Dry season analysis using MODIS data for forest and agricultural area in Negeri Sembilan, Malaysia

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Abstract. Tropical forest together with oil palm and rubber, two of the important plantation crops in Malaysia play a huge significant role in providing biodiversity, maintaining ecosystem, maintaining carbon balance and have huge economic value for Malaysian economy. These plantations highly sensitive to long term droughts causing crops productivity decline. The study focusing on the drought effect on these plants production using remote sensing technology. Satellite images of study areas were collected by using MODIS according to study time frame of drought. The images collected were employed, pre-processed to eliminate all the interference on the satellite images and analysed to develop various vegetation indices particularly for dry characteristics namely, Normalised Difference Water Index (NDWI), Water Index (WI), Short Wavelength Infrared (SWIR) and Water Stress Index (SIWSI). Then, meteorological data such as humidity, precipitation, temperature and solar radiation of the areas analysed to categorise the time-frame of the drought. Lastly, dry season map consisting vegetation indices for the study areas constructed.

1. Introduction

Tropical forests are a major reservoir of planet’s biological diversity and have a crucial role in climate and hydrological and biogeochemical cycling. The forests comprise a critical component of the global Earth system through providing social, cultural and economic significance as sources of important renewable and non-renewable resources [1]. Nowadays, with projection of human population in 2020 in Southeast Asia is nearly 30 million, tropical forests is facing pivotal challenges with extra food, land and the most importantly is water for basics living needs. Remote forest areas are also increasingly accessible to hunters and commercial timber extraction that is before was escape from agriculture clearing and wood extraction activity [2]. Societies in urban areas is began searching for comfortable social areas that is away from busy city lives, contributed to increasing number of conversion of forest into nature-friendly house, forest park, commercial waterfalls, nature walk, and other recreational areas. With this, more intense pressure is added to forest and agricultural plantation.

As years goes by, a huge areas of tropical forest experienced land degradation, because of land conversion for crops and other land uses [3]. The highest rate was recorded in Indonesia, and the South and southeast of the Brazilian Amazon [3]. Lack of information on vegetation water status of the tropical forests leads the situation and to a significant deterioration of forest that results of and biodiversity depletion. In agriculture and forestry sector, it is important to assess plant water content as found in [4] study for drought assessment of natural communities. Other previous study was [5] have assessed forest fire risk. Other study by [6] assessed water level status for assessing landscape disturbances. In fact many studies was conducted, insufficient attention was given to vegetation.
water status study of tropical forest regions other than Amazon particularly during 2005 ENSO episode dry periods. Numerous publication have found that there were almost one to tent of studies was conducted for other forest types. For chaparral forest study was carried out by [7]; for Walnut Gulch [8]; for Bartlett Experimental Forests, USA [9] and for Senegal was [10]. An example for tropical forest was for Amazonian of Tapajos National Forest, Santarem in Brazil which was far well-established. However, studies for other tropical forests area was far insufficiently conducted except for Southeast Asia tropical forest by Asner, Nepstad, Cardinot, & Ray ; A. Huete et al. ; A. R. Huete et al. [11–13]. A study by A. R. Huete et al. [13] for different tropical forest types: drought deciduous in MacKlong Watershed, Thailand, evergreen dry forest in Sakaerat, Thailand, finally for humid evergreen forests in Bukit Soeharto, Indonesia.

Recent development of satellite data available for free, promote further scientific research on water status for tropical forest. The utilization of remote sensing indices based on free download and registered user namely Moderate Resolution of Spectroradiometer (MODIS) permit an advanced application particularly for forest water index based on near-infrared (NIR) reflectance and MODIS shortwave reflectance wavelengths (SWIR). Research on tropical forest and agricultural lands properties should herald a new era for water status assessment. Yet there is still much to explore about optimal use of the data acquired by pixel reflectance of the NIR and SWIR. For example, the potential of the NIR with 841–876 nm and SWIR wavelengths of 1628–1652 nm data which can be acquired by MODIS. The advantages of MODIS data is to provide more frequent data at larger temporal and spatial scale which can support limitations of underlying database for forest and agricultural water use within monsoon pressure [14–17].

This is because a study by Gu et al. [18] showed that during the dry periods vegetation had a greater loss in water content than in greenness which is depicted in vegetation indices such as NDVI. Oil palms physiological condition including factors such as presence of grassland during different planting phases has contributed to a lower NDVI and NDWI value in oil palm [19] which showed that presence of Imperata grassland may also contribute to a misleading of the indices value in the species. Forage species were highlighted as the plants that dominated the ground in the early stages of the tree crop development, or approximately the first five years. Therefore, this study was conducted to evaluate precipitation data from two meteorology stations, Gemencheh and Tanah Merah and analysed the vegetation indices (NDVI, NDWI and SIWSI) values from MODIS satellite images.

2. Methodology

2.1 Study area
The study had been done in Negeri Sembilan, one of the state in northern part of Peninsular Malaysia. The study focused on three different type of vegetation areas, natural forest of Angsi Reserve, Forest, the rubber estate and oil palm estate around the Angsi Reserve Forest. The main characteristics of study areas are its remain dry throughout the year, influenced by the Southwest Monsoon from May to August and Northeast Monsoon from November until February that causing the convective rain. The latest extreme dry season was during 2016.

2.2 Meteorological data.
Daily precipitation data retrieved from Malaysia Meteorology Department, starting from year 1997-2017 was employed for the precipitation analysis expect for 2017 which until 25th October 2017 only.

2.3 Satellite data
This study employed using MODIS satellite images product, the MODIS Terra Surface Reflectance 8 – Day L3 Global 500m resolution (MOD09A1) Version 5 were collected on the year 2000, 2006 and 2017, focusing on the year which the dry event appearing obtained from Land Process Distributed Active Achieve Centre (LPDAAC) (Table 1). MOD09A1 provided 13 bands but in this study only bands 1-7 used, consisting red (band 1), Near-Infrared (NIR) (band 2), blue (band 3), green (band 4)
and Shortwave Infrared Reflectance band (SWIR)(band 5, 6, 7) that suitable for obtaining the vegetation signal [20]. MODIS products stored in Enhanced Hierarchy Data Format (HDF-EOS), a simple format to help resize the data. Therefore, by using MODIS MRT conversion toolkit plug-in, ENVI version 5.3, the HDF-EOS format converted into .dat format before analysed in Exelis Visual Information Solution (ENVI) software [21,22]

Table 1. MOD09A1 products used in the study.

| Time frame  | Full code                                                                 |
|-------------|---------------------------------------------------------------------------|
| 14 APRIL 2000 | MOD09A1.A2000105.h28v08.006.2015136062718                               |
| 30 APRIL 2000 | MOD09A1.A2000121.h28v08.006.2015137071143                               |
| 2 JUN 2006   | MOD09A1.A2006153.h28v08.005.2008124111303                               |
| 2 JUN 2006   | MOD09A1.A2006153.h28v08.006.2015117053919                               |
| 13 MARCH 2017| MOD09A1.A2017073.h28v08.005.2017082063237                               |

2.4 Image analysis

MOD09A1 is a Level 3 product that does not require pre-processing step as it is the combination of the MODIS Terra Surface Reflectance Daily L2G Global 500 m and 1 km (MOD09GA) products. MOD09A1 products resulted from the combination of 8-days high observation, the lowest cloud present, aerosol loading and low view angle Level 2 products [23]. The products cover whole part of Peninsular Malaysia and a part of Indonesia were subset into the region of interest (ROI) by using ENVI Ver 5.3. Then, the bands combination method was used to enhance the images for interpretation. The combination of band (i) 1,4,3 produced true colour, meanwhile combination of (ii) 7,2,1 assist to visualise different vegetation on the ground and combination of band (iii) 2,6,1 highlighted the cloud.

2.5 Spectral indices

NDVI, NDWI and SIWSI were used in this study, retrieved after calculated from the MOD09A1 product. NDVI indices was frequently used in remote sensing study for monitoring and detection of drought. It is justified on the basic that vegetation healthy state correlated with moisture condition and reflecting the photosynthesis rate[24,25]. Furthermore, it can help differentiate between non-vegetation and vegetation area [26].

Next, NDWI act as monitoring indices to study the large area vegetation canopies’ moisture as it measure water content in canopies interacted with solar radiation [27]. Both NDVI and NDWI has a valid range from (-1.0) – (1.0). Meanwhile another index, the SIWSI index focusing on the tissues’ water content and has valid ranging from (0.0) – (1.0) [28].

The NDVI variation profiles from Negeri Sembilan derived from calculation in ENVI version 5.3 by using the following formula in Table 2. The value was calculated into averagely per year and the same steps goes for other indices.

Table 2. Spectral reflectance and MODIS bands used.

| Index      | Formulation            | Source |
|------------|------------------------|--------|
| NDVI       | \( \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \) | [29]   |
| NDWI       | \( \frac{\rho_{\text{NIR}} - \rho_{\text{SWIR}}}{\rho_{\text{NIR}} + \rho_{\text{SWIR}}} \) | [27]   |
| SWISI 5,2  | \( \frac{r_5 - r_2}{r_5 + r_2} \) | [28]   |
| SWISI 6,2  | \( \frac{r_6 - r_2}{r_6 + r_2} \) | [28]   |
2.6 Sampling of the habitats.

The ground thruthing had been done in the ROI of MOD09A1 images to collect the MODIS satellite images for the control area. A total of four GPS points collected as landmarks and references for Angsi Reserve Forest (Table 3) and three GPS points collected for Felcra Mendom oil plantation. The total of points low because the points were taken from pre-ground thruthing. Lastly, all the points were overlaid on the MOD09A1 images, then further validated by using Google Earth Pro to identify the sampling area [30].

| GPS point                  | x                   | y                   |
|---------------------------|---------------------|---------------------|
| Veterinary                | 2°45'24.78"N        | 101°59'45.64"E      |
| Rubber Integrated (Company)| 2°45'0.85"N        | 101°59'34.21"E      |
| PJ Perdana lake           | 2°44'16.57"N        | 101°59'26.83"E      |
| Fishing lake              | 2°43'39.13"N        | 102° 0'41.54"E      |

| Felcra Mendom oil plantation | x          | y                   |
|------------------------------|------------|---------------------|
| Mendom mosque               | 2°53'00.15"N| 101°06'6.23"E       |
| Mendom oil palm             | 2°53'20.14"N| 101°55'47.24"E      |
| Oil palm                    | 2°53'1.55"N  | 101°56'6.22"E       |

3. Results

3.1 Precipitation

Figure 1 shows the result of daily precipitation average in Negeri Sembilan based on two meteorology stations, Gemencheh Station (GS) and Tanah Merah Station (TMS). Both of these two stations covered the precipitation reading of the ROIs. As shown in the figure, the lowest daily precipitation reading are 0.87 mm (year 2005) and 3.80 mm (year 2013). We conclude that both year, 2005 and 2013 had lowest daily average because the total of both stations for 2005 and 2013 are the lowest compared to other years. Meanwhile, the highest daily average on year 2000 for both GS and TMS was 5.14 and 6.23, respectively.

Figure 1. Daily precipitation average for Gemencheh Station (GS) and Tanah Merah Station (TMS).
Meanwhile, Figure 2 shows the total rainfall for both GS and TMS. We can see that the lowest precipitation was during year 2005 with only 3955.1 mm compared to another year, concluding that year 2005 was the driest year throughout the 20 years (1997 – 2017). 2017 year’s data was not completely given therefore; the result for year 2017 was assumed irrelevant.

Figure 2 also shows the total precipitation for each years. The lowest total precipitation for Gemencheh is during year 2005 with only 2322.9 mm throughout the whole year and year 2000 had the highest precipitation (3881.4 mm) for the whole year, meanwhile in Tanah Merah. The lowest total precipitation is during the whole year 2013 that is 1388.3 mm and the highest is during year 2000 with 2281.0 mm. As a conclusion, the total precipitation for both Gemencheh and Tanah Merah Station was with decreasing trends. Meanwhile, Table 4 shows the values of highest and lowest daily precipitation.

| Station       | Lowest precipitation | Highest precipitation |
|---------------|----------------------|-----------------------|
|               | Year | (mm) | Year | (mm) |
| Gemencheh     | 2005 | 0.871 | 2000 | 5.140 |
| Tanah Merah   | 2013 | 3.805 | 2000 | 6.232 |

3.2 Indices

By calculating the value from formula the value of NDVI, NDWI and SISWI of each dataset for years 2000, 2006 and 2017, the maximum and minimum of the value are visualised in Figure 3. The first five dots on the line graph represent the NDVI value, second five dots represent the NDWI value, the third five dots value represent the SISW1(5,2) value and the last five represent SIWSI(6,2).

The range for indices’ maximum as shown in Figure 3 is in between 0.4 and 1.0 as the smallest maximum value is 0.41 (SISWI 5,2) and the biggest maximum value is 0.99 (NDWI). Meanwhile, minimum indices ranging from -1.0 to 0.9 as the smallest minimum valued -1.0 (SISWI 5, 2) and biggest value of minimum is 0.86. Therefore, we can see that SISWI (5, 2) year 2006 has the lowest minimum value.
Figure 3. Daily precipitation average and maximum and minimum value of vegetation indices (NDVI, NDWI and SIWSI).

Note: Primary axis: Maximum and minimum value of vegetation indices (NDVI, NDWI and SIWSI).
Secondary axis: Daily precipitation (1997-1999 and MOD09A1 dataset).

The highest daily precipitation average is 6.2 mm in year 2000, exceeding 1.0 NDVI values and the lowest daily precipitation average is 1.84 mm in year 2017, approaching -1.0 SIWSI (5, 2) value. However, the precipitation data for year 2017 do not collected for 365 days so the value is quite irrelevant. Then, the highest daily precipitation value located higher than indices maximum value. Meanwhile year 1997, 1998 and 1999 precipitation value 4.7 mm, 5.3 mm and 5.2 mm, respectively are close together. Hence, this indicated sufficient amount of precipitation to maintain NDVI value for those years. We can conclude that, as the highest daily precipitation approaching 1.0, the NDVI value will be approaching +1.0 indicates that there no stress in vegetation canopies that was supported by the high amount of precipitation. In NDVI and NDWI, when the value approaching to bigger number, the NIR increased and Red bands and SWIR decrease indicated high vegetation and high water-contain.

This is different with SWISI index, the index showed values above and below zero. SIWSIs are normalized indices and the values thereby theoretically vary between -1 and 1. A study from Fensholt, (2003) indicated that an index value above zero means that the reflectance from channel 6 or 5 is higher than the channel 2 reflectance and this indicates canopy water stress. Throughout the years, all the index showed values above zero, meaning occurrence of water stress but also showed values below zero. The worst condition recorded by channel 5 and 6 application was year 2000 with index value approaching 1.0, indicated water stress for the area.

4. Discussion

In this study, year 2000 was represented the highest average of daily precipitation of Tanah Merah station, and 2005 as the dreariest day recorded for Gemenech station. We can see that the lowest precipitation was during year 2005 with only 3955.1 mm compared to another years, concluding that year 2005 was the driest year throughout the 20 years (1997 – 2017).

The study found precipitation data used for dry season analysis for the oil palm and showed a good agreement with oil palm FFB report. Our analysis on annual Fresh Fruit Bunch (FFB) yields for previous years of 1987 to 2005 showed in Figure 4, which FFB yield was lower during El-Niño 1987
with 15.2 tonnes for Negeri Sembilan state. In particular, El Niño 1997/98 reduced yield by 12.5% or 16.0 tonnes in comparison with 1997 (Unpublished, 2013). There were 16.1 tonnes produced in 2005, which was also a reduction of 10.2% from 2003 FFB yields. Similar results were recorded in Shanmuganathan and Narayanan (2012) when they characterized July 2005 and December 2005 as nearly approaching year 2006 (as refer to MODIS image applied) as having caused a negative impact on oil palm yield. Elsewhere, a study by Gadgil and Gadgil (2006) showed agricultural crop and Gross Domestic Product (GDP) of India was greatly influenced by the performance of monsoon precipitation. The study thus highlighted that monsoon precipitation gives adverse effects to FFB yield which have critical growth at precipitation between 1300-1500 mm annually. Climate variability indicated by either rainfall or temperature or both, are found to impact negatively on palm oil revenue [34].

Figure 4. Fresh Fruit Bunches yield for 1987-2005 (Negeri Sembilan state recorded with dotted black line) [35]

Daily precipitation values for 1997-1999 showed sufficient amount of precipitation to maintain NDVI value for those years. Hence, the study found NDVI generated from MODIS satellite is potential for assessing the effects of precipitation for vegetation dry-season monitoring. A study by Schultz et al., (2016) found NDVI is including the most frequently used vegetation index in remote sensing science, this is because higher daily precipitation indicated higher NDVI value.

Other index of NDWI is more related to fuel moisture content (i.e. type of vegetation or land cover) that utilized near-infrared and shortwave band which is suitable to measure amount of water available in the internal leaf structure found in a study of [37]. Wheatear insufficient samples included to show significant of the pattern, the utilization of the index for this study of dry-season assessment is very meaningful. The index showed close similarity to NDVI results, indicated there is a potential the index to be separately applied with NDVI study.

Another plausible explanation of the SWISI, maybe the presence of other than vegetation features on the land that not notify by the study. This caused the SWISI value indicated water stress, whereas NDVI showed in opposite way. The main thing to emphasize here that, our calculation of minimum and maximum for all the region of interest was not for specific features (pixel), but as an average for whole AOI of the area. So, our study not properly follow that the index is only useful
when the vegetation has reached a certain ground cover [10]. In the future, our work will be focused at region samples for indices calculation.

5. Conclusion

Remote sensing widely used in monitoring drought assessment and cooperating simple vegetation indices such as NDVI with another indices like NDWI and SIWSIs can increase the accuracy of the results. The results shows that the vegetation indices used and the precipitation data can be used in the study of agriculture and forestry. This study also have large potential in assessing Net Primary Productivity (NPP) for tropical forest.

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