UNIVERSITI PUTRA MALAYSIA

VEGETATION HEALTH ASSESSMENT IN PEAT SWAMP FOREST AND AGRICULTURE USING THE INTEGRATION OF VEGETATION INDICES AND DROUGHT INDICES

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By

NURUL FATIN BINTI MUSA

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The application of remote sensing and Geographical Information System (GIS) can be applied to assess vegetation healthiness for vegetated land in Peninsular Malaysia. One of the methods that can be applied to identify which vegetation areas are stressed is to use vegetation and water indices. In the meantime, Aboveground Biomass (AGB) assessment can be an indicator of the condition of vegetation. The study was conducted on an oil palm and rubber plantation in Felcra Mendom, Lenggeng, Negeri Sembilan. Meanwhile, the forest site was in a highly degraded peat swamp forest in the Raja Musa Forest Reserve, Selangor. Firstly, the Standardised Precipitation Index (SPI) classification, calculated from 20 years of rainfall data starting from 1998 to 2017. Then, using digitally processed MODIS MOD09A1 and WorldView3 (WV3) images based on ENVI and ArcGIS software, the Normalised Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Shortwave Water Stress Index (SIWSI), Green Normalised Difference Vegetation Index (GNDVI), Generalised Difference Vegetation Index (GDVI), Normalised Difference Red Edge (NDRE) and Bare Soil Index (BSI) were retrieved. The satellite images were acquired during the dry season of Mei, June, and July of 2017, and 2018 for all the study areas. Physical characteristics of vegetation such as Height, DBH, LAI, and soil moisture were collected to estimate the AGB of each study area. Accordingly, SPI showed Negeri Sembilan, and Selangor weather fluctuated throughout 20 years, experiencing both dry and wet seasons. The rainfall data was classed by the SPI classification and identified years 2017 and 2000, averagely as the driest in the last 20 years. However, MOD09A1 based indices retrieved from 2017 images show Seremban and Raja Musa were identified as having low dry conditions during this year, indicating that 2017 was a low stress year. In contrast, based on MOD09A1 2006 indices, both regions were identified as having higher stress with lower water content. Continuously, $NDVI_{WV3}$ revealed that oil palm was the least stressed area, with $NDVI_{WV3}$ = 0.92, whereas the unburned area was more susceptible to drought risk. As

depicted by the utilisation of the red-edge band in NDRE of WV3, the study suggests the burn area had the lowest water stress of the forested land. The ground AGB prediction equation developed showed significance for the unburn area with $r^2 = 0.94$. Unburn had the highest significant $r^2 = 0.98$ in the vegetation indices biomass equation developed. Finally, a Vegetation Suitability Classification to classify the level of vegetation healthiness was regressed. The classification shows burn and unburn forested areas had lower stress levels. This vegetation suitability range accumulated values of 3.25 – 7.14 and 4.91 – 7.41 for burn and unburn peat swamp forest, respectively. This shows that different vegetation assessments of vegetation and water stress can be used in future forest management, particularly for forest fire management strategy. Furthermore, this discovery is useful for planters and managers in monitoring agricultural plantations to maintain plantation annual productivity.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN KESIHATAN VEGETASI DI HUTAN PAYA GAMBUT DAN PERTANIAN MENGGUNAKAN INTEGRASI INDEKS VEGETASI DAN INDEKS KEMARAU

Oleh

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Aplikasi penginderaan jauh dan Sistem Maklumat Geografi (GIS) dapat diterapkan untuk menilai kesegaran vegetasi untuk lahan berumput di Semenanjung Malaysia. Salah satu kaedah yang dapat diterapkan untuk mengetahui kawasan vegetasi yang ditekankan adalah menggunakan indeks tumbuh-tumbuhan dan air. Sementara itu, penilaian Aboveground Biomass (AGB) dapat menjadi petunjuk keadaan tumbuh-tumbuhan. Kajian ini dilakukan di ladang kelapa sawit dan getah di Felcra Mendom, Lenggeng, Negeri Sembilan. Sementara itu, kawasan hutan berada di hutan paya gambut yang sangat rusak di Hutan Simpan Raja Musa, Selangor. Pertama, klasifikasi Indeks Pemendakan Standard (SPI), dikira dari 20 tahun data hujan bermula tahun 1998 hingga 2017. Kemudian, menggunakan gambar MODIS MOD09A1 dan WorldView3 (WV3) yang diproses secara digital berdasarkan perisian ENVI dan ArcGIS, Indeks Vegetasi Normalisasi (NDVI), Enhanced Vegetation Index (EVI), Shortwave Water Stress Index (SIWSI), Green Normalized Difference Vegetation Index (GNDVI), Generalized Difference Vegetation Index (GDVI), Normalized Difference Red Edge (NDRE) dan Bare Soil Index (BSI) diambil. Gambar satelit diperoleh pada musim kering iaitu pada Mei, Jun, dan Julai untuk tahun 2017, dan 2018 untuk semua kawasan kajian. Ciri-ciri fizikal tumbuh-tumbuhan seperti Ketinggian, DBH, LAI, dan kelembapan tanah dikumpulkan untuk menganggarkan AGB setiap kawasan kajian. Oleh itu, SPI menunjukkan cuaca Negeri Sembilan, dan Selangor berubah-ubah sepanjang 20 tahun, mengalami musim kering dan basah. Data hujan dikelaskan berdasarkan klasifikasi SPI dan mengenal pasti bahawa tahun 2017 dan 2000, sebagai yang paling kering dalam 20 tahun. Walau bagaimanapun, indeks berdasarkan MOD09A1 yang diambil dari gambar 2017 menunjukkan Seremban dan Raja Musa dikenal pasti mempunyai keadaan kering yang rendah pada sepanjang tahun, ini menunjukkan bahawa 2017 adalah tahun tekanan rendah. Sebaliknya, berdasarkan indeks MOD09A1 2006, kedua-dua wilayah tersebut dikenal pasti mengalami tekanan yang lebih tinggi dengan

kandungan air yang lebih rendah. Seterusnya, $NDVI_{WV3}$ mendedahkan bahawa kelapa sawit adalah daerah yang kurang tertekan, dengan $NDVI_{WV3}$ = 0.92, sedangkan kawasan yang tidak terbakar lebih rentan terhadap risiko kemarau. Seperti yang digambarkan oleh pemanfaatan jalur tepi merah di NDRE WV3, kajian menunjukkan kawasan pembakaran mempunyai tekanan air terendah di kawasan hutan. Persamaan ramalan AGB dasar yang dikembangkan menunjukkan kepentingan bagi kawasan yang tidak dibakar dengan r^2 = 0.94. Unburn mempunyai r^2 = 0.98 signifikan tertinggi dalam persamaan biomass vegetasi yang dikembangkan. Akhirnya, Klasifikasi Kesesuaian Vegetasi untuk mengklasifikasikan tahap kesihatan tumbuh-tumbuhan menurun. Klasifikasi menunjukkan kawasan hutan yang terbakar dan tidak terbakar mempunyai tahap tekanan yang lebih rendah. Nilai kesesuaian tumbuh-tumbuhan ini merangkumi nilai terkumpul 3.25 - 7.14 dan 4.91 - 7.41 untuk hutan paya gambut yang terbakar dan tidak terbakar. Ini menunjukkan bahawa penilaian vegetasi dan tekanan air yang berbeza dapat digunakan dalam pengelolaan hutan di masa depan, terutama untuk strategi pengelolaan kebakaran hutan. Tambahan pula, penemuan ini berguna bagi pekebun dan pengurus dalam memantau ladang pertanian untuk mengekalkan produktiviti tahunan ladang.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

USDA	United States Department of Agriculture
SPI	Standardised Precipitation Index
MetMalaysia	Malaysia Meteorology Department
GIS	Geographical Information System
NDVI	Normalised Difference Vegetation Index
SIWSI	Shortwave Infrared Water Stress Index
EVI	Enhanced Vegetation Index
NDRE	Normalised Difference Red edge
GNDVI	Green Normalised Difference Vegetation Index
GDVI	Generalised Difference Vegetation Index
RVI	Ratio Vegetation Index
BSI	Bare Soil Index
GPP	Gross Primary Production
UAV	Unmanned Aerial Vehicles
MODIS	Moderate Resolution of Spectro-radiometer
NIR	Near-Infrared
SWIR	Short-Wave Reflectance Wavelengths
RGB	Red,Green,Blue
NSOP	Negeri Sembilan Oil Palm
FFB	Fresh Fruit Bunch
DBH	Diameter at Breast Height
AGB	Aboveground Biomass
LiDar	Light Detection and Ranging
LAI	Leaf Area Index

GPS	Global Positioning System
EOS	Earth Observation System
nm	Nanometer
cm	Centimeter
m	Meter
ha	Hectare

CHAPTER 1

INTRODUCTION

1.1 Background of The Study.

Peninsular Malaysia is known for large agricultural crop production such as rubber and oil palm. Oil palm and rubber are some of the common agriculture species that were commercially planted in Malaysia and contributed to the Malaysian economy. The optimum humid tropical condition, high precipitation rates with warm temperatures of 24°C - 32°C, and high solar radiation of Malaysia are favourable to these species to achieve optimum growth in this country (Corley & Tinker, 2003). Malaysia, along with Indonesia and Thailand, has one of the world's largest oil palm production, with an oil palm industry worth more than $50 billion per year (Denis, 2014). Next, as in year 2017, approximately about 32% of world oil palm production was produced in Malaysia accordingly to the Index Mundi (2017). Continuously, the rubber plantation was the second leading economic source for Malaysia, after the oil palm production industry as in 2014 (Engku et al., 2015). Moreover, the rubber plantation industry helps to improve and provides steady incomes to more than 400,000 small landowners in Malaysia. At the same times, Malaysia's rubber industry had produced 13 million tonnes and also exported 681 356 tonnes of natural rubber by the end of year 2018 (Malaysian Rubber Board, 2018).

However, good water management was required for both oil palm and rubber plantations to produce optimum crop production because these plantations were sensitive to surrounding temperature changes, particularly the continuous dry season or drought, and poor water management to support and maintain water resources (Huete et al., 2008). Climate change is also one of the major determinants of crop production and tropical forest management in many Southeast Asian countries. All of these factors could directly or indirectly cause the increase of male flowers on rubber trees and palm tree flowers fall (Corley & Tinker, 2003; Huete et al., 2008). This had an indirect effect on the cultivation of young flowers, disrupting the pollination process and potentially reducing crop production.

Meanwhile, tropical forests are an important part of the Earth's ecosystem. A crucial element to maintaining the climate, biogeochemical and hydrological cycles (Sheil, 2018). Tropical forests offer social, cultural, and economic significance as major sources of non-renewable and renewable resources (Achard et al., 2002). Furthermore, due to vast lowland tropical forests that contain around 20% of Southeast Asia's tree species abundance, Malaysia has a significant diversity of biodiversity and habitats relative to other countries. Peninsular Malaysia's tropical forest, on the other hand, contains a long list of red-listed timber species that serve as a valuable timber pool and suitable habitat for a variety of flora and fauna. Many studies have shown that these plants play an important part in carbon stabilisation in the atmosphere (Girardin et al., 2014).

The Southwest Monsoon season (SWM), which usually occurs from May to September and is dominated by the low-level south-westerly winds causing the dry season in Peninsular Malaysia and particularly extreme in the western part of Peninsular Malaysia (Malaysia Metereology Department, 2018). During SWM, the number of warmer days and nights increased, and monthly precipitation decreased (Tan et al., 2019). Moreover, according to Amirabadizadeh et al. (2015), the dry conditions of Malaysia especially the north-western part, have been critical compared to the last three decades based on 1971-2011 precipitation data collected. Next, continuous dry weather leads to drought, affecting the environment, agriculture, and socio-economic conditions. (Bhuiyan et al., 2006). Drought affects agricultural crop production and causes negative impacts that depreciate the life quality in Malaysia, particularly in the peninsular part of Malaysia (Zin et al., 2013).

Additionally, the United States Department of Agriculture (USDA) in the year 2007 discussed that even a small impact on oil palm production can affect social and economic implications at different scale levels. Malaysia's climate has been changing throughout the century, with a steady decline in precipitation mean value from 1900 to 2009 (The World Bank Group, 2015). Moreover, Malaysia has large variations in the amount of rainfall annually and monthly and has suffered from drought during 1992, 1998, and 2014 (Abdullah et al., 2014). This indirectly contributes to high evatranspiration rate, leading to greater water loss. Which resulted from stomach closing, water shortage, and compromised physiological response (Mafakheri et al., 2010). Eventually, it affected the productivity of vegetation. For example, the total oil palm production in Malaysia was significantly reduced by 20 percent in 1997-98 due to El Niño and the long dry season in Perak to Johor, had affected the oil palm production in 2014 and 2015 (Ling, 2014; Yusop, n.d.). Specially to grow optimum crops, oil palm requires an annual water supply of 1800 to 1200 mm and a daily water supply of 4 mm to 5 mm, and the productivity of oil palm would decrease by 10% for every 100 mm of water reduction (Carr, 2011; Jazayeri, Rivera, Camperos-Reyes & Romero, 2015).

At the same time, the continuous dry season results in drought which harms the environmental, agricultural, and socioeconomic circumstances (Bhuiyan et al., 2006; Y. Liu et al., 2016; Wilhite, 2000). The drought has been defined as a “deficit of water relative to normal conditions” by Sheffield & Eric (2011). The intensity of the dry season is expected to increase in environments heavily influenced by the El Nio-Southern Oscillation (ENSO) weather pattern, such as Malaysia, due to seasonal temperature rises and changes in precipitation, such as the continuous dry weather in Malaysia, which has subsequently become a recurring phenomenon that has resulted in the agricultural sector and water supplies being severely restricted (Zin et al., 2013). For example, the major dry season in early 2014 has caused Malaysia to experience a shortage of water supplies that directly affects both the growth and health of vegetation (Othman et al., 2016). That contributes to a rise in the occurrence of fire in the case of peatlands which are subject to higher dry events (Lo & Parish, 2013). This event also indirectly affected the production of oil palms and caused rubber trees to shed leave, leading to a reduction in the crude percentage (Chong & Ranjeetha, 2014; Kunjet et al., 2013). Therefore, it was important to improve the ability to monitor and understand the drought and its vulnerabilities and also how to reduce drought's impacts in Malaysia, generally (Yusof et al., 2012). Furthermore, the current management of peatlands to control the impact of the dry conditions is mostly unsustainable and can have significant negative impacts on biodiversity and climate change (Parish et al., 2008).

Subsequently, after the 1998 El Niῆo incident, the standard operating procedures have been established to support the National Drought Management policy for the monitoring of drought in Malaysia. The Standardised Precipitation Index (SPI) and rainfall patterns were used to determine drought by allocating risk thresholds to the area. The climate change problems in Malaysia were managed based on the precipitation value produced by the Malaysia Meteorological Department (MET) (Malaysia Metereology Department, 2018). A study has been done by Yusof et al. (2012) in applying the SPI classification to analyse the rainfall characteristics in Malaysia. The study stated that different regions have different possibilities of having drought during the dry season and different ranges of rainfall during the wet season. Other than Malaysia, other countries such as Pakistan, Turkey, and India also utilised SPI to study extreme event classification of either wet or dry season and also to study agriculture drought (Dutta et al., 2015; Khan & Gadiwala, 2013; Kumara et al., 2009; Sirdaş & Şen, 2001). Then, the nature of probability distribution and rainfall records played important roles in calculating SPI (Mishra & Singh, 2011).

Since then, many drought classification indices have been integrated with the remote sensing technique in the analysis application. Remote sensing technique has been widely used due to its enormous potential in many study areas, such as for measuring the effects of the dry season around the globe, land-use observation, and more. The study has shown that the satellite-based model is as effective as the traditional dry-monitoring predictor and can provide information not only on the distribution of drought but can also represent the drought-induced impacts on streamflow, forest catchment, and land use (Hashim et al., 2016). Satellite analyses were also used to assess the effect of drought on ecosystems, including vegetation health and growth, by assessing the photosynthetic ability of the vegetation (Asner & Alencar, 2010; Tucker & Choudhury, 1987). Besides, the dry season triggered precipitation deficits, decreased photosynthetic potential, and changes in absorption of solar radiation in photosynthetically active wavelengths by plants, which were commonly used by the Visible Satellite and Infrared combinations to track these changes (Asrar et al., 1984; Hatfield et al., 1984; Tucker & Choudhury, 1987; Wardlow et al., 2012).

Moreover, the mathematical spectral channel configurations in satellite images were used as a key indicator of the presence, situation, and vigour of green plants, such as the Normalized Difference Vegetation Index (NDVI) to determine chlorophyll and photosynthetic vegetation response (Onyia et al., 2018). It is useful to detect biomass reduction in the tropical forest as a consequence of abiotic stress (Sande et al., 2017). Plant biomass is mainly a product of photosynthesis, a process involving carbon dioxide, water as a bi-product, and solar rays as an energy source, and mineral nutrients as essential components. In most cases, carbon dioxide and solar radiation seldom restrict the production of biomass, compared to abiotic stresses such as water deficit and soil salinity, and usually, vegetation doesn't adapt easily (Krishnamurthy et al., 2011; Lane & Jarvis, 2007). Since then, several possible indices have been established, such as The Normalised Difference Vegetation Index (NDVI), Indices based on Shortwave infrared such as Shortwave Infrared Water Stress Index (SIWSI), Enhanced Vegetation Index (EVI), Red edge reflectance such as Normalised Difference Red Edge (NDRE), Green Normalised Difference Vegetation Index (GNDVI), Generalised Difference Vegetation Index (GDVI), Ratio Vegetation Index (RVI) and Bare Soil Index (BSI).

Remote sensing has been suggested in several previous studies, such as the identification of forest destruction caused by a natural-caused occurrence and human-induced interference by the use of image differentiation techniques, and even the improvement of agricultural management for more effective plans (Chemura et al., 2015; K. L. Chong et al., 2017; Fuller et al., 2002; Mishra et al., 2014; Pal, 2005). Satellite images and aerial images from the skies using unmanned aerial vehicles (UAV) are some of the new strategies for collecting up-to-date information such as land cover change, land classification, and area mapping. It can also be used to improve the vegetation indices and to establish the existing indicators, circumstances, and vigor of green vegetation by using different satellite resolutions.

In the research analysis, for instance, accessible free satellite data such as the Landsat satellite series and the Moderate Spectro-Radiometer (MODIS) were used. The implementation of free download and authorized consumer remote sensing indices, namely MODIS, allows advanced applications, especially for forest water indexes based on near-infrared (NIR) reflectance and short-wave MODIS reflectance wavelengths (SWIR). MODIS developed multi-land and ocean products that can be used for terrestrial, regional, and local environmental climate evaluation, grouped into radiation budget variables, ecosystem variables, and land uses (Xiaoxiong et al., 2006). The use of high-resolution satellite images such as the System Probatoire d'Observation de la Terre (SPOT) has been proven to be reliable in previous studies as imagery such as on evergreen tropical forests and riparian research (Zhang and Zhang, 2007; Kamp et al, 2013). Other recent high-resolution satellite images include the IKONOS, Quickbird, GeoEye, and WorldView series.

At the same time, the water stress level also heavily affects the AGB of vegetation, which can be assessed and monitored through the soil moisture level. Accurate water stress evaluation can improve agricultural productivity by maximising plant water use, maximising plant breeding methods, and reducing forest fires (Kamarudin et al., 2021). Matese et al. (2018) and Żelazny & Lukáš (2020) reported that remote and proximal sensors might be good indicators for assessing water status fluctuation. Furthermore, the Infrared spectral shown a promising potential to determine water stress. The study of Zhang et al. (2017) showed the Visible Infrared Imaging Radiometer Suite (VIIRS) has a higher accuracy level than the Soil Moisture Active Passive (SMAP) and the Global Land Data Assimilation System Model (GLDAS). It also can be supported by other studies that have shown the Deep Neural Network had better correlation with ground measurement, compared to the same model as the previous study (Lee et al., 2019).

Therefore, in this study, the images of WorldView-3 and MODIS will be co-operated in the analysis. MODIS satellites are one of the free satellite data available and the benefits of MODIS data are the provision of more regular data on a larger temporal and spatial scale that could complement the shortcomings of the forest and agricultural water use database under the monsoon season pressure (Gebremichael & Barros, 2006; Homlinson et al., 2001; Pennec et al., 2011; Ranatunge et al., 2003). Meanwhile, the WorldView-3 (WV3) satellite, one of the WorldView series, was launched in 2014 with a 1.24 m image resolution (DigitalGlobe, 2014). In addition, WV3 had four additional new bands; (i) coastal (400-450 nm); (ii) yellow (585-625 nm); (iii) Red edge (705-145 nm) and (iv) NIR2 (860-1041 nm). An addition to the traditional RGB-NIR band. WV3 has also been shown to be appropriate for the identification of tropical forests and urban structures due to higher image resolution (Cho et al., 2015; Hartling et al., 2019; Li et al., 2015).

1.2 Problem statement

The prolongation of the dry season leading to drought has many impacts on different aspects of economic activity, especially forestry, agriculture, and socio-economic activities. For example, Devendra (2012) mentioned that the increase in temperature led to a rise in water stress, a decrease in soil moisture and crop yields, and a change in soil due to changes in water balance. The dry Season also affects the management decisions on agricultural plantations such as palm oil and rubber, which are vulnerable to changes in water content and surrounding temperatures, with indirect negative impacts on locals (Devendra, 2012; Huete et al., 2008; Zin et al., 2013).

Oil palm and rubber are one of Malaysia's main sources of agricultural production economic. Total exports of oil palm output amounted to 27,86 million in 2019, growing 12% from the year 2018 (MPOB, 2020). However, according to one of the private oil palm companies, Negeri Sembilan Oil Palm Berhad (NSOP), the 2017 Fresh Fruit Oil Palm (FFB) palm oil palm production decreased by 4% relative to the 2015 FFB (NSOP, 2017). It was also pointed out that the decline in yield was attributed to the previous case of El Niῆo in the year 2016 in Negeri Sembilan.

Meanwhile, the prolonged dry season increased the possibility of forest fires happening in peat swamp forest areas (Lo & Parish, 2013; Musri et al., 2020). During the dry season, the forest canopy cannot provide optimum protection to the ground surface, which triggers the natural causes of serious uncontrolled fire out-breaks on the forest floor (Kareksela et al., 2015). At the same time, the carbon content and carbon storage rate are more prominent during the dry season, compared to the wet and immediate season (Hemati et al., 2015). This natural event has been the focus of many researchers since the impacts of it have been bigger. Many researchers who have studied the threats of drought see the need to improve the quality of drought monitoring and management. Yet, most of the studies heavily focused on Indonesia compared to Malaysia (Tangang & Juneng, 2004). Therefore, by studying the healthiness level, we can determine the vegetation conditions affected by the water shortage caused by the drought.

Next, the traditional approaches have been used for many years to collect vegetation sample parameters, such as a set of comprehensive tree inventory information, including species types, Height (H), Diameter at Breast Height (DBH), and other measurements, which can be used to estimate timber volume, AGB and ecological studies, as these are the most commonly used parameters (Sumida, 2015; Sumida et al., 2013). However, although these traditional approaches have been seen to be successful, they can end up causing a disturbance in agricultural production. This approaches also disturbing the distribution of tropical forests, by change the natural structure and continuous cutting down the trees, either for study sample or to build access road into deeper area. Subsequently, many studies have utilised satellite-based indices and the Drought Classification Index to increase accuracy and mitigate the effects of traditional methods. Previous satellite technologies, however, restricted the indices' observations due to low resolution and impacts on specific areas only. In addition, understanding of how to effectively combine different sensor data and modelling algorithms are still in lack even though many interest on this similar study (Gao et al., 2018).

Therefore, by applying a combination of high-resolution satellite spectral and ground data estimation, stronger estimation and accuracy can be obtained. In addition, the development of vegetation suitability classification to determine the healthiness level of different vegetation during the dry season, can help to measure sensitivity and condition of the canopy, and the vigour of green vegetation. Hence, the classification able to provide a better explanation of monitoring and management planning for larger plantations and protected forest.

1.3 Objectives of The Study.

The general objective of this study was to assess the level of health of the different vegetation using the AGB estimation and vegetation suitability classification derived from high resolution satellite, ground data, and drought classification index. To achieve the goal, three objectives have been formulated:

1. To study vegetation healthiness level using different vegetation indices and water index.

2. To estimate Aboveground Biomass (AGB) for oil palm, rubber and peat swamp forest based on the ground information.

3. To develop a Vegetation Suitability Classification from suitable remote sensing vegetation indices to classify and represent the vegetation's healthiness level.

1.4 Hypothesis

Firstly, the SPI classification able to categorise 20 years of rainfall data based on classification and identify low rainfall years. Then, the scale of satellite-based indices will vary for different types of vegetation, such as agricultural land and peat swamp forest with different degrees of dryness. Following that, the regression of AGB regression models based on ground and satellite data will improve AGB estimates for oil palm, rubber, and peat swamp forests. Finally, the healthiness level and vigorousness of the oil palm, rubber, and peat swamp forests were classified differently by the Vegetation Suitability Classification.

1.5 Significance of the study

Firstly, this study was able to visualise the drought pattern using the SPI classification from three different weather stations. Then, the study established a visualization of the land cover classification and the map of each vegetation studied. The newly developed Vegetation Suitability Classification regress by this study was able to help improve the estimation of vegetation dryness and water stress levels by applying the combination of ground-based and satellite-based indices. Lastly, the outcomes can provide key information for monitoring and mitigation plans for future studies to mitigate the risk of drought on vegetation healthiness.

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