Vegetation Indices for Identifying Melaleuca Forest from Multispectral Satellite Sensors

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Abstract. Melaleuca forest or locally known as Gelam forest mostly occur in beach ridges interspersed with swales (BRIS) sandy areas, coastal, wetland, peatland, and lowland regions. It is a mono-specific species dominance ecosystem, where Melaleuca cajuputi trees are dominant. It is fringing along the coast of Terengganu and Kelantan and certain parts along the west coast of Peninsular Malaysia. The landscape is small but it has equal importance to other ecosystems in terms of local environmental functions and economic contributions. The benefits include timber for building constructions and furniture and other traditional uses, such as for fuel wood, charcoal, tea-tree, honeybee breeding areas and others. However, this forest is inevitable from threats by anthropogenic activities such as land clearing and conversion to other land uses that can affect the ecosystem. These activities occur because most of this ecosystem reside on stateland areas, where development is rapid. Only small patches of this forest was protected as Permanent Forest Reserve, which is secure from any threat. Currently the information about the tracts and extents of this forest is very scarce. Therefore, this study was carried out to acquire latest information on the distribution and extent of Melaleuca forest in Peninsular Malaysia through the utilization of remotely sensed data. Optical images from Landsat-8 OLI were used as primary input for this study. Spectral characteristic from visible and infrared regions were analyzed to produce a specific vegetation index for recognizing Melaleuca forest ecosystem on the images. The study demonstrated that the Melaleuca forest covers some 23,000 ha in Peninsular Malaysia that are intact but vulnerable to surrounding threats. The findings of study should attract attentions from the relevant State Governments to take appropriate management actions to protect this unique and priceless ecosystem in the future.

1. Introduction
Malaysia has been endowed with vast amount of natural resources including luxuriant wetland forest, which is one of the most diverse and complex ecosystems of the world. The wetlands in Malaysia can be divided into three major ecosystems, which are mangrove, peat swamp and freshwater swamp/ heath forests. These wetlands have been identified to provide habitats for many species and providing important regional impacts, such as hydrological, biological and ecological roles in the ecosystem. Malaysia needs to conserve these important ecosystems for addressing flood problems, mitigating el-nino effects, estimating national water budgets and conserving biodiversity. Other than these ecosystems, there is a unique Melaleuca swamp forest that is also exists in Malaysia.

Melaleuca swamp or Melaleuca forest, known locally as “Gelam” forest is actually one of the freshwater swamp forests. The name is given after a tree species, Melaleuca cajuputi because the forest comprises almost exclusively of that tree species. The M. cajuputi tree is native plant from the family
of Myrtaceae and the genus Melaleuca. There several species in this genus but in Malaysia, *M. cajuputi* is common. Vernacular name used for this species include Cajaput, Cajaput-tree, Cajeput, Gelam Bark, Paper Bark Tree, White-wood (English), Gelam, Kayu Puteh, Kayu Putih, and Gelam Tikus (Malay) [1]. Melaleuca forests are native to Southeast Asia, New Guinea and Australia and not found in the other parts of the world [2]. It was reported that the extents of this forest in Peninsular Malaysia in year 1997 was at least 41,520 ha. Terengganu had the largest extent (29,100 ha), followed by Kelantan (11,020 ha), and Melaka (1,400 ha). Other states in Malaysia has no significant Melaleuca forest [3].

Gelam has been exploited for the supply of poles and small scale charcoal industry by the local communities. ‘Madu Gelam’ is a local honey harvested in Gelam area and sold by the villagers in this area and claimed to have a different taste from the honey collected from other forests. The *M. cajuputi* is remarkably resilient, with an ability to withstand frequent flooding, acidic and low nutrient soils and mild fires. This tree sheds its papery bark, has showy flowers that produces honey and leaves containing fragrant oils that can be distilled and used for medicinal purposes [4].

The connectivity of both mangroves and Melaleuca forest is very distinct where the health of one will eventually affect the other, both economic and ecological functions. Threat to these ecosystems mainly from fragmentation and land use changes are inevitable and are significantly reduced their coverage and ecological roles. Anthropogenic activities to the forests (e.g. land use change, logging and burning), are also another contributing factors to the changes of the wetlands. Land clearing and human habitation put significant pressure on Melaleuca forest [5]. Knowing the importance as well as the anthropogenic threats on the ecosystems, tracing their habitat becomes important. Therefore, this rarest types of wetland should be recognized as one of the living assets to the country.

Mapping wetland vegetation over large regions has been done commonly using satellite imagery [6]. However, studies related to the mapping of this forest, especially in Malaysia are rarely found. Extensive research and documentation of mangrove distribution and mapping are well covered e.g. [7], [8], [9]. However less attention is given to Melaleuca forest as compare to other heath forest such as the mangrove. One of the reasons is that this forest is considered as abandoned and less commercial values. Among the first attempts to map the Melaleuca forest by using remote sensing technology was in 1977 at South Florida, although the forest is not native there [10]. In Malaysia, no scientific literature is found particularly on the application of remotely sensed data for comprehensive mapping of Melaleuca forest distribution. However, several studies related to the habitat, ecology, biophysical and biochemical characteristics of *M. cajuputi* species are available e.g. [5], [11], [12], [13], [14]. Given these limitations, this study is therefore conducted. The ultimate aim was at producing map of Melaleuca forest distribution in Peninsular Malaysia and making the spatial data available for the future studies and managements related to this forest.

2. Material & Methods
The Landsat-8 Operational Land Imager (OLI) satellite images were used as the primary input to identify and classify the Melaleuca forest in Peninsular Malaysia. Ground truth data was also use to support the identification of the forest on the satellite images, as well as to assess the accuracy of the classification products. This study was conducted following the framework as depicted in Figure 1.

2.1 The study area
The study area covers the entire Peninsular Malaysia. Forests in these regions can be divided into three major types, which are inland dipterocarps (dryland), peat swamp, mangrove forests (wetlands). Melaleuca forest ecosystem is one of the wetland forests that is found in Peninsular Malaysia. However, the extents of this forest is not substantial and only found in certain parts of the region. The forest is a unique ecosystem and the third largest wetland forests after the peat swamp and mangroves. It occupies extensive areas of alluvial flats along the coasts dominated by sandy soil originated from marine deposit. This type of soil is addressed as “tanah beris” or “tanah bris” by Terengganu locals, referring to an acronym of BRIS for “Beach Ridges Interspersed with Swales”. It is suggested that BRIS soil system is well distributed across Terengganu coastal area [15]. Swales part of BRIS soil is a depression area that
tends to retain rainwater and become waterlogged, particularly in monsoon months. Depression area forms a palustrine wetland, a seasonal freshwater swamp mainly occupied by *M. cajuputi*. This occurs mainly in the east coast of Peninsular Malaysia, particularly in Kelantan and Terengganu, and also in northern coast of Borneo, including Sarawak and Sabah.

![Flowchart of the study](image)

**Figure 1.** The flowchart of the study

### 2.2 Satellite data

The satellite images were acquired within year 2019 were used to identify Melaleuca forest in the study area. All images are available at [https://earthexplorer.usgs.gov/](https://earthexplorer.usgs.gov/). At least 12 scenes of Landsat images are required to complete the entire Peninsular Malaysia (Figure 2). However, cloud covers are presence on some of the images, hence, more than one dates over the same scene were acquired to remove the clouds by using F_mask algorithm [16]. Since the spectral information is crucial in study, the digital number of the images have been converted to top-of-atmospheric (TOA) reflectance. Only bands 1 – 7 i.e. coastal aerosol (C), blue (B), green (G), red (R), near infrared (NIR), short wave infrared 1 (SWIR-1) and short wave infrared 2 (SWIR-2) were used in study.

### 2.3 Images classification

Supervised classification technique was performed on the images to classify land uses within the study area. Appropriate enhancement techniques were applied to the images to make the Melaleuca forest appears better on the images. A unique physical feature of the given wetlands is the seasonal change of land-cover types annually covered by exposed soils, shallow flooding water, and wetland plants. Therefore, in addition to the individual spectral bands of the Landsat images, vegetation indices (VIs) such as normalized difference vegetation index (NDVI) [17], land surface water index (LSWI) [18], (also known as normalized difference infrared index (NDII)) [19], soil-adjusted vegetation index (SAVI), and enhanced vegetation index (EVI) were also derived from the images [20]. These VIs were derived to delineate the Melaleuca forest from other forests hence improving the quality and accuracy of the classification. The VIs that were used in this study are summarized in Table 1. To demonstrate the performance of both multispectral images and Vis, the classification process was conducted in three stages (Figure 1). The first stage used only the original multispectral bands as input, the second stage
applied the VIs as input, and the third stage incorporated both multispectral and VIs as classification input.

2.4 Accuracy assessment

The accuracy of the classification was assessed by using ground truth dataset that was collected in early year 2020 at certain locations where Melaleuca forest was identified. Figure 3 shows some of the stands conditions at several locations visited. The pictures revealed that, although the forest is dominated by the same tree species, not all have the same stand conditions; size and height of the trees are different from one location to another. The size of the stands can reach up to 30 cm diameter at breast height (dbh) with the tallest trees at 10-12 m. The locality and surrounding environment play important roles, therefore to recognize this forest at the field is by recognizing the species, *M. cajuputi*. 

![Figure 2. Landsat scenes that were used for the classification. Numbers within the scene boundary indicates path/row ID of Landsat satellites.](image)
Table 1. Vegetation indices that were used derived from the images

| Vegetation indices | Formula | Description |
|-------------------|---------|-------------|
| NDVI              | \( \text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}} \) | Commonly used to delineate vegetation from other features on images and to measure vegetation vigor. It is sensitive to atmospheric effects. |
| LSWI/NDII         | \( \text{NDVI} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}} \) | Normalized ratios between NIR and SWIR bands, in particular, to normalize the temporal anomaly that exists during the period of flooding and transplanting of wetland plants. |
| SAVI              | \( \frac{(\text{NIR} - \text{R}) - (1 + \text{L})}{\text{NIR} + \text{R} + \text{L}} \) | SAVI was established to improve the sensitivity of NDVI to soil backgrounds, where \( \text{L} \) is the soil conditioning index, which improves the sensitivity of NDVI to soil background. The range of \( \text{L} \) is from 0 to 1. In practical applications, the values of \( \text{L} \) are determined according to the specific environmental conditions, but 0.5 is used under most common environmental conditions. When \( \text{L} \) is close to 0, the value of SAVI is equal to NDVI. |
| EVI               | \( 2.5 \times \frac{(\text{NIR} - \text{R})}{\text{NIR} + C_1 \text{R} - C_2 \text{B} + \text{L}} \) | Simultaneously correct soil and atmospheric effects resulted from interaction between the soil and the atmosphere. It includes the values of NIR, R, and B, which are corrected by the atmosphere; \( \text{L} \) represents soil adjustment parameters, and its value is equal to 1; and parameters correspond to constant values \((C_1 \text{ and } C_2)\) equivalent to 6 and 7.5, respectively. |

Note: NIR = near infrared, G = green, B = blue, R = red, and SWIR = short wave infrared channels.

3. Results & Discussion

3.1 Images classification products

The study indicated the multispectral and VIs played different roles in defining Melaleuca forest on the images. Figure 4 shows some portions of Melaleuca forest that was found in Bachok, Kelantan and how the forest appears on the images. The forest appears dark on G (Figure 4-c), NIR (Figure 4-e) and SAVI (Figure 4-j). This is due to the natural ecosystem of the Melaleuca forest, which is covered by swamps and sometimes inundated by ground water. This occurs because the moisture, especially in the soils, absorbed most of the illuminations in green and infrared spectral regions and reduced the reflectance energy. In this case, SAVI worked very well to delineate the Melaleuca forest from other features. Therefore, the integration of individual multispectral bands with VIs have improved the separability between Melaleuca forest and other features, thus increased the classification accuracy. The other bands and VIs did not have that capability in delineating the forest from other vegetated (green) areas. Figure 5 shows the spectral profiles of different features within the same areas on the images. It demonstrates that only certain bands and certain VIs have the ability to separate the Melaleuca forest from other features (Figure 4-l).

However, there are areas that the Melaleuca forest is interrupted by invasive species, *Acacia mangium*. Although it is not dominant, *A. mangium* can live together with *M. cajuputi* within the same ecosystem, especially at the fringe/edge of Melaleuca forest. *A. mangium* also has identical biophysical characteristics (Figure 6) that make the identification of both species in a same area difficult. The classification results also inevitably included the *A. mangium* as Melaleuca forest at certain areas where this condition occurred.
Overall the images classification process has produced a classified Melaleuca forest. Raster that have been classified as this forest were extracted and converted to vector form. Melaleuca forest were found largely occurred along the east coast region including Terengganu and Kelantan, and some parts in the west coast region include Negeri Sembilan, Johor, Melaka, Selangor. The study also found that this forest was not found in Kedah, Pahang, Penang, Perak, and Perlis. Figure 7 showing distribution of Melaleuca forest in the Peninsular Malaysia that has been derived from the image classification. The extents of the forest is listed in Table 2.

**Figure 3.** The stands of *M. cajuputi* trees in Melaleuca forest at (a) Johor, (b) Terengganu, (c) Kelantan, (d) Melaka. Shoots on a branch of a *M. cajuputi* tree (e).
Figure 4. Images showing several land use/cover classes over Bachok, Kelantan. The images are displayed in grayscale for bands (a) coastal aerosol, (b) blue, (c) green, (d) red, (e) NIR, (f) SWIR-1, (g) SWIR-2, (h) NDVI, (i) LSWI, (j) SAVI, and (k) EVI. Combination of EVI, B5, B4 is displayed in RGB with the vectors of Melaleuca forest overlaid (l). Dimension of each image is 25 x 25 km.
Figure 5. Spectral profiles of several land covers extracted from the images.

Figure 6. Leaves and flower of *M. cajuputi* (left) and *A. mangium* (right).

Table 2. Extents of Melaleuca forest in Peninsular Malaysia over the year 2019.

| State           | Extent (Ha) | Percentage cover (%) |
|-----------------|-------------|----------------------|
| Johor           | 415.22      | 1.8                  |
| Kelantan        | 6,350.31    | 27.8                 |
| Melaka          | 626.47      | 2.7                  |
| Negeri Sembilan | 217.57      | 1.0                  |
| Selangor        | 521.04      | 2.3                  |
| Terengganu      | 14,748.72   | 64.5                 |
| **Total**       | **22,879.33** | **100.0**            |
Figure 7 Distribution of Melaleuca forest in Peninsular Malaysia over the year 2020.

3.2 Accuracy assessment

A total of 104 observation points covering states of Terengganu, Kelantan, Negeri Sembilan, Melaka, Johor and Selangor were used to determine accuracy of the classification. This dataset was compared with the land use/cover classes around the Melaleuca forest areas. The first stage of classification whereby only multispectral bands were used has produced classification at an accuracy of 72.3%. The mixture of other wetlands, especially paddy fields, peat swamp and mangrove forests into Melaleuca forest attributed to the low accuracy. It indicated that the individual bands of multispectral dataset has limited capability in delineating Melaleuca forest. On the other hands, the classification that was produced from VIs has increased the accuracy up to 84.5%. When the VIs were applied in the second stage of classification, all non-vegetative areas were completely separated from vegetation covers while keeping high density forests at high index values [21]. Hence eliminated the confusion between Melaleuca forest and other wetland areas such as paddy fields and mangroves. However, some peat
swamp forest with low stand density remain interrupted. The incorporation of both multispectral and VIs on the third stage of classification finally gave a satisfactory classification results with an accuracy attained at 93.7%. Although some small patches of *A. mangium* forest interrupted the classification, it is negligible as the accuracy was sufficiently reliable for this study.

4. Conclusion
The study demonstrated that the use of Landsat-8 OLI satellite images are doing well at delineating Melaleuca forest in Peninsular Malaysia. The integration of multispectral bands and VIs has improved the classification accuracy at the greatest extend, i.e. from 72.3% to 93.7%. Green and NIR bands together with SAVI were the most important input for the classification. The study found that about 23,000 ha of Melaleuca swamp forest in Peninsular Malaysia that are remain intact until year 2020. Terengganu has the largest extent of this forest, followed by Kelantan, Melaka, Selangor, Johor and Negeri Sembilan. Although this forest is considered as one of the minor forest types in Malaysia, it plays equal important roles to environment and its surrounding livelihood.

The full role Melaleuca forest has been consistently underestimated or overlooked entirely, resulting in unacceptable wetland losses. Efforts towards the conservation of this forest with particular importance for their biological diversity, economic and social values are vital to ensure that the natural resources and physical environment of Melaleuca forest remain in balance and continue to serve future generations sustainably. The most effective way to ensure this forest will keep exist in the future is through the gazettement into reserved forest. This action will legitimately protect the forest from any development and human activities that can disturb the natural habitat of the forest. Relevant agencies, such as Forestry Department Peninsular Malaysia and States Forestry Department are having the full rights to take necessary actions. Data and information that were produced by this study will be useful as a starting point for further actions.

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