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The Application of SPOT Imagery in Observing the Environmental Impact of Oil Palm Plantation Activities

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ABSTRACT

The establishment of oil plantations involves massive land clearing and requires large geographical areas. Despite their positive contribution to the economic and social status of the planters, oil palm plantations always have negative impacts on the environment. The primary goal of this study is to observe and detect the changes in peat swamp forest in Pekan District and identify whether oil palm plantation activities are the cause of land use change in the study area. In this study, we use SPOT images that allow us to examine a large study area within a short time without ground access to the forest. We found that oil palm plantation activities in this area are a major contributor to land use change. About 290.27 hectares of peat swamp forest were converted to other land uses, primarily to establish new oil palm plantations. It shows that oil palm plantations cause deforestation and other environmental issues. The use of remote sensing imagery in oil palm monitoring will help farmers and authorities manage the negative impacts on the environment. Expanding this technology in the oil palm sector will also improve efficiency, productivity and yield.

1. Introduction

Oil palm is the major vegetable oil, with 40% of total global edible oil production worldwide and plays a significant role in socio-economic development in tropical countries. Socio-economic is commonly divided into three components, namely environmental, social and economic. From an economic perspective, oil palm plantation successfully offers job opportunities, eliminate the poverty, creates business opportunities and boost local economic development. Both farmers and non-farm households enjoyed income enhancement, new business opportunities and poverty alleviation. In rural areas, oil palm downstream activities were used as an alternative to change socio-economic status of rural communities and boost local economic development.

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In social perspective, participation in oil palm plantation comes with various benefits like health facilities, education facilities, religious centre and other public amenities. In Malaysia, these facilities usually provided for organized smallholders under the Federal Land Development Authority (FELDA), FELCRA Berhad or state departments agencies. For example, each FELDA settlers were provided with a house, while each of FELDA settlement schemes were developed with school, clinic, mosque and community hall.

Despite positive impacts on economic and social perspectives, production of oil palm has always been associated with negative impacts on the environmental including deforestation, soil erosion, wildlife habitat damage and peat degradation [1]. The peat swamp forests are vulnerable to threats due to anthropogenic activities such as urban expansion, infrastructure development and plantation activities. Oil palm plantation activities in peatland areas changes in the moisture content, depth of peat and ash content [2]. Expanding oil palm plantations in tropical peatland areas raises concern and criticism from European countries. They imposed various trade barriers such as an import ban, high tax rates on palm oil products and anti-palm oil labelling on food, personal care and household products.

The European Union Deforestation Regulation (EUDR) is one example of unfair treatment of palm oil products. The European Parliament and European Commission enforced the EUDR to halt deforestation and promote deforestation-free products on the European market. The EUDR defines a product as deforestation-free if the product itself, the ingredients or their derivatives are not subject to deforestation after 31st December 2020. To comply with EUDR, it is mandatory for companies to perform due diligence to ensure only deforestation-free products are allowed to be imported and distributed into European market. Table 1 listed the crops that affected by this regulation [3].

Table 1
List of crops subjected to EUDR

Crop or Product
Oil Palm
Rubber
Cocoa
Coffee
Cattle
Wood
Soy

Source: Köthke *et al.,* [3]

These barriers not only affect the income or revenue of plantation owners but also threaten the socio-economic status of nonfarm households that gain economic benefits from oil palm activities. Large plantations and smallholder farmers are experiencing a decline in demand and prices, at least for a short-term period [4]. Thus, it is vital to observe or measure the impacts on the environment caused by oil palm plantation activities. Negative impacts and unsustainable practices in oil palm plantation activities may affecting the socio-economic status of oil palm smallholder’s farmers, who affected by the barriers. Environmental impacts from oil palm plantation and an increasing demand for palm oil products requires the Malaysian oil palm producers and regulatory agencies to take aggressive efforts to counter the critics.

Observation and monitoring large plantation areas requires technology and innovation adaptation. Remote sensing (RS) defined as a process to acquire, process and interpret images that are typically acquired from satellite or aircraft with sensor systems [5]. RS technology has become a popular method to monitor land use and land cover (LULC), especially for large, difficult and remote areas. This technology allows fast and effective mapping, monitoring and observation in the agricultural sector, especially large-scale plantation activities. The application of remote sensing technology provided economic potential by enhancing efficiency and productivity in oil palm plantations, especially on labour management and fertilizing method [6].

RS technology became popular tool to perform the change detection on earth surface. In a study in Kedah, RS multitemporal imageries was used to observe the changes on mangrove forest for a ten-year period, starting from 2000 to 2010 [7]. Remote sensing data also was applied to examine the shoreline changes in Tanjung Burung Forest Reserve and its impact on mangrove stands [8].

In oil palm sector, remotely sensed data has been used in for various purposes and disciplines. Remotely sensed imagery applied to ease observation performance and productivity improvement in oil palm plantations. The planters can use RS images to map their oil palm plantations, estimate palm oil production and measure the productivity [9]. They applied high resolution images to monitor and map the plantation and enabled agricultural production to be more efficient [6]. Besides that, this technology was applied successfully in counting the oil palm trees and the healthy level of the trees [9]. It can identify low productivity areas, to conduct yield estimation assessment and optimize resources allocation for better yield.

Remote sensing offers valuable information about water management in oil palm plantations, such as irrigation needs, soil moisture levels and the size of water bodies [10]. By using imagery from remote sensing satellites, the planters can reduce the flood risk and other water-related issues. Hyperspectral and multispectral imagery in remote sensing can enable early detection of pests and diseases affecting oil palm trees [11]. It helps the farmers act for early prevention of the diseases. For the benefit of authorities, the satellites can observe the impacts of oil palm plantation activities, track plantation expansion, assess land use changes, identify encroachment and deforestation areas and ensure compliance with laws, regulations and standards.

The main objective of this study is to detect the changes in peat swamp forests due to agricultural activities, especially oil palm cultivation. High resolution RS images were used to examine the changes (if any) in peat swamp forest due to oil palm activities in study area. The advantages of using RS imagery in agricultural and forestry management is cost effective approach to obtain real-time information on the earth. This technology offers a time-saving method to monitor large plantation areas since it can map and observe large geographical areas without any ground access. Besides that, images from the RS technology also help the stakeholders observe or monitor the forest and plantation areas regularly. The findings of this study describe the actual impacts of oil palm plantation activities on land use change in tropical peat swamp forests. The study also expected to show the importance of latest technology and innovation in monitoring plantation activities.

First part of this paper is introduction to the study, which briefly explained about oil palm industries and its contribution to the socio-economic development. Second part describes the materials and methods that used in this study, including study area, data acquisition, data processing and change detection analysis. The next part of this paper highlighted the findings and discussion of the study while the fourth section highlighted several suggestions for the stakeholders and proposed some ideas for future studies. The final part is conclusion for this research. In addition to the conclusion, this part also addressed some limitations during conducting this study and the implications from this research.

2. Materials and Methods
2.1 Overview of SPOT Imagery

The Satellite Pour l'Observation de la Terre (SPOT) is a series of commercial earth-observation satellites that developed to capture imagery for earth surfaces such as agriculture, land use, forestry and coastal areas. As of 2024, there are seven series of SPOT satellites, which are listed in Table 2. In this study, we used SPOT images to detect the changes in peat swamp forest caused by oil palm plantations for a ten-year period, from 2012 to 2022.

Table 2
Characteristics of SPOT Sateliite Series

Series	Lauching Date	Instrument	Ground Sample Distance		Swath Width
			Pachromatic	Multispectral	
SPOT 1	22nd February 1986	HRV	10 m	20 m	60 km
SPOT 2	22nd January 1990	HRV	10 m	20 m	60 km
SPOT 3	26th September 1993	HRV	10 m	20 m	60 km
SPOT 4	24th March 1998	HRVIR	10 m	20 m	60 km
SPOT 5	4th May 2002	HRG & HRS	5 m x 5 m	10 m x 10 m	60 km
SPOT 6	9th September 2012	NAOMI	1.5 m at nadir	6 m at nadir	60 km
SPOT 7	30th June 2014	NAOMI	1.5 m at nadir	6 m at nadir	60 km

The SPOT satellite is one of the sensors that applied to monitor and map oil palm plantations. This sensor provides an accuracy of 96.9% after the implementation of image classification [6]. The Normalized Different Vegetation Index (NDVI) has an accuracy value of 83.3%. The Panchromatic Normalized Different Vegetation Index (PANNDVI) has an accuracy of 80.74% while the Second Modified Adjusted Vegetation Index 2 (MSAVI2) recorded an accuracy of 78%.

2.2 Study Area

Pahang is the largest state in Peninsular Malaysia with agricultural activities are a major contributor to the economy. Pekan District is one of the districts in Pahang, with the land size of 3,805 km^2. The district is located 50km at the south of Kuantan City, on the banks and the mouth of Pahang River. The climate of this district is humid throughout the year (81% - 86%) with strong winds and heavy rains during the northeast monsoon. Annual rainfall range for the district is varies from 2,000 to 3,500 mm, with a lot of rain even on driest season. The average of temperature is 23°C to 33ºC.

Pekan District was selected as the area of interest (AOI) for the study because this district has the largest peat swamp forests in Peninsular Malaysia. Estimated 87,045 hectares of this forest are protected in four Permanent Forest Reserves namely Nenasi, Resak, Pekan and Kedondong Forest Reserves. The flora and species in these forests are including 216 of plant species, 192 of bird species, mammal species (62), fish species (56), 17 of frog species and 21 species of snakes, lizards and tortoises [12].

The Malay people are the largest community (86.8%) in this district, followed by Orang Asli's tribes (9.9%), Chinese (1.5%), Indian () and other minorities (1.3%) [13]. The main economic activities in this district are plantations, fishery industries, automotive manufacturing and higher education. Oil palm is the most planted crop in this district with 104,733 hectares of planted area and it became the second largest oil palm producer after Rompin District [14]. Both large-scale growers and small-scale farmers cultivate oil palm in Pekan District. This study was focused on the peatland area in Mukim of Bebar. Figure 1 shows the location of Pekan District in the State of Pahang.

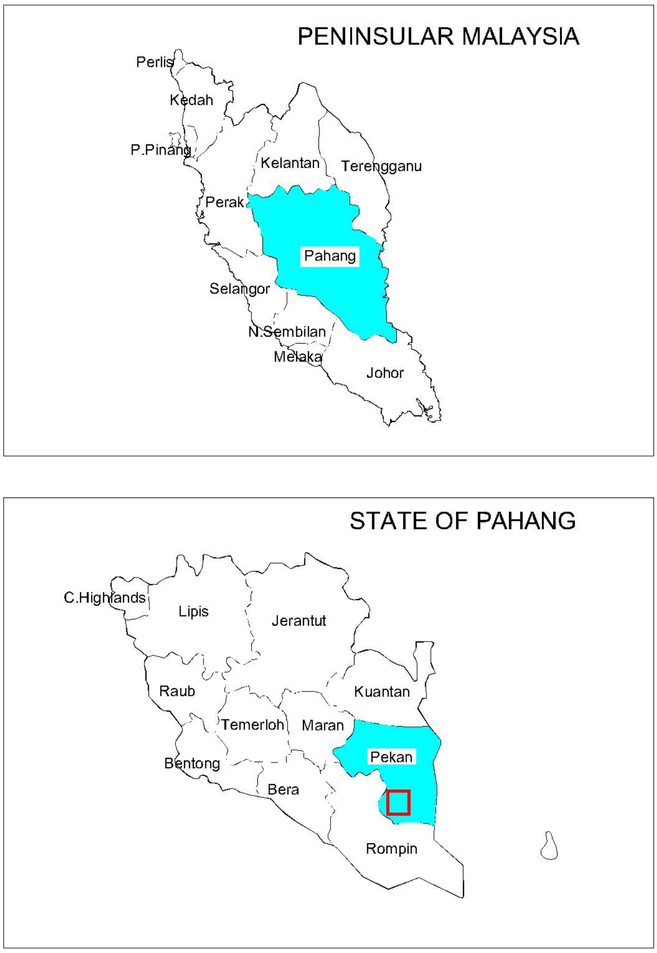


Fig. 1. Maps of study area

2.3 Source of Data

We used SPOT imagery to measure the changes (if any) in peat swamp forest for a ten-year period. The SPOT-5 and SPOT-6 raw images were obtained from the Malaysia Space Agency's (MYSA) archive. These images were taken in the same area on different dates. The details of these images are shown in Table 3.

Table 3
List of remote sensing data

Type of Satellite	Date of Image	Product Level
SPOT 6 (XS & PAN)	30th March 2022	Raw R Sensor
SPOT 5 (J & THR)	12th May 2012	Raw Level 1A

Source: Malaysia Space Agency, 2022

2.4 Methodology

The raw images require pre-processing procedures, including panchromatic sharpening, automatic rectification and subsets of images. These procedures were performed using CATALIST Professional software. First, all images were re-projected into World Geodetic System (WGS 84) projection to match with the Malaysia topographic mapping system. Then, a pan sharpening procedure was applied to produce a high-resolution image by combining a high-resolution panchromatic image with a low-resolution multispectral image.

All images were orthorectified to remove distortion caused by topographic relief and sensor tilt. The orthorectification of images requires a digital elevation model (DEM) and ground control points (GCPs) [15]. Then, the subset of images was performed to save time and reduce the usage of computer storage [16]. Figure 2 shows the orthorectified image that was used in this study.

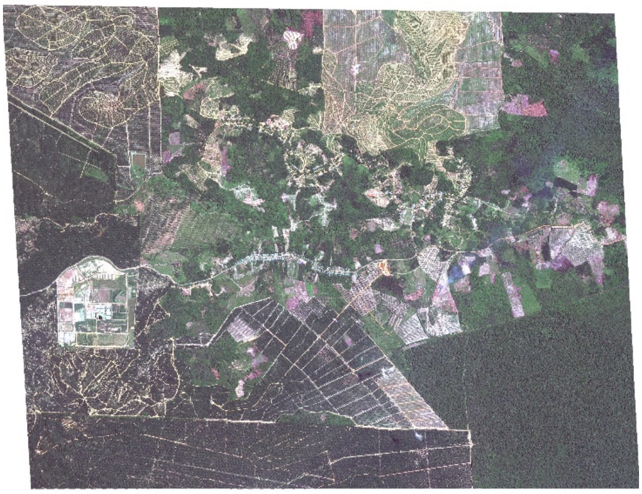


Fig. 2. AOI for the study

The change detection analysis was carried out using CATALYST Professional software. Both images were laid together to identify any differences between the two images.

3. Results and Discussion

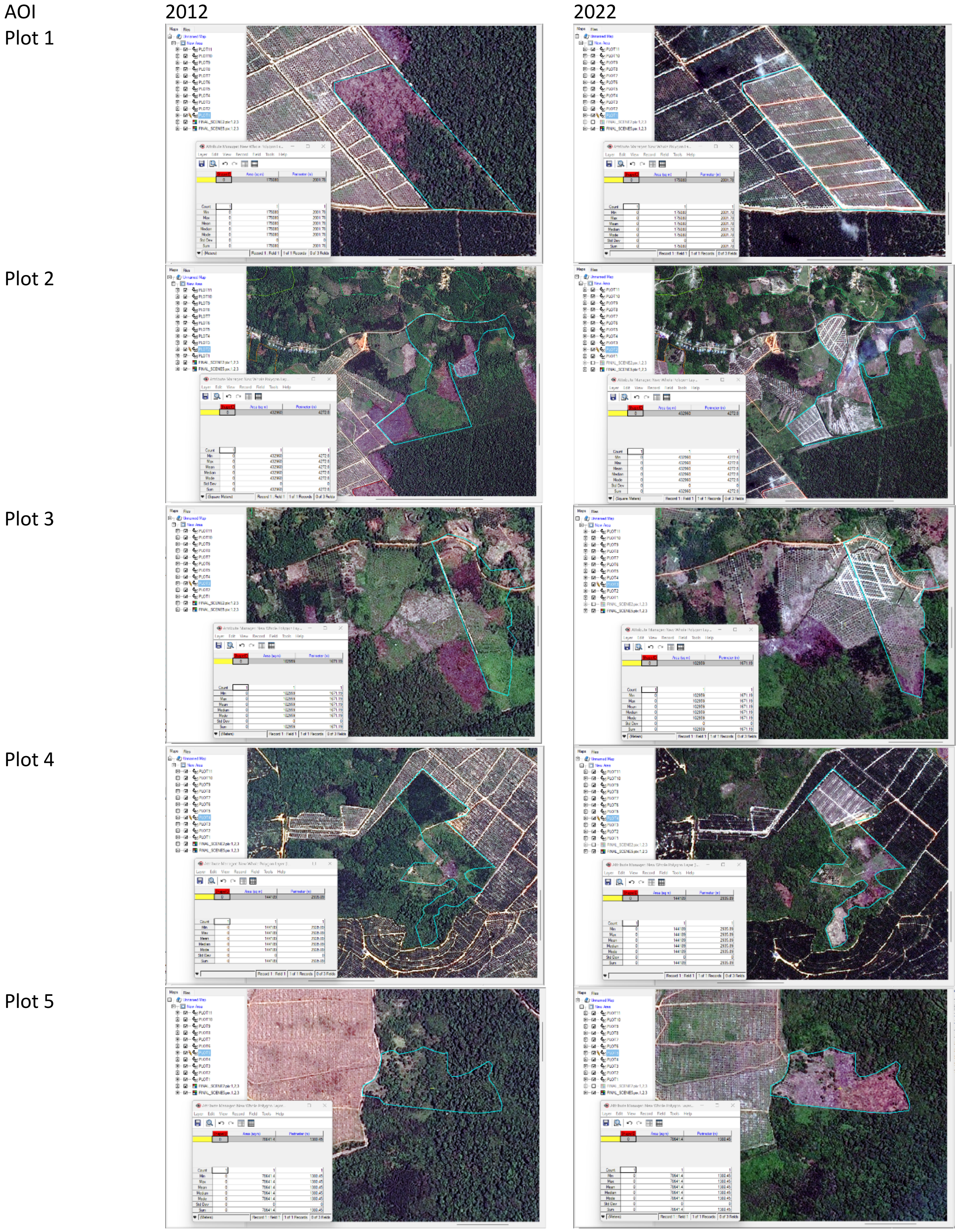
3.1 Land Use Change Detection

The findings from this study show land use change for a ten-year period, from 2012 to 2022. Change detection is a fundamental task in remote sensing, aiming to detect changes in land use or land cover at different times for the same geographical area [17]. The images from 2012 to 2022 clearly showed that tropical peat swamp forests are affected by oil palm plantation activities. We found land use change in eleven areas in AOI. Table 4 describes the changes in peat swamp forests in study area.

Table 4
Land use change detection between 2012 to 2022

Plot	Previous Land Uses (2012)	Current Land Use (2022)	Size of Conversion Area (Ha)
1	Peat swamp forest	Oil palm plantation	17.51
2	Peat swamp forest	Oil palm plantation	43.3
3	Peat swamp forest	Oil palm plantation	10.3
4	Peat swamp forest	Oil palm plantation	14.42
5	Peat swamp forest	Oil palm plantation	7.86
6	Peat swamp forest	Oil palm plantation	24.12
7	Peat swamp forest	Oil palm plantation	11.56
8	Peat swamp forest	Oil palm plantation	21.67
9	Peat swamp forest	Oil palm plantation	14.06
10	Peat swamp forest	Oil palm plantation	53.85
11	Peat swamp forest	Settlement area	71.62
Total Conversion Areas			290.27

In general, a total of 290.27 hectares of peat swamp forest were cleared and converted to other land uses. About 75.33% (218.65 hectares) of the conversion areas were converted to establish new oil palm plantations. In addition, the remaining 71.62 hectares of forests have been cleared for new houses for local communities. The images for all eleven plots were shown in Figure 3.



Plot 6

Plot 7

Plot 8

Plot 9

Plot 10

Plot 11

Fig. 3. Land use change areas in the AOI

3.2 Discussion

The major cause of the reduction of peat swamp forest area is the land conversion for oil palm plantations. This result indicated that oil palm plantation activities have significant impacts on the environment through the conversion of peat swamp forests and the degradation of peatlands. A significant hectare of peat swamp forest was converted to oil palm and other land uses. As of 2019, an estimated 27% of Malaysia's peatlands have been converted to oil palm plantations, mostly in Sarawak and Sabah [18]. In general, remote sensing imagery is effective tool in observing the impacts of oil palm plantation activities on environment. This innovative and cheapest tool to mapping and observing large geographical area and in a short or limited time.

4. Suggestion

It is illogical to prevent the expansion of oil palm in tropical regions like Malaysia since this crop plays a significant role in socio-economic development and improves the socio-economic status of the farmers. Future oil palm expansion will likely occur in high-altitude areas (more than 300 metres) due to a lack of suitable land in low altitudes areas [19]. In addition to the high-altitude areas, future expansion may also threaten tropical peatland areas. Thus, the authorities and stakeholders are requiring monitoring and formulating strategies to reduce or manage the negative impacts of plantation activities. In fact, sustainable practices in oil palm plantation will minimize the negative impacts to the environment. Moreover, the sustainability in plantation operation will improve the oil palm yield, which helps the producers increase the production without expanding the plantation with additional areas. It is important to protect the remaining peat swamp forests in Pekan District and other parts of Malaysia.

In complement to sustainable practices, the farmers also encourage to apply innovation and latest technologies in oil palm operation. Technologies like remote sensing imagery and unmanned aerial vehicle (UAV) can be integrated into the plantation operation. The transition towards sustainable plantation practices requires new knowledge, skills and innovation, mostly related to digital applications without denying farmer's experiences and informal knowledge [20]. The most challenging part in adapting innovation and promoting sustainability in oil palm is educating the farmers about the shifting from old practices that they have been applying for decades to the sustainable and innovative practices [21].

There are some suggestions that can be considered for future research. First, future research may consider applying remotely sensed data from different types of satellites, such as Landsat, Sentinel and EOS SAT. Other technology in remote sensing, such as Light Detection and Ranging (LIDAR), can also be adapted to enhance the accuracy of change detection analysis. The application of LIDAR systems not only improves spatial understanding and object interaction but can estimate the distance between an origin and a surface or obstacle [22].

The imagery from these sensors offers different dates, quality and resolutions. The second suggestion is to use other variables such as the number of flood incidents, the number of peat fire cases, the status of riverbanks or land erosion caused by oil palm plantation activities. In addition, future research may use RS imagery to explore the impacts of oil palm plantations on other types of forest or land surfaces, such as nipa swamp forests, mangrove areas and riparian zones.

5. Conclusions, Limitations and Implications

We examined the impact of expanding the oil palm on the peat swamp forest in Mukim of Bebar, Pekan District. The findings showed that the expansion of oil palm has negative impacts on the environment through the conversion and degradation of peat swamp forests. In addition to the findings, we proved that major losses of peat swamp forests in AOI are caused by the establishment of new oil palm plantations. The study explored the potential of remote sensing applications in the oil palm industry, mainly for impact observation and monitoring. This technology strengthens the ability and effectiveness of government policies on monitoring, observing and managing the impacts of oil palm and other agricultural expansion. Images captured by remote sensing satellites offer the latest and most accurate data about the conditions of oil palm or its impacts on the environment. Moreover, the application of remote sensing technology will increase the productivity of oil palm plantations and make the industry more sustainable.

We are facing some limitations while conducting this study. First, the short history of high-resolution remotely sensed data offers limited options and allows us to detect changes only for a short-term period. We are also facing difficulties in having more options for images because cloudless images are often limited to capture since the AOI is in a tropical region. The third limitation is time constraints, which affect the number of ground-truthing points used to validate the accuracy of the images.

These findings are useful to protect and conserve the remaining peat swamp forest in Pekan District and other parts of Malaysia. This study provides the latest information on the condition and status of peat swamp forests that are vulnerable to the expansion of oil palm plantations, which will help the Malaysian authorities review land development policies and improve enforcement strategies for protecting remaining pristine tropical peat swamp forests across the country. Our results are also useful to enhance the level of sustainable oil palm plantation practices and certification, especially for smallholder farmers. The findings of the study allow oil palm growers and stakeholders to protect and enhance the marketability of palm oil products, especially in existing European markets. Higher yield, sustainability approaches, value addition and innovation are considered vital to the current and future oil palm industry.

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