

An Analysis of Spatial and Temporal Variation of Net Primary Productivity over Peninsular Malaysia Using Satellite Data

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1. Introduction

Net Primary Productivity (NPP) is the fundamental process in the biosphere functioning and is needed for assessing the carbon balance at regional and global scale. Anthropogenic activities in many forest ecosystems have resulted in changes in NPP. Various models have been developed for the estimation of NPP and NPP is considered as one of the most-modeled ecological process. However the differences in term of approaches and complexity of most models have often yield comparable estimates of NPP values. In the context of Malaysia forest, the quantity and spatial distribution of NPP both seasonal and temporal are not well understood. The use of various satellite remote sensing data which has become the most preferred technique for estimating global NPP will be very useful in understanding forest NPP of Malaysia, especially aspects related to its quantum, spatial variability, and distribution across seasons.

Preliminary analysis of NPP over Malaysia forest using NOAA AVHRR data has been made (Ab.Latif, 2005). Despite various shortcomings, results of the analysis indicated that the use of remote sensing data can be very useful in providing information about NPP especially over large area coverage. In this preliminary study, focus of the analysis was only on the distribution of annual NPP, thus only providing very basic background information. Further analysis will be carried out using three types of satellite data NOAA AVHRR, MODIS and Landsat-TM.

2. Methodology

2.1 Satellite Data

2.1.1 NOAA AVHRR

Five scenes of NOAA AVHRR HRPT and LAC data for the year 2004 were acquired from NOAA for this study. The entire scenes were found to be relatively cloud free. Specifications of the acquired NOAA-17 AVHRR data are as in Table 1.

Table 1: Acquired NOAA AVHRR Data of Peninsular Malaysia

Year	Date	Spacecraft ID	Source
2004	9 January	NOAA-17 AVHRR	NOAA (NESDIS)
2004	8 April	NOAA-17 AVHRR	NOAA (NESDIS)
2004	4 July	NOAA-17 AVHRR	NOAA (NESDIS)
2004	2 October	NOAA-17 AVHRR	NOAA (NESDIS)
2004	23 August	NOAA-17 AVHRR	NOAA (NESDIS)

MODIS Data

Both Terra/MODIS (Moderate-Resolution Spectroradiometer) and Aqua/MODIS will be analyzed in order to develop better estimate of NPP for the whole Peninsular Malaysia and also for a smaller area such as Pasoh Forest Reserve. Figure 1 shows an example of MODIS data for 2004 of Peninsular Malaysia.

2.1.3 Landsat Data

Landsat-7 ETM+ images with spatial resolution of 30m x 30m were used. For NPP from Landsat data, a sample of NPP for one state, that is the state of Pahang. This data was acquired in June 20002 and the scene covered the whole states of Pahang and part of the northern region of Johor. Various scenes of Landsat images for the states of Pahang is shown in Figure 2, and the mosaic image for the state of Pahang is shown in Figure 3.

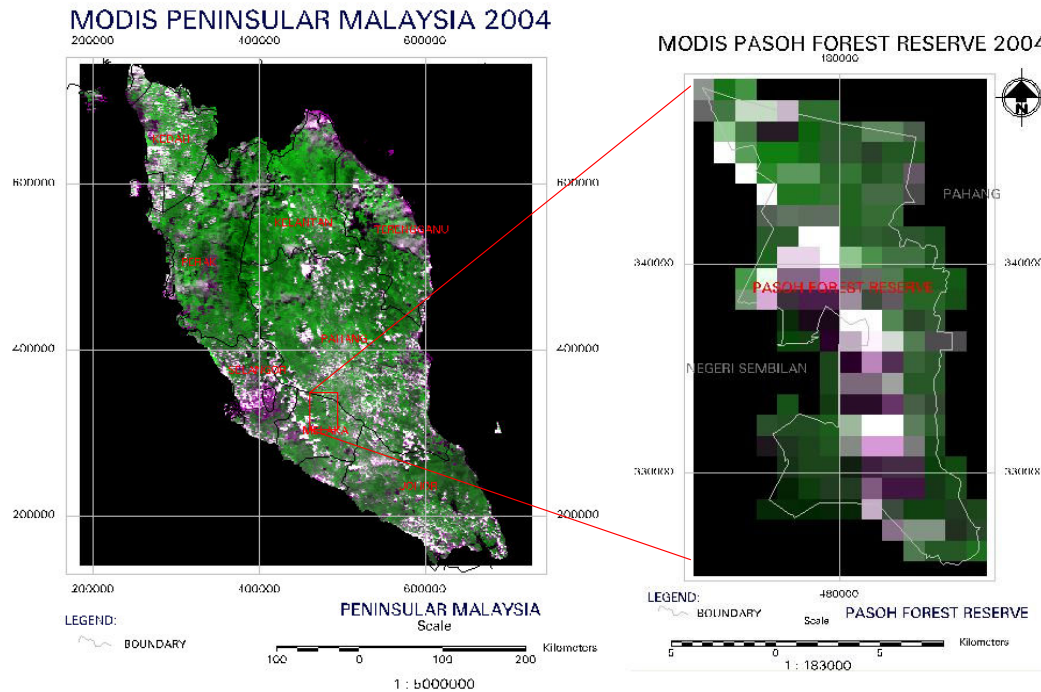
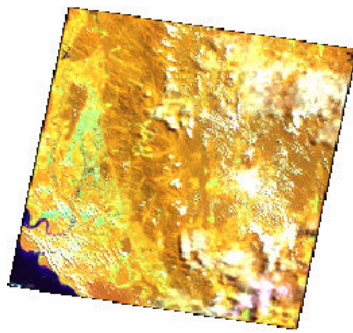
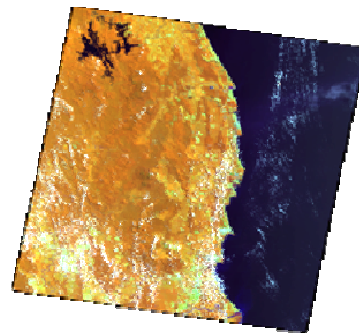


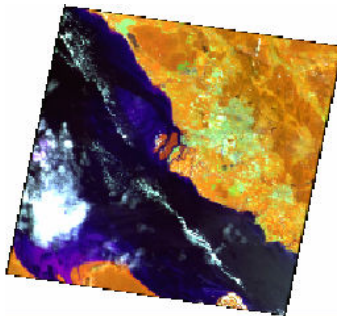
Figure 1: MODIS satellite Image of Peninsular Malaysia



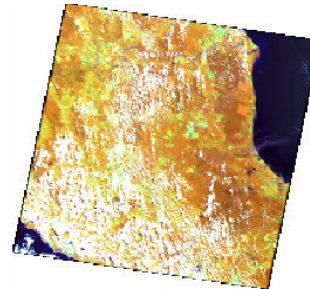
a) Scene 1 : Path 127 Row 57



b) Scene 2 : Path 126 Row 57



c) Scene 3 : Path 127 Row 58



d) Scene 4 : Path 126 Row 58

Figure 2: Four Scenes of Landsat-7 Satellite Images (2002)

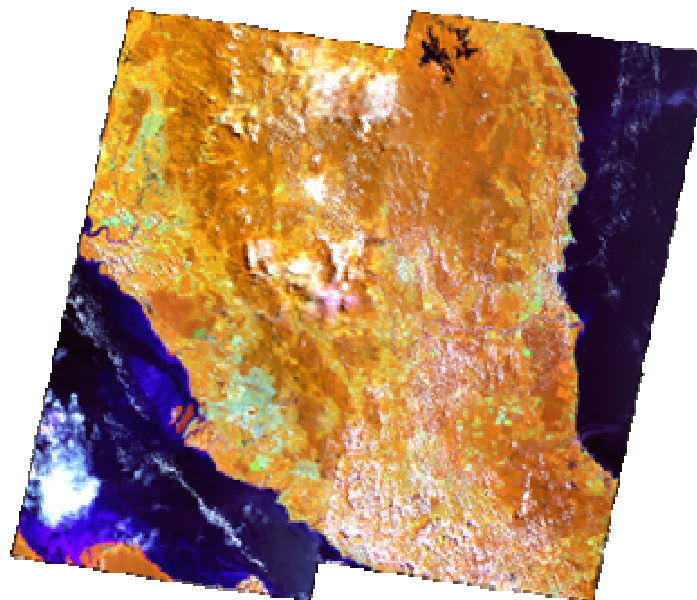


Figure 3: Mosaic Landsat Image of Pahang (Combination of bands 4,5,3)

2.2 Processing of satellite Images

The preprocessing of all the satellite image using a series of correction procedures was carried out in order to remove or minimize errors due to sources unrelated to land surface characteristics in the raw satellite signals. These include the re-projection of all the images to their through geographical coordinate and remove all the atmospheric effect such as the effects of aerosol and water vapour, bidirectional reflection variations, residual clouds and subpixel contamination through radiometric procedures. Analyses were carried out using ERDAS Imagine (version 8.5) and ENVI (version 4.0) image processing software.

2.2.1 Model for The Estimation of NPP

The carbon budget consists of several major processes that describe the exchange of carbon dioxide between terrestrial ecosystems and the atmosphere. Gross Primary Productivity (GPP) is the total carbon assimilated by vegetation. A fraction of GPP is lost back to the atmosphere as the result of autotrophic respiration (R_a). Net Primary Productivity (NPP) is the balance between GPP and autotrophic respiration. NPP is allocated to wood, foliage, roots and reproductive tissues (Running et al, 2003). NPP is expressed by GPP and autotrophic respiration (R_a) as describe in Equation (1).

$$NPP = GPP - R_a \quad (1)$$

The autotrophic respiration is affected by air temperature (T , °C) and gross primary production as describe by the following empirical relationship (Furumi et al, 2002);

$$R_a = GPP * [(1.825 + 1.145T)/100] \quad (2)$$

Satellite remote sensing provides consistent and systematic observations of vegetation and has played an increasing role in the characterization of vegetation structure and estimated Gross Primary Production (GPP) and Net Primary Production (NPP) of forest (Xiao et al, 2004). These satellite-based studies have used the Light Use Efficiency (LUE) approach to estimate Gross Primary production as;

$$GPP = LUE_g * (FAPAR * PAR) \quad (3)$$

where,

GPP = Gross Primary Productivity

LUE_g = Light Use Efficiency (gCMJ⁻¹PAR)

PAR = Photosynthetically Active Radiation (MJm⁻²) in time period

FAPAR = fraction of PAR absorbed by vegetation canopy

Photosynthetically active radiation (PAR) is actually restricted to just a portion of electromagnetic spectrum from 0.4 to 0.7 micrometers (μm) which is comparable to the range of light the human eye can see. The value of PAR is assumed to be approximately 0.5 of the incoming solar radiation (Prasad, et al, 2002; Brogaard et al, 2005; Sims, et al, 2005). FAPAR is the fraction of PAR absorbed by vegetation canopy. LUE_g is the Light Use Efficiency (gCMJ⁻¹PAR) in GPP calculation from empirical relationship of meteorological data. LUE is a biome-specific value representing optimal potential of the vegetation for converting PAR to GPP (Nichol, et al, 2000). LUE_g is expressed as;

$$\text{LUEg} = 0.8932 + (0.0163 * T_a) + (0.0015 * \text{Pt}) - (0.0022 * \text{GDD}) \quad (4)$$

Where,

T_a = mean temperature (°C),

Pt = is annual precipitation (mm),

GDD = the mean of growing degree day

GDD is derived from the differences of mean and minimum value of temperature. The calculations of LUEg coefficient were derived from surrounding stations using a distance-weighted spatial interpolation technique. *FAPAR* is usually estimated as a linear or nonlinear function of NDVI (Coops, et al, 1998; Tania, 2004). *FAPAR* have a potential range from 0 (no interception or no absorption) to 1 (total interception or total absorption) as describe by following empirical relationship closely related to Normalized Differences Vegetation Index (NDVI);

$$FAPAR = \text{NDVI} * 1.67 - 0.08 \quad (5)$$

Where,

NDVI = Normalized Difference Vegetation Index

NDVI is the ratio between red and near infrared bands (Xiao et al, 2004; Jiang, et al, 1999) and can be calculated using the following formula;

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (6)$$

Data from vegetated areas will yield positive values for the NDVI due to high near-infrared and low red or visible reflectance. The global NDVI value for vegetated area is 0.04 to 0.52 and the value will increase if the data is from surface reflectance value (Shunlin, 2004). NPP can be estimated using the empirical relationship between vegetation distribution and climate variable by using the Miami Model. In the Miami Model formulation (Jiang, et al, 1999; Prasad, et al, 2002; Zhou, et al, 2002) is calculated as a function of either annual precipitation P (mm) or mean annual temperature T (°C).

$$\text{NPPp} = 3000 * (1 - e^{-0.000664 * P}) \quad (7)$$

$$\text{NPPt} = 3000 * / (1 + e^{1.315 - 0.119 * T}) \quad (8)$$

For the calculation of NPP using Landsat-7 image, the constant of LUE used in the model is based on Tania (1998). The suitable constant of LUE for tropical area using Landsat image is 1.8 $\text{gCMJ}^{-1} \text{PAR}$. The flowchart of methodology for the estimation NPP from satellite data are as shown in Figure 4 (NOAA and MODIS) and Figure 5 for Landsat.

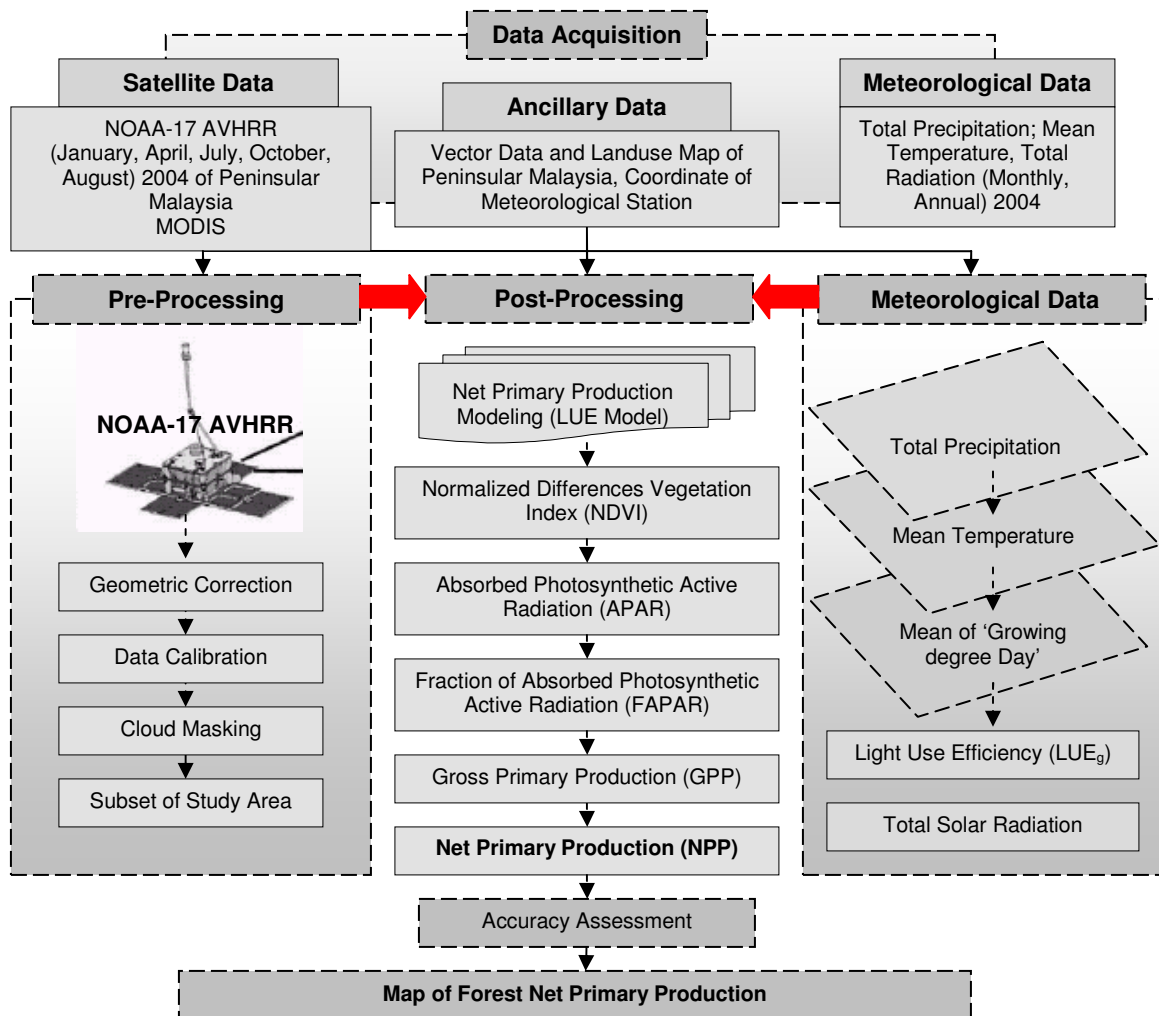


Figure 4: Flowchart of Methodology for the calculation of NPP from NOAA and MODIS image

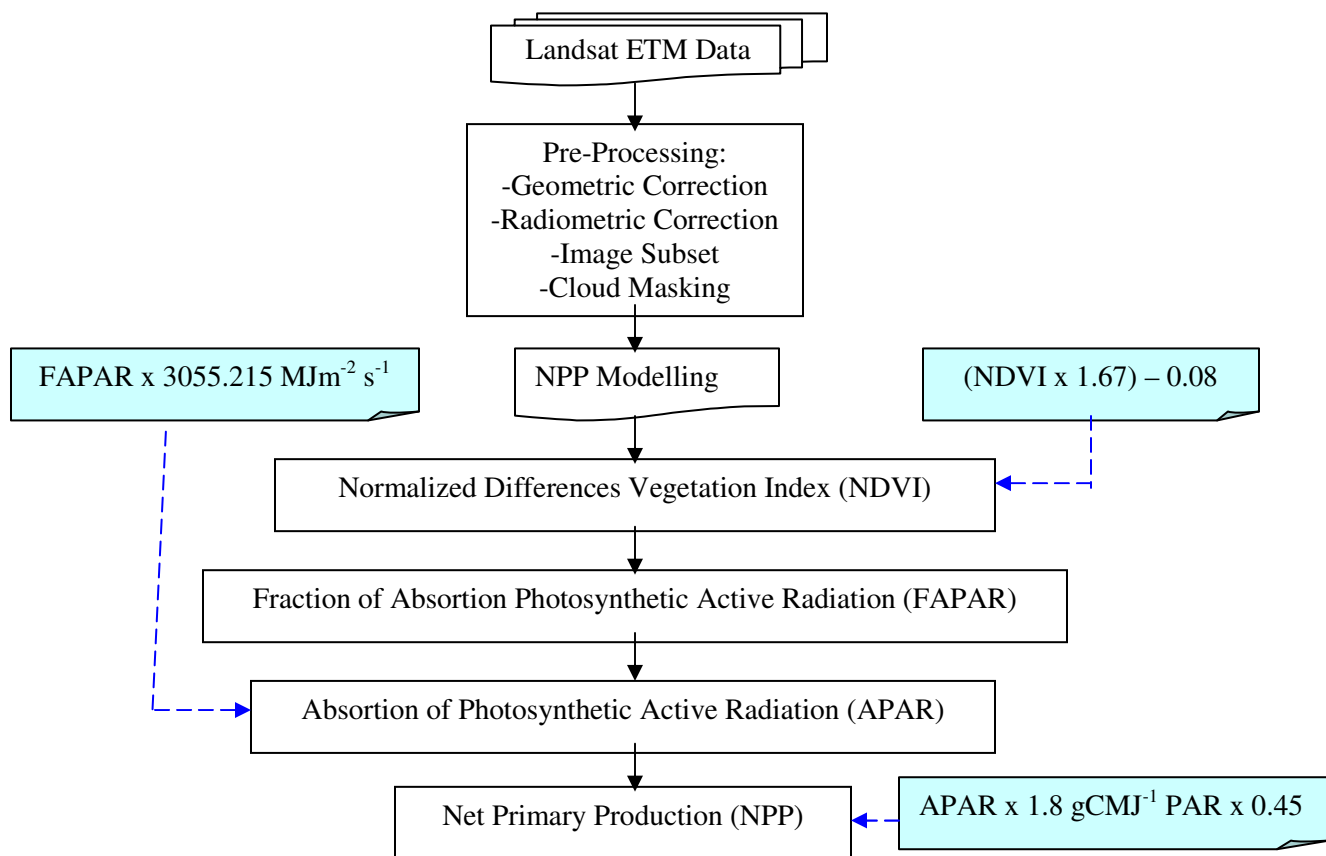


Figure 5: Flowchart of Methodology for calculating NPP from Landsat data

3. Result and Analysis

The estimation of NET Primary Production in this study has been carried out using Light Use Efficiency approach (LUE Model). Seasonal and annual values of NPP for Peninsular Malaysia forest were estimated using NOAA AVHRR and MODIS data. While the Landsat TM data is used to estimate the NPP values for forest area for the state of Pahang.

3.1 Seasonal Variation of NPP for Peninsular Malaysia forest

The mean monthly value of NPP for the months of January, July and October is shown in Figure 6. The percentage of NPP varies from 13.1% to 51.23% with the highest value in the month of April with the value of 301.65 gCm²month⁻¹ followed by October with 217.78 gCm²month⁻¹, January (189.6 gCm²month⁻¹) and July (89.22 gCm²month⁻¹). The main factors that contribute to the monthly or seasonal variation of NPP are the changes in two metrological parameters that are temperature and rainfall. As Malaysia experience very little temperature variation, the effects of temperature on the seasonal NPP is also very minor.

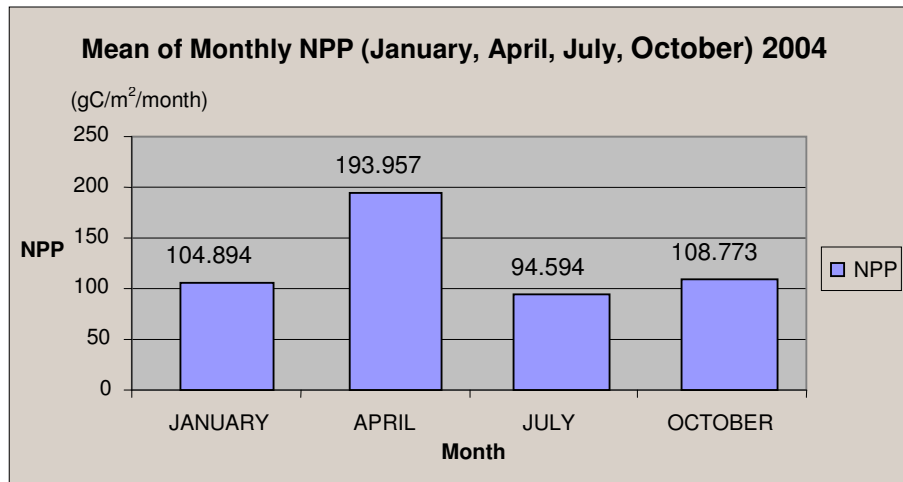
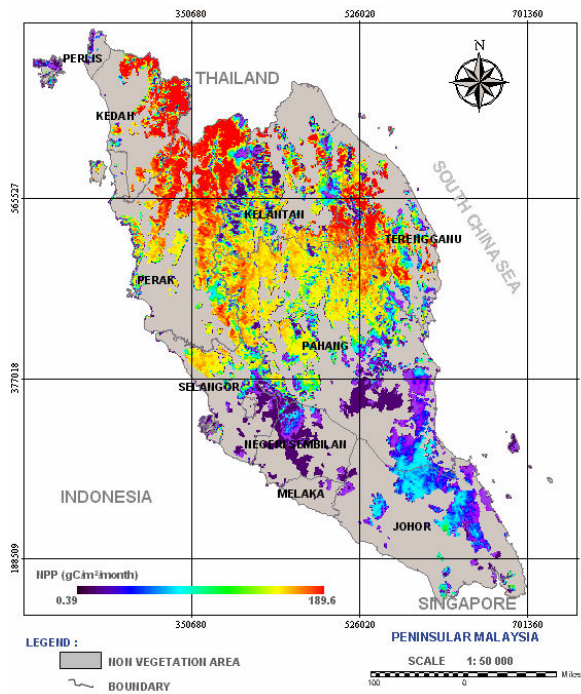
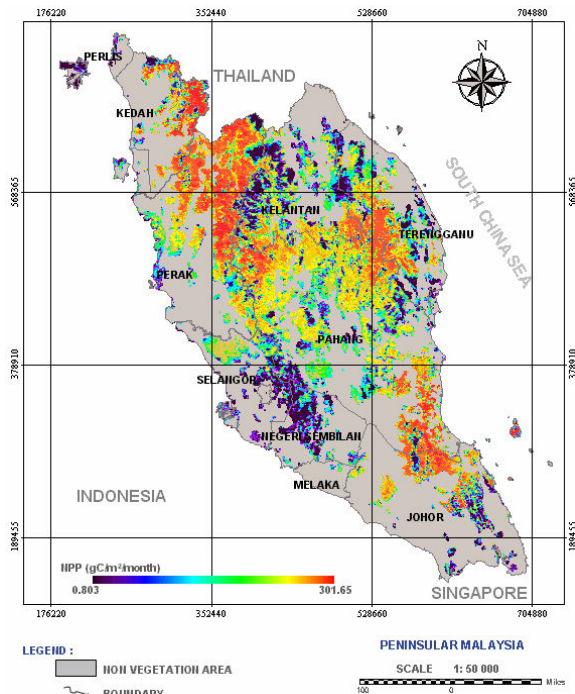


Figure 6: Mean Value of NPP (January, April, July, October) 2004

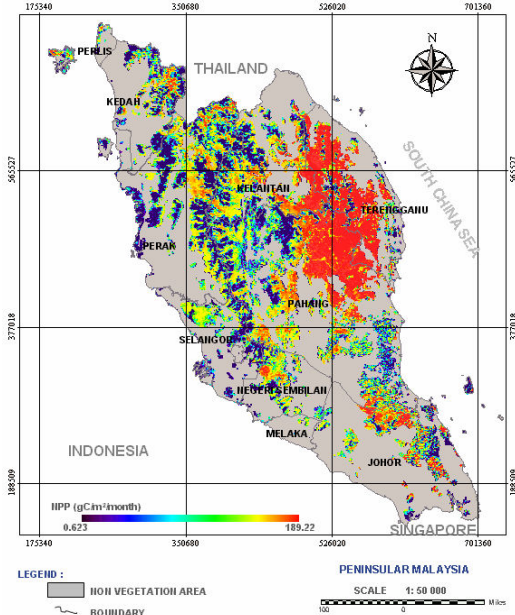
The seasonal distribution of NPP for Peninsular Malaysia is demonstrated in Figure 7.



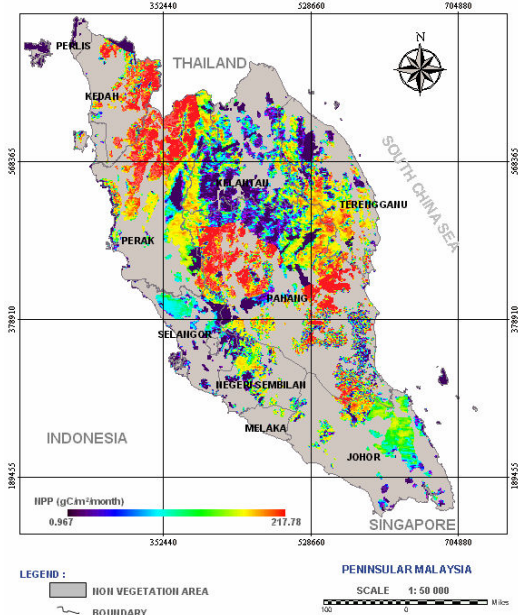
(a) January 2004



(b) April 2004



(c) July 2004



(d) October 2004

Figure 7: Seasonal Distribution of NPP for Peninsular Malaysia: (a) NPP for January, (b) NPP for April, (c) NPP for July, and (d) NPP for October.

3.2 Annual Distribution of NPP

The value of Net Primary Production was closely related to the value of total solar radiation, concentration of carbon dioxide and the water use efficiency. The highest value of NPP is normally closely related with areas of highest vegetation cover. This is mainly due to the highest reflectance in near infrared region. As shown in Figure 8, the highest value of annual NPP value is $5265.9 \text{ gCm}^2\text{yr}^{-1}$, while the minimum value is $55.43 \text{ gCm}^2\text{yr}^{-1}$. The highest NPP located in the central part in the north Peninsular Malaysia, where the forests are denser compare to the southern region. This includes the area under the National Park which covered part of the forested area in the states of Pahang, Terengganu and Kelantan.

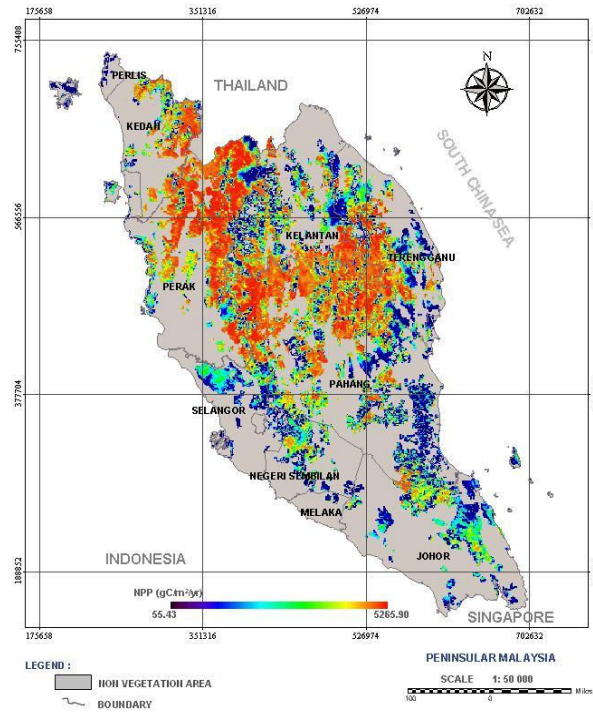


Figure 8: Mean Annual Net Primary Productivity of Peninsular Malaysia 2004 (NOAA)

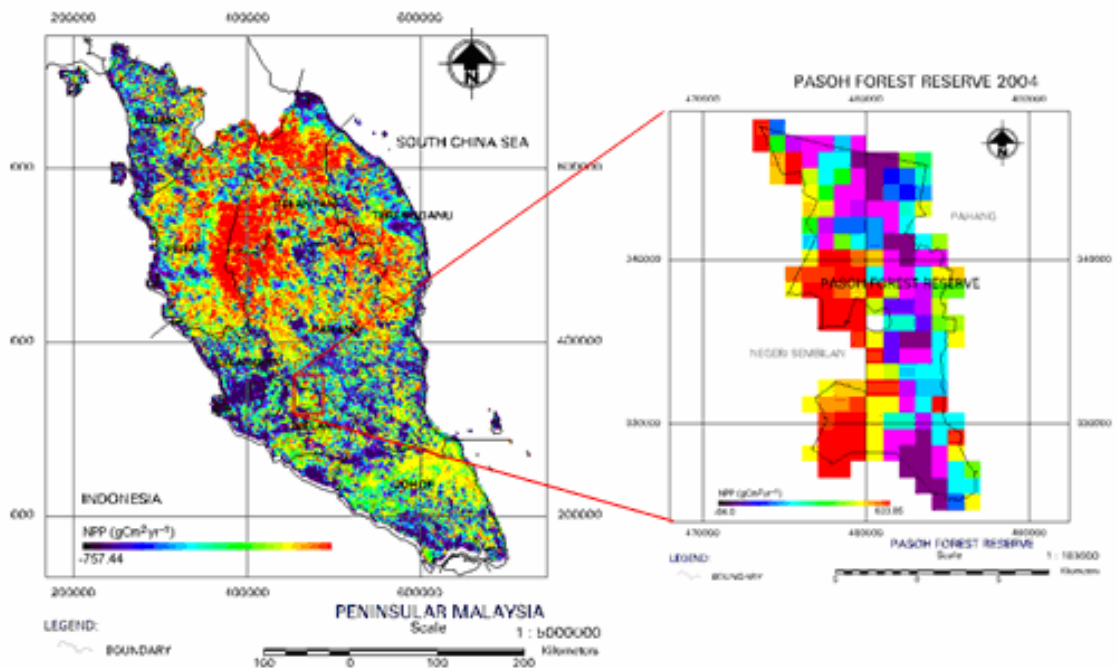


Figure 9: Mean Annual Net Primary Productivity of Peninsular Malaysia 2004 (MODIS)

3.3 Estimation of NPP using Landsat data

The estimation of NPP using Landsat data is only carried out for the forest area in the state of Pahang. The subset Landsat TM image and the subset forested areas for the state of Pahang is shown in Figure 10a and 10b. While Figure 11 shows the major forest types of Pahang which consisted of five main types of forest; (i) the upper montane forest, (ii) lower montane forest, (iii) upper dipterocarp forest, (iv) hill dipterocarp forest, and (v) low land forest.

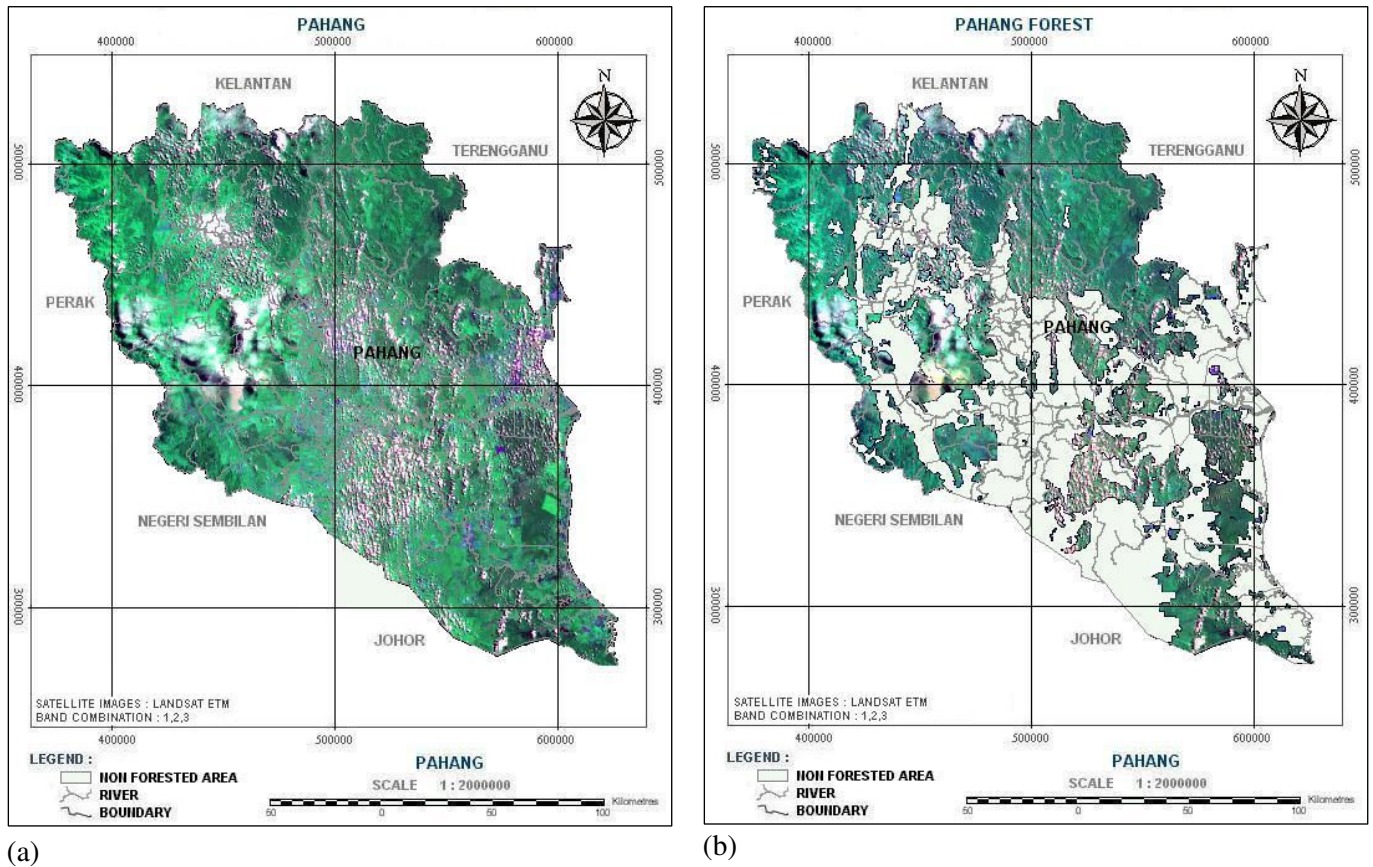


Figure 10: (a) Landsat image of Pahang (2002) and (b) Pahang forest area

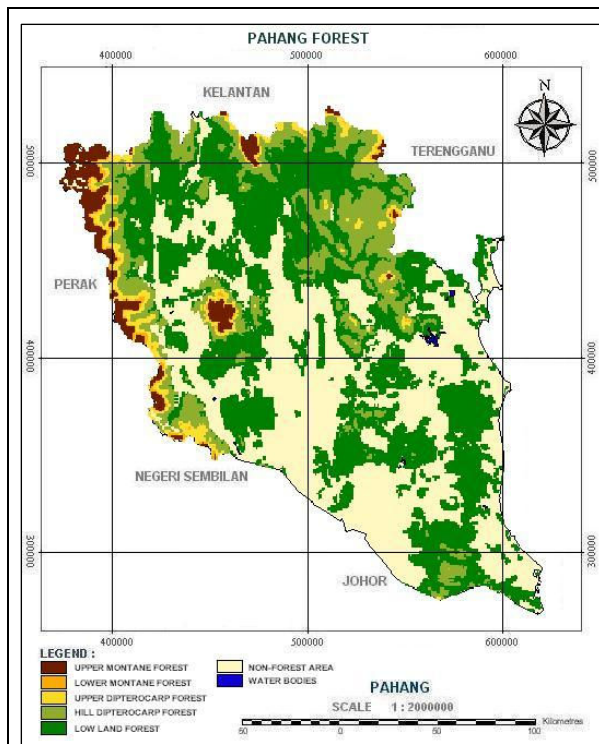


Figure 11: Forest types of Pahang

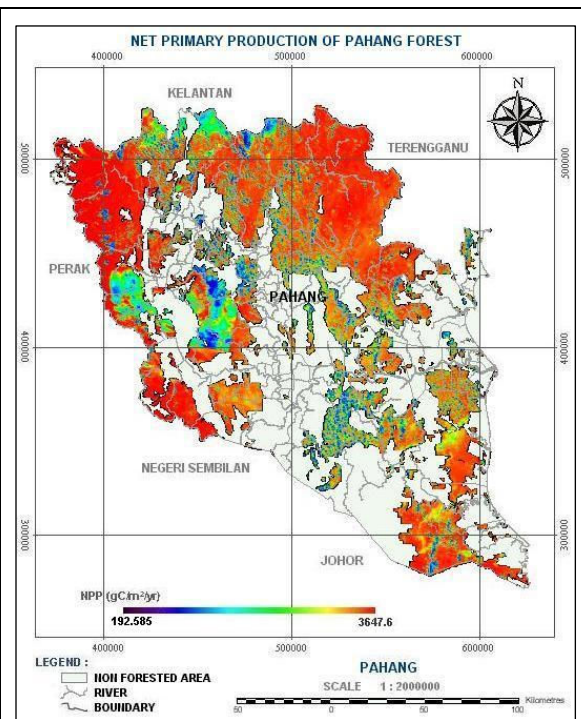


Figure 12: NPP for forest area in Pahang

An analysis of NPP from Landsat TM image for the states of Pahang indicated that the average value of NPP for forest area is about 3,500 gCm²yr⁻¹, the highest value of NPP is about 3,647.8 gCm²yr⁻¹ and the lowest value is about 192.58 gCm²yr⁻¹. Most of the area with high value of NPP is areas covered inland and hill forest. The areas in the Southern part of Pahang are areas covered with Peat Swamp forest. Part of this area has already been converted to agricultural land such as oil palm and other development activities, thus showing lower value of NPP.

CONCLUSION

In this study various types of remote sensing data have been used to analyze the NPP value for forest areas in Peninsular Malaysia. Various types of remote sensing data, with different spatial and temporal resolution can be utilized to analyzed NPP for forest area in Malaysia at different scales.

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