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Remote Estimation of Gross Primary Production (GPP) using MODIS data in Kelantan: A Preliminary Assessment

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Abstract. Kelantan state is located in the north-eastern of Peninsular Malaysia, with 5.8 million hectares is covered by forested areas. Gross primary production (GPP) is the amount of carbon captured by plants and it is an important biophysical parameter in the spatio-temporal dynamics of CO₂. GPP estimates derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) are converted to the forest area and compared. GPP is estimated through a light use efficiency model (LUE) and enhanced vegetation index (EVI) as a proxy of greenness to address spatial and temporal variation in terrestrial photosynthetic activities. This study is important because the output will be used as a reference to estimate the approximate total carbon in Kelantan. Estimation GPP of Kelantan state is also useful for natural resource and land management, regional carbon cycle analysis, ecosystem status assessment, and environmental change monitoring. The objective of this study is to estimate Gross Primary Production (GPP) value of forested area in Kelantan using MODIS data. MODIS data was preprocessed, classified and analysed to get the estimated GPP of study site. The results show that average GPP value of Kelantan was estimated within the range of 0 to 646 gC/m²/month. In average, GPP in Kelantan was at 428.63 gC/m²/month. Gua Musang recorded the highest GPP value, while the lowest GPP value detected were in Kota Bharu, Tumpat and Bachok where lot of development are found at the area. The estimation of GPP in Kelantan using MODIS data is a timely significant method. However, the requirement of more study that uses MODIS data in different terrestrial types and vegetation is needed for future study.

1. Introduction

Moderate Resolution Imaging Spectroradiometer (MODIS) is a multispectral sensor that has a total of 36 bands that have different spatial resolutions ranging from 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) with wavelengths starting at 0.620 μm - 14,385 μm . This satellite sensor orbits/surrounds the earth polar every 2 days with an altitude of 705 km, the width of the land coverage on the surface of the earth every round is around 2330 km. Besides, it provides images of the entire planet Earth every 1 to 2 days with high radiometric sensitivity. With a total characteristic of 36 bands of wavelength and 12-bit radiometric sensitivity, the MODIS sensor installed on the Terra and Aqua satellites can measure almost all land cover, sea and air parameters so that, its usefulness is very wide [1].

Gross primary production (GPP) is defined as the overall rate of fixation of carbon through the process of vegetation photosynthesis. It is used to quantify the amount of biomass produced within an



ecosystem over a unit of time, regardless of the amount of respiration. GPP is a significant important parameter for the carbon cycle and climate change research. Remote sensing combined with other climate and meteorological data offers a convenient tool for large-scale GPP estimation [2]. GPP can be estimated by using the eddy covariance technique as it provides a relatively direct measure of GPP at scales of a few hundred meters, but such observations are limited as the cost and time required to operate eddy covariance sites precludes the deployment of the large network of homogeneously-instrumented towers needed to accurately sample global GPP [3]. Remote sensing technology provides a promising approach to overcome these limitations. Over the year, various techniques can be used to determine primary production by satellite observations. For example, using MODIS satellite observations in conjunction with a light-use efficiency model to produce GPP estimates at the 1 km scale and using satellite observations directly to determine both GPP and agricultural production at the native 250 m resolution of MODIS using spectral vegetation indices through the growing season[4].

Therefore, Kelantan, one of the tropical states in Malaysia with a mixture of land use provide an excellent opportunity to provide a very large test site for testing the validity of MODIS derived estimates of tropical GPP. MODIS enhance vegetation index (EVI) product are potentially useful for routinely monitoring terrestrial ecosystem and vegetation changes. Although monitoring of forest resources and land clearance is a high national priority, calling for the development of suitable remote sensing approaches for land cover inventory and monitoring is not yet up to date. Kelantan has experienced rapid changes in land cover in recent years including clearance of native forest and large expansions of rubber plantations. Consequently, it provided an ideal study area to test the suitability of our remote sensing land cover discrimination. Hence, the goals of the present study were to evaluate the performance of existing MODIS GPP products (MOD17A2) for estimating gross primary productivity of forest area in Kelantan.

2. Methodology

This study focused to estimate the GPP of Kelantan state which the area lies in the north-east of Peninsular Malaysia. Kelantan has a total area of 15,000 km² with various land cover and land use types (Figure 1). Nine months of MODIS data were analysed starting from January to September 2019. The data acquired from the United States Geological Survey (USGS) website was downloaded and analysed. The resolution of MODIS data is 1 × 1 km² with 36 spectral bands ranging from 450 nm to 2100 nm. From the 36 spectral bands, seven bands were designed for the study of vegetation and land surface which were blue (459-479 nm) – band 3, green (545-565 nm) – band 4, red (620-670 nm) – band 1, near-infrared NIR (841-875 nm, 1230-1250 nm) – band 2 and 5, and short wave infrared SWIR (1628-1652 nm, 2105-2155 nm) – band 6 and 7. MODIS data were analysed using ENVI 5.3 and ArcMap version 10.3 for image classification and area calculation.

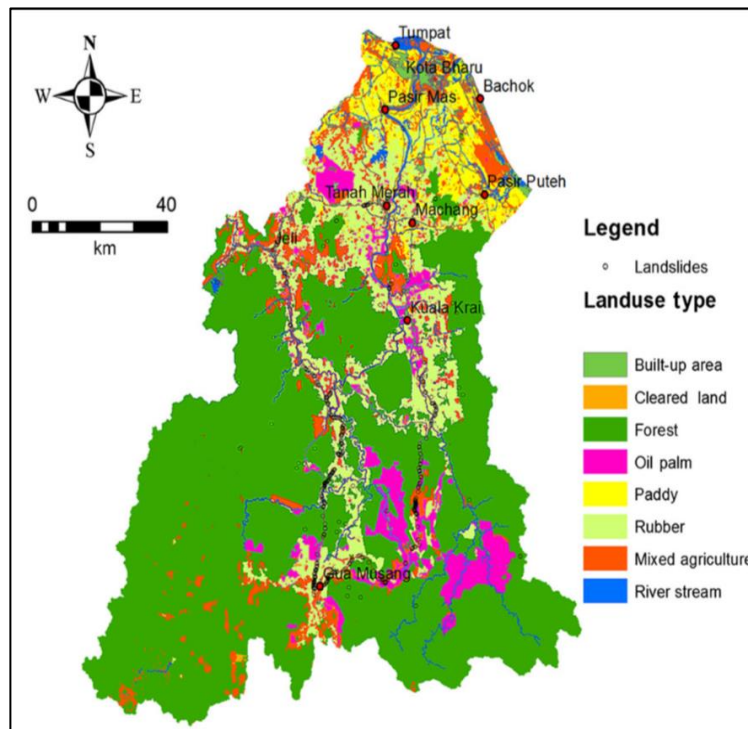


Figure 1: Types of land use and land cover (LULC) in Kelantan.

The MODIS data were pre-processed to reduce unwanted noise and geometric errors to obtain the desired image outputs. This step enhanced the image data quality by reducing or eliminating numerous radiometric and geometric errors due to internal and external conditions [5]. Pixel brightness transformation, geometric transformation and image clipping process were done before the final image data been analysed. These processes were prepared using ENVI software version 5.3. The GPP value of each images was calculated using equation (1).

$$GPP = \varepsilon_{max} \times 0.45 \times SW_{rad} \times fAPAR \times f(VPD) \times f(T_{min}) \quad (1)$$

Where,

ε_{max} - maximal LUE,

SW_{rad} - short-wave downward solar radiation,

PAR - 45% is assumed

$f(VPD)$ and $f(T_{min})$ - reduction scalars for water stress and low temperature.

Next, image classification was executed and the GPP value was calculated for each pixel. The process of image classification includes transforming multi-band raster imagery into a single-band raster with a variety of categorical classes related to different GPP values. The GPP values were categorised in a few classes based on the value range. These processes were performed through ArcMap software version 10.3. The classified GPP value was counter check with the satellite image from Google Earth to verify the location and land use types of the selected sites.

3. Results and Discussion

Evaluation of the MODIS Gross Primary Productivity (GPP) data of Kelantan states produced a seven categories of GPP estimation value. From this preliminary study, the GPP value in Kelantan was estimated between 0 to 646 $\text{gC}/\text{m}^2/\text{month}$. In average, the GPP in Kelantan was expected at 428.63 $\text{gC}/\text{m}^2/\text{month}$ with a standard deviation of 143.20 $\text{gC}/\text{m}^2/\text{month}$. Figure 2 shows the variation of GPP which translated as the sum of the photosynthesis transpired in the study area.

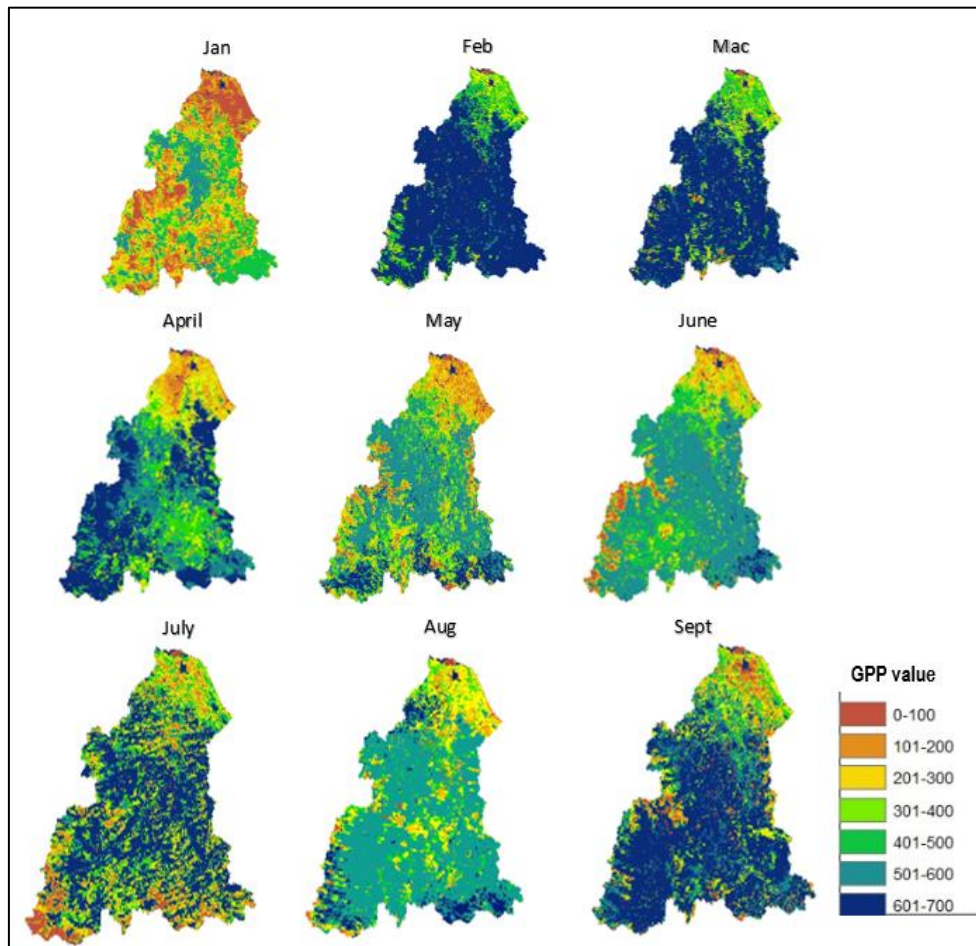


Figure 2: The GPP estimation value of the study area calculated for each month (Jan- Sept)

The GPP value with the distribution of area covered for Kelantan state is presented in Table 1. From the analysis, 52.2 per cent of the GPP in Kelantan lies between 501 to 600 $\text{gC}/\text{m}^2/\text{month}$. The highest GPP value was detected in Gua Musang district followed by Kuala Krai, Jeli, Tanah Merah districts. This was due to the detection of canopy cover by permanent reserve forest which majorly located at the aforementioned districts. About 323 km^2 of the study area embraced the high GPP value between 601 to 700 $\text{gC}/\text{m}^2/\text{month}$. Area verification showed that Felda Chiku in Gua Musang showed the highest value of GPP readings in which, the area was surrounded with oil palm plantation and also enclosed by forest area.

Table 1: GPP value and the coverage estimated from MODIS data.

| GPP value | Area (km ²) | Percentage (%) |
|----------------|-------------------------|----------------|
| 0-100 | 473.5 | 3.2 |
| 101-200 | 763.5 | 5.2 |
| 201-300 | 1463.0 | 9.9 |
| 301-400 | 1122.7 | 7.6 |
| 401-500 | 2931.5 | 19.8 |
| 501-600 | 7725.5 | 52.2 |
| 601-700 | 323.2 | 2.2 |

Meanwhile, develop areas such as Kota Bharu and Bachok districts recorded the low GPP among others. This was proofed when the mentioned districts showed a low GPP value that only range between 0-100 gC/m²/month. A lower value of GPP can be explained by the differences in biomass that may be imposed by two factors. Firstly, biomass was influenced by vegetation density. Low biomass carbon storage was detected due to less number of emergent trees compared to the presence of shrubs [6]. Secondly, the small value in biomass may also be influenced by both biogenic and anthropogenic disturbances [3].

The previous study by [6] found that the total biomass and carbon stock of standing trees in Bukit Bakar Forest Reserve, Gunung Basor and Gunung Stong Tengah recorded a high accumulation of carbon stock in Kelantan. It is also estimated that the lower altitude produces the highest value of biomass [6]. This study had supports the finding of previous research. However, the results obtained in this study only touched the prevailing areas of Kelantan state. More work is required to understand the spatial and temporal variations as well as productivity parameters in estimating the gross primary production in Kelantan. It is suggested that a combination of ground survey and remote sensing provided valuable and accurate information for the assessment.

4. Conclusion

The GPP is the rate of fixation of carbon dioxide by photosynthesis process. It is the primary measure of carbon supply and t metabolic activity by vegetation in a specific area. In this study, the average estimation of GPP value of Kelantan state area was evaluated. It ranged from 0 to 646 gC/m²/month. The highest value of GPP (646 gC/m²/month) was found at Felda Chiku, Gua Musang while the lowest value of GPP (0 to 100 gC/m²/month) was found at Kota Bharu and Bachok districts. Remote sensing image from MODIS satellite is a lucrative product to estimate GPP value in efficient time, with effective cost and practical in energy uses. Thus, this data can be used to predict the GPP of a wide-scale area. This evaluation of satellite-driven carbon productivity is important for quantifying the role of vegetation in the global or regional carbon cycle. It is also essential in assessing the quality of the forest area and contributes information to the management and stakeholders.

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