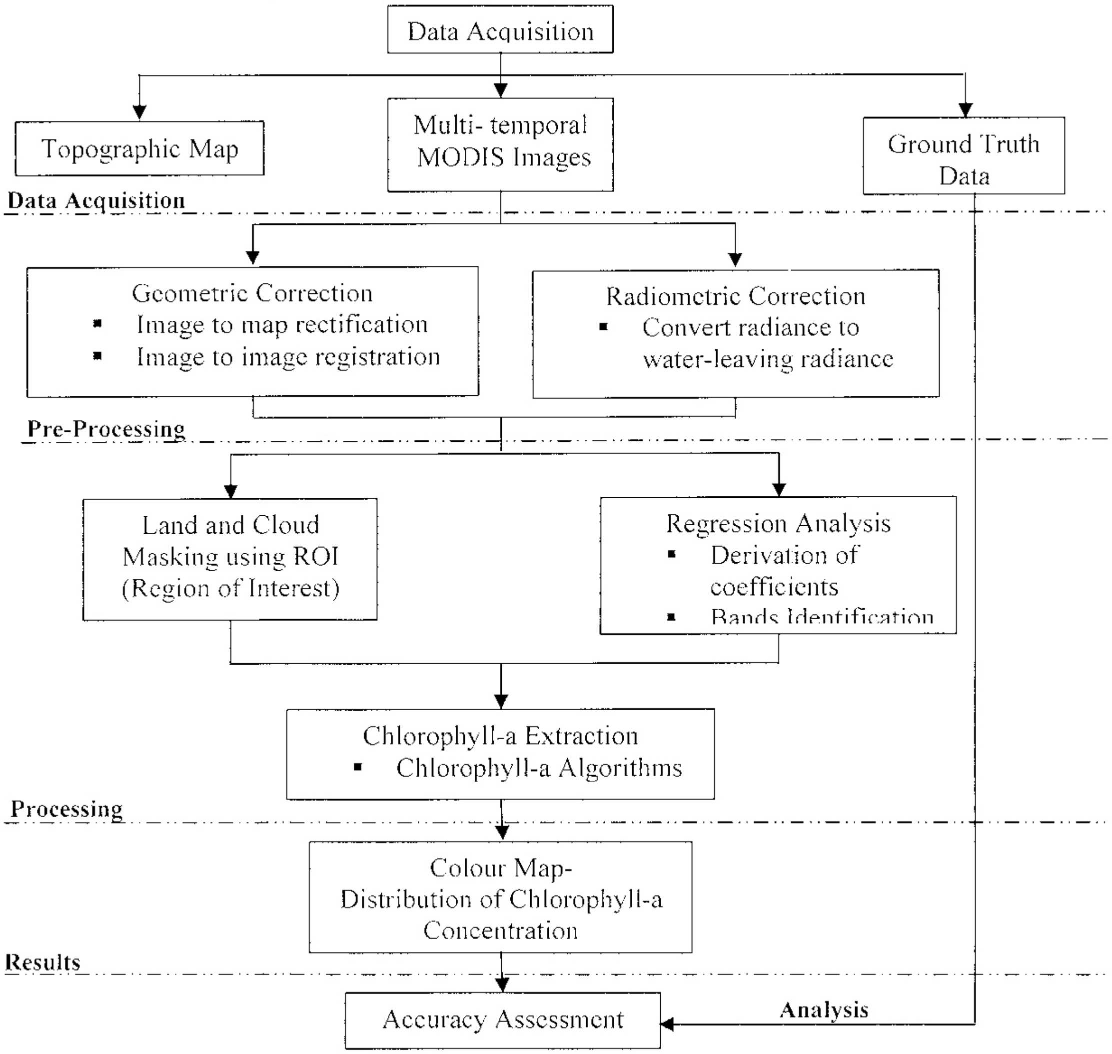


Figure 2: Flowchart of methodology.

A series of MODIS images of different dates in 2003 and 2004 were downloaded. The downloaded data were for different monsoon periods, which include north east monsoon period (January), inter- monsoon period (March) and south west monsoon period (June). Also, an image of the same date with the obtained ground truth data i.e. 13 June 2001 was also downloaded. All the images were corrected for geometry. The data were processed to extract water-leaving radiance. The water- leaving radiance contains information about the water column (Chang et al., 2003). The land area was mask out so that the water pixels can be discriminated from the land pixels. Since MODIS data also suffers from cloud cover problems; the cloud affected areas were also masked out from the image. A regression analysis between measured chlorophyll-a concentration and water- leaving radiance of different visible bands was carried out using four in-situ data. The visible bands that give the highest R^2 were selected to be used in the chlorophyll-a extraction. For Gordon's algorithm, bands 9 (443 nm) and 12 (551 nm) images were used. The chlorophyll-a concentration was quantitatively estimated by using the algorithms as below:

(i) Gordon's algorithm (1978)

$$Chl = a\,(L_w\,551\ /\ L_w\,443)^{\,b} \;\ldots\ldots\ldots\ (3.1)$$

(ii) NDCI (Normalized Difference Chlorophyll Index) algorithm (1999)

$$\ln(Chl) = a(R) - b \;\ldots\ldots\ldots\ (3.2)$$

$$\text{and}\quad R = [(L_w443/L_w488) - (L_w551/L_w488)]$$

(iii) Clark 3- bands algorithm (1990)

$$\ln(Chl) = a + b(R) \;\ldots\ldots\ldots\ (3.3)$$

$$\text{and}\quad R = \ln[(L_w443 + L_w531)/(L_w551)]$$

(iv) Aiken's algorithm (1995)

$$Chl = \exp[a + b^{*}\ln(R)] \;\ldots\ldots\ldots\ (3.4)$$

$$\text{and}\quad R = (L_w488/\ L_w551)$$

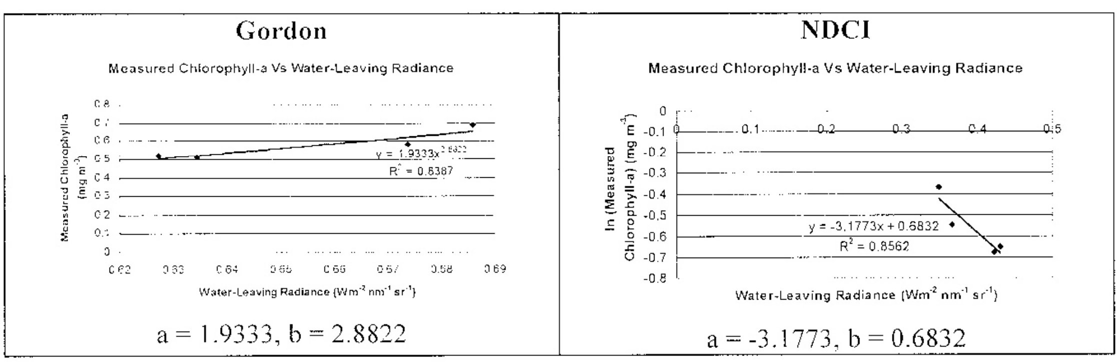
where,

Chl = chlorophyll-a concentration (mg m^{-3})
a and b = regression coefficients
Lw_{xxx} = water- leaving radiance in wavelength xxx nm

5.0 Results

5.1 Regression Analysis

Regression analysis between the measured chlorophyll-a and water- leaving radiance was carried out using the algorithms. Most of the chlorophyll-a algorithms utilized only the spectral signature in the visible range (Gordon, 1983; Okami, 1982). The coefficients a and b from the regression analysis are as shown in Figure 3.



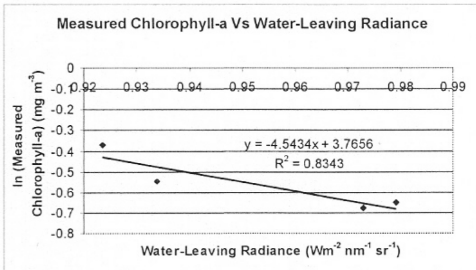
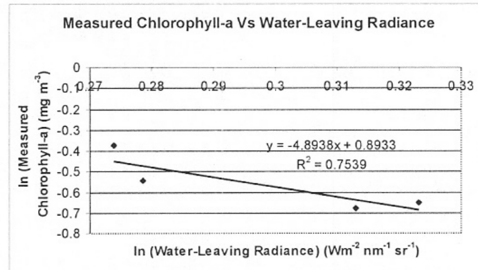
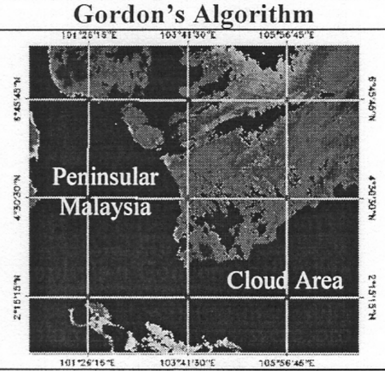
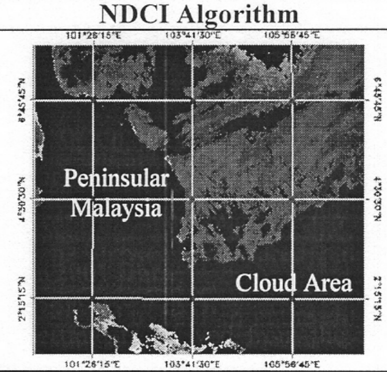
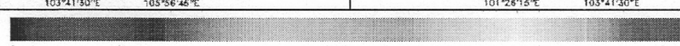
Clark 3- Bands	Aiken
	
a = 3.7656, b = -4.5434	a = 0.8933, b = -4.8938

Figure 3: The coefficients derived from the regression analysis.

5.2 Chlorophyll-a Concentration Mapping from 13 June 2001 Data

Chlorophyll-a maps were produced using the coefficients derived from the regression analysis on the 13 June 2001 data (Figure 4). The chlorophyll-a concentration extracted from Gordon and NDCI algorithms is ranges from 0.1-1.0 mg m^{-3}, while the chlorophyll-a concentration from Clark 3- Bands and Aiken algorithms is between 0.1-0.7 mg m^{-3}. The chlorophyll-a concentration is higher in the coastal waters and decreases away from the coastal waters.

Gordon's Algorithm	NDCI Algorithm
	



0.1 0.5 1.0 1.5 2.0 mg m^{-3}

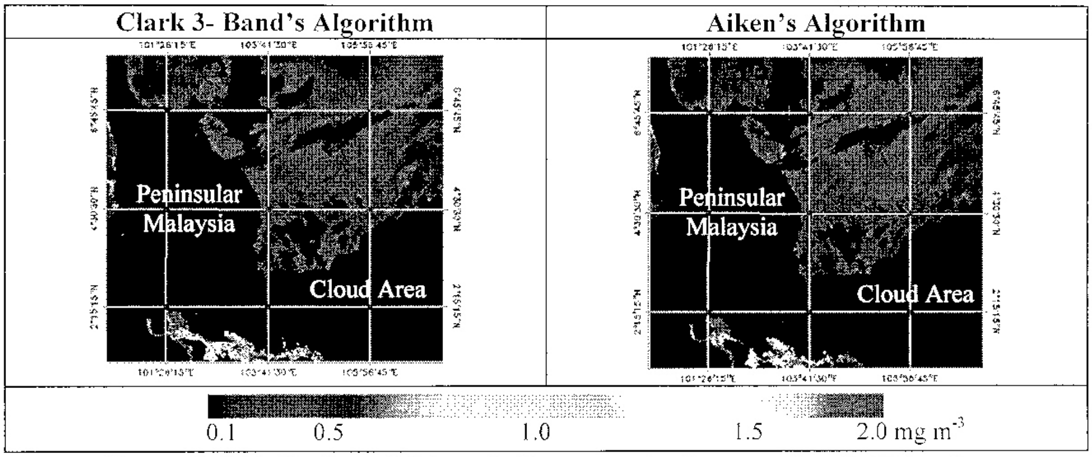


Figure 4: Distribution of chlorophyll-a concentration over South China Sea (13 June 2001).

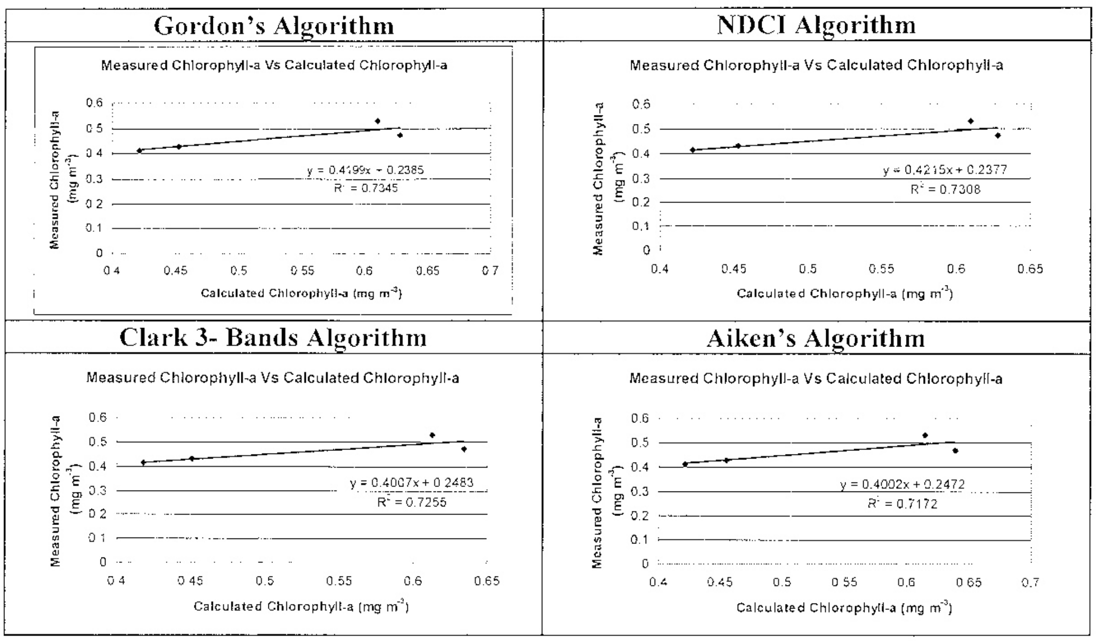


Figure 5: The correlation between the measured and calculated chlorophyll-a concentration at four check points.

Table 1: Summary of R^2 values for the four algorithms.

Algorithm	R^2
Gordon (1978)	0.7345
NDCI (1999)	0.7308
Clark 3- Bands (1990)	0.7255
Aiken (1995)	0.7172

The correlation between the measured and calculated chlorophyll-a concentration at four check points is shown in Figure 5 and Table 1. The highest R^2 value of 0.735 is produced by the Gordon's algorithm, while the lowest R^2 value is 0.717, from the Aiken's algorithm. The other two algorithms, NDCI and Clark 3- bands produced R^2 value of 0.731 and 0.726 respectively. The higher the R^2 value, the better the accuracy from the algorithm. Therefore, it can be concluded that the Gordon's algorithm gives the highest accuracy, followed by NDCI, Clark 3-bands and the Aiken's algorithm.

5.3 Chlorophyll-a Extraction for different Monsoon Periods

The algorithm that was selected to be used in deriving chlorophyll-a information for the different monsoon periods was Gordon's algorithm. This is because the Gordon's algorithm gives the highest accuracy when compared with the other algorithms such as NDCI, Clark 3-bands and Aiken algorithm. Instead of using 4 sampling points, 6 sampling points were used in the regression analysis between chlorophyll-a concentration and water- leaving radiance. The reason for increasing the number of sampling points is to obtain the coefficients with better R^2 value. The correlation between measured chlorophyll-a and water- leaving radiance is shown in Figure 6 with a R^2 value of 0.941. The coefficients (a = 2.1326 and b = 3.1262) which were derived from the regression analysis. were used to calculate the chlorophyll-a concentration for different monsoon periods in 2003 and 2004 (Figure 7).

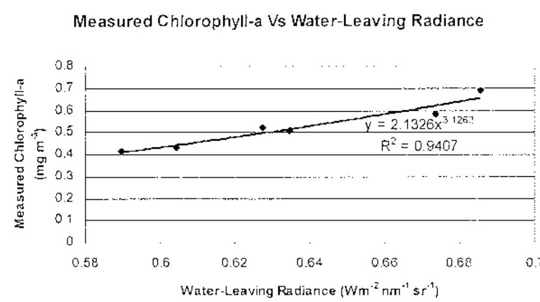
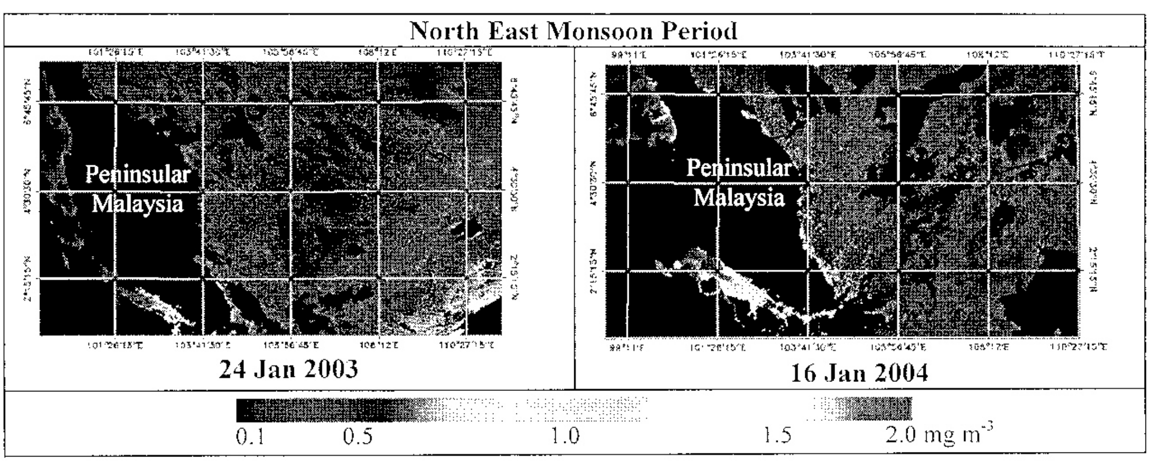


Figure 6: Measured chlorophyll-a vs. water- leaving radiance.



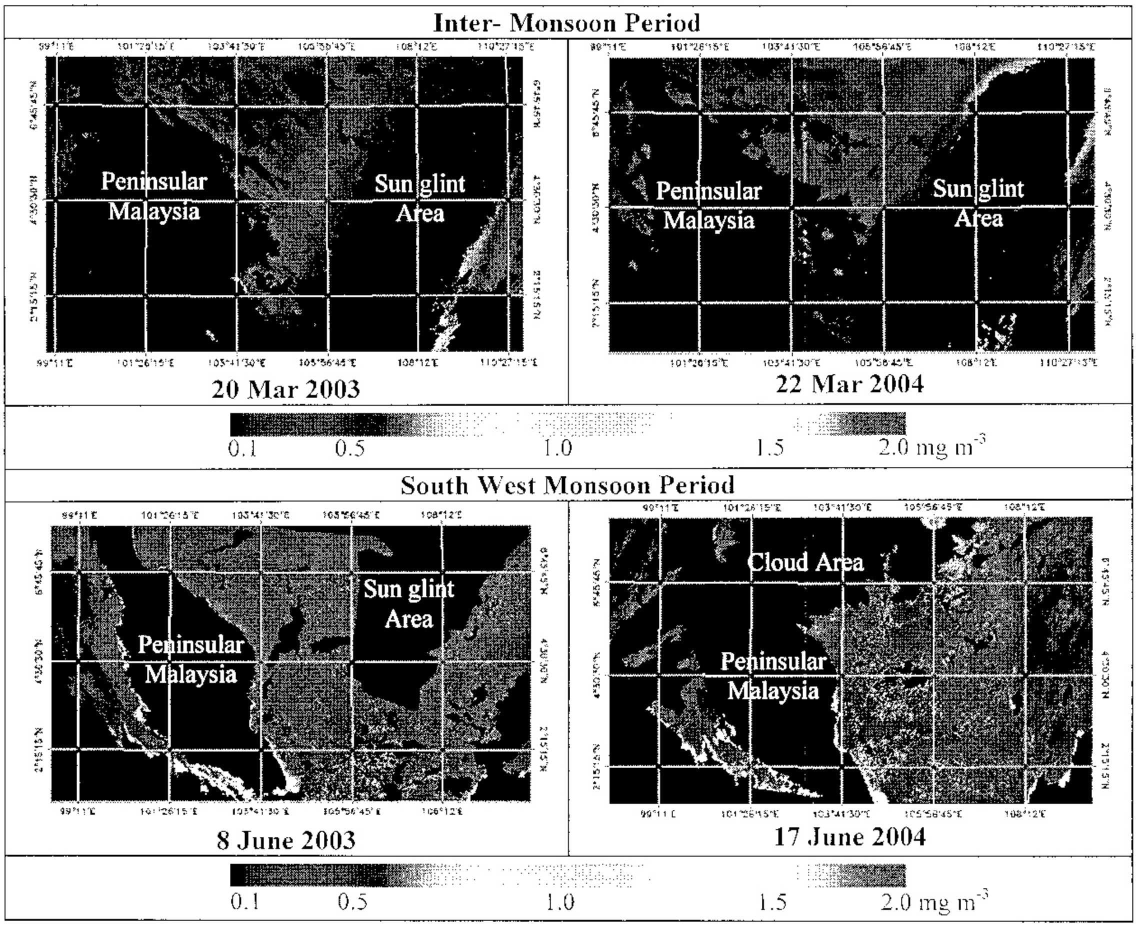


Figure 7: Distribution of chlorophyll-a concentration over South China Sea for different monsoon periods.

The north- east monsoon period starts from the month of December to February, an inter-monsoon period falls in the month of March, April and May and the south west monsoon period starts from the month of June to September. In 2003, the chlorophyll-a concentration in the coastal waters during north east and south west monsoon periods range between 0.1-0.5 mg m^{-3}, while the chlorophyll-a concentration in 2004 has increased to more than 0.5 mg m^{-3}. This means that the chlorophyll-a concentration has increased over time. The results of year 2003 and 2004 show that during the north east monsoon and south west monsoon periods the chlorophyll-a concentration over the South China Sea is between 0.1-1.5 mg m^{-3}, while the chlorophyll-a concentration during the inter- monsoon period is between 0.1-1.0 mg m^{-3}. The chlorophyll-a concentration during inter- monsoon period is lower when compared to the north east and south west monsoon periods. The chlorophyll-a concentration during both north east and south west monsoon periods can be affected by factors like monsoon winds, currents, upwelling and others.

6.0 Conclusions

From the study, it can be concluded that bands 9 and 12 give the best correlation with R^2 of 0.84 between chlorophyll-a and water- leaving radiance using 4 points in the regression using Gordon's algorithm. The regression analysis using measured chlorophyll-a and calculated chlorophyll-a at the 4 points showed the Gordon's algorithm gave the best correlation R^2 of 0.735. Therefore, the algorithm was used to calculate the chlorophyll-a distribution during the north east monsoon, south west monsoon and inter- monsoon periods in 2003 and 2004. The chlorophyll-a concentration during the north east monsoon and south west monsoon period was between 0.1-1.5 mg m^{-3}, while the chlorophyll-a concentration during inter- monsoon period ranges from 0.1-1.0 mg m^{-3}. Thus, the chlorophyll-a level is lower during inter- monsoon period when compared to the monsoon period. The chlorophyll-a concentration in the monsoon period might be affected by factors like monsoon winds, currents, upwelling and others. However, the accuracy of the results for the 2003 and 2004 data could not be checked since ground truth data is not available. It is recommended that more ground truth points should be used in the regression analysis to improve the results.

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