Evaluation of 2015 Vegetation Fire Activity Distribution in Peninsular Malaysia using Integrated Satellite and Land Activity Data

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Abstract. The decline in air quality is a significant global issue, with agricultural practices and biomass burning being a few of the factors contributing to harmful pollutants. In 2015, Malaysia faced severe air quality deterioration due to forest fires and agricultural burning, worsened by El Niño–Southern Oscillation (ENSO) conditions. Vegetation fires, particularly forest fires, emit pollutants and cause temperature fluctuations, significantly impacting air quality. Although satellites like NOAA's GOES-16 and NASA's MODIS are used for fire detection, data coverage and capture frequencies create uncertainties. This study examines local vegetation burning data from the Fire and Rescue Department of Malaysia (BOMBA), MODIS hotspots from the Fire Information for Resource Management System (FIRMS), and MODIS Burned Area Monthly L3 Global 500m (MCD64A1). The analysis focuses on the spatial distribution and trends of vegetation burning in Peninsular Malaysia's forests and agricultural lands in 2015. It also compares fire detection data from BOMBA and MODIS to identify discrepancies between the local and remote sensing datasets. The research aims to enhance understanding of vegetation fire activities in Peninsular Malaysia, offering insights for more effective fire management and mitigation strategies.

1 Introduction

Air quality deterioration has become a critical issue globally, mostly impacted by various anthropogenic activities, notably agricultural practices and biomass burning (Chen et al. 2017). In 2015, Peninsular Malaysia experienced an extreme for El Niño–Southern Oscillation (ENSO) where forest fires and agricultural burning cases increased and led to

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widespread haze (Khan et al. 2020, Khoir et al., 2021). This underscored the need for comprehensive monitoring and analysis of fire-related activities.

The release of harmful pollutants and greenhouse gases such as fine particulate matter (PM2.5), total particulate matter (TPM), carbon dioxide (CO2), carbon monoxide (CO), methane (CH4) and Volatile Organic Compile (VOC), which could alter local temperature pattern (Sivaramanan 2015). The urgency to mitigate these impacts has led to the development of advanced satellite technologies. For example, National Oceanic and Atmospheric Administration (NOAA) satellites, Aqua and Terra satellites that equipped with Moderate Resolution Imaging Spectroradiometer (MODIS) and, have become a useful tool in detecting and monitoring vegetation fires globally (Nakau et al. 2006). However, the efficacy of satellite data in capturing fire activities is often challenged by discrepancies arising from differences in orbital paths, sensor capabilities, temporal resolution, and obstruction from cloud coverage. These variations can lead to significant uncertainties in fire detection and subsequent data interpretation (Nakau et al. 2006). To address these challenges, it is essential to corroborate satellite data with ground-based observations and localized reports.

This study aims to provide a detailed evaluation of vegetation fire activity distribution in Peninsular Malaysia for the year 2015 by integrating satellite data with bottom-up land activity data. We utilize local vegetation burning data from the Fire and Rescue Department of Malaysia (BOMBA), MODIS hotspots from the NASA Fire Information for Resource Management System (FIRMS), and the MODIS Burned Area Monthly L3 Global 500m (MCD64A1) dataset. By analysing the spatial distribution and temporal trends of vegetation fires across different forested and agricultural regions, this research seeks to elucidate the discrepancies between satellite-based fire detections and ground-reported fire incidents. This research not only highlights the importance of multi-source data integration but also underscores the responsibility of accurate fire monitoring in addressing broader environmental and public health challenges associated with air quality deterioration. The findings further enable the application of machine learning techniques for drone-based fire detection, significantly increasing the accuracy of forest fire identification. These insights could also support future projects, particularly in the areas of fire prediction and emissions estimation, providing a foundation for more effective mitigation strategies

2 Material and method

2.1 Data collection

This study analyzed vegetation fire activity distribution in Peninsular Malaysia for 2015 using various data sources such as vegetation fire cases from the Fire and Rescue Department of Malaysia (BOMBA) in CSV format, MODIS hotspots from the Fire Information for Resource Management System (FIRMS) as shapefiles, MODIS Burned Area Monthly L3 Global 500m (MCD64A1) as shapefiles files, and land use data from the Town and Country Planning Department (PLAN Malaysia) as shapefiles.
The datasets of vegetation fire cases from the Fire and Rescue Department of Malaysia (BOMBA) are retrieved from BOMBA's internal Reporting Incident System (SPI) database. The datasets include the address, burn area in hectare units, date, time, states, and burning type for vegetation land. However, the records for vegetation land in BOMBA’s SPI system are based on observations. So, land use data from the Town and Country Planning

Department (PLAN Malaysia) is applied to study the exact land use burning information. The land-use datasets of PLAN Malaysia are provided for each file in different states in Peninsular Malaysia. There are three column categories for land use information: land use 1, land use 2, and land use 3. Land use 1 shows general land use categories such as forest, agriculture, water bodies, and other human activity areas such as industrial and residential. Land use 2 and 3 specified the type of land use 1. For example, land use 1 for forest could categorized separately for tropical forest and peat land forest. Note that the fire case detection could be in residential and industrial areas, which refer to the vegetation or grass area near human activity. However, some fire activity location still falls on missing information for land use so it will decide to use land use information provided by SPI. In the analysis, these fire cases are categorized as Mixed Grassland. The table below shows the land use categories in PLAN Malaysia's land use datasets and the final categorized land use.

Table 1. Land use categories in PLAN Malaysia's datasets and the final categorized land use

Data Sources	Land use 1	Land use 2	Land use 3	Final Categorized Landuse
PLAN Malaysia	Forest	Terrestrial Forest	Protective Forest	Forest, Tropical Forest
		Terrestrial Forest	Others	Forest, Tropical Forest
		Peat Land Forest	Protective Forest	Forest, Peat Land
		Peat Land Forest	Others	Forest, Peat Land
		Wet Land Forest	Protective Forest	Forest, Wet Land
		Wet Land Forest	Others	Forest, Wet Land
		Cleared Forest	Cleared Forest	Forest, Empty Land
		Cleared Forest	Others	
		Agriculture Forest	Oil Palm	Forest, Empty Land
		Coastal Area Forest	Protective Forest	Forest, Coastal Area
		Cleared Forest	Others	Forest, Empty Land
	Agriculture	Aquaculture	-	Agriculture, Aquaculture
		Animal Farming	Grazing Field	Agriculture, Grazing Field
		Agriculture	Oil Palm	Agriculture, Oil Palm
		Agriculture	Orchad	Agriculture, Orchad
		Agriculture	Rubber	Agriculture, Rubber
		Agriculture	Coconut	Agriculture, Coconut
		Agriculture	Coco	Agriculture, Coco
		Agriculture	Paddy	Agriculture, Paddy
		Agriculture	Mixed Plantation	Agriculture, Mixed Plantation
		Agriculture	Banana	Agriculture, Banana

		Agriculture	Spices	Agriculture, Spices
		Agriculture	Vegetables	Agriculture, Vegetables
		Agriculture	Empty Land	Agriculture, Emplty Land
		Agriculture	Herb Plantation	Agriculture, Herb Plantation
		Agriculture	Sugar Cane	Agriculture, Sugar Cane
		Agriculture	Tea	Agriculture, Tea
		Agriculture	Tobacco	Agriculture Tobacco
		Agriculture	Others	Agriculture, Others
	Empty land	-	-	Empty Land
	Coastal Area	-	-	Coastal Area
	Water Body	-	-	Mixed grassland
	Industry	-	-	Mixed grassland
	Transportation	-	-	Mixed grassland
	Commercial	-	-	Mixed grassland
	Residential	-	-	Mixed grassland
BOMBA	Others Forest	-	-	Forest, Others

MODIS hotspots from the Fire Information for Resource Management System (FIRMS) are chosen as a comparison dataset for satellite fire points. The datasets provide the fire points according to the brightness, date, time, and coordinates for the location. However, the product of MODIS hotspots does not provide any burn area information. Therefore, the MCD64A1 product is used to compare the detection of burn area sizes with BOMBA datasets. MODIS is a product consisting of Aqua and Terra satellites for day and night data capturing. MODIS satellite performs in cycle 4 times per day monitoring up to 250 meters in Malaysia with satellite Aqua time capturing 16.00 & 23.00 and Terra satellite time capturing 2.00 & 12.00 for GMT zone. (Hamidi et al. 2014; Ismail et al. 2019).

2.2 Data Processing

The software tools employed included ArcMap 10.8 for GIS mapping and spatial analysis, and Python for data organization and graph plotting. The methodology began with the collection and processing of data. BOMBA data were sorted and geocoded using Geocode Awesome Table to generate coordinates, which were then imported into ArcMap using the input XY function to create point shapefiles (Westerncapegovernment 2021). Spatial analysis was performed by mapping land use information to the fire incident data, and the resulting table was extracted and analysed in Python. The MODIS hotspots are filtered with ArcGIS using different land use types from PLAN Malaysia according to Table 1. The attribute tables were extracted, and organized in Excel, and graphs were plotted to visualize the distribution and trends of hotspots. MODIS burned area data were processed by opening the shapefiles in ArcMap. Burnt areas were calculated using ArcMap with a coordinates system called Kertau RSO Malaya Meters. The resulting attribute files were exported to Excel for statistical descriptive analysis and graph plotting using Python. After processing all datasets, a comprehensive comparison was conducted by merging the data to analyze differences in fire detection methods and calculating percentage discrepancies. Statistical analysis was also performed on the land use fire data, focusing on the type and time-series trends of fire incidents within each month. By integrating satellite data with ground-based reports, this study provided a detailed evaluation of vegetation fire activity distribution across different land use types in Peninsular Malaysia. This approach enhanced the understanding of fire dynamics, highlighted discrepancies between various fire detection methods, and informed more effective fire management strategies.

3 Result and discussion

The analysis of vegetation fire incidents across different land uses and months reveals significant variations in frequency and distribution, sourced from BOMBA fire cases (B) and MODIS Fire Hotpots (M). Forest fires reached the highest in March for B and April for M, with B reporting 109 incidents in March, and M reporting 306. The lowest number of forest fire incidents occurred in November, with B reporting 14 and M reporting 4. Agricultural land fires were also recorded most frequent in March, with B reporting 483 incidents and M reporting 211. The least incidents were recorded in November, with B reporting 53 and M reporting 19, Coastal areas had the highest number of fire incidents in March, with B reporting 4 incidents, and M reporting 6 incidents while several other months had not reported in M for incidents. Fires on empty land were highest in February, with B reporting 149 incidents, and the lowest was in November with 30 incidents reported by B. Mixed grassland fires peaked in March, with B reporting a striking 2,223 incidents.
In Malaysia, the El Niño event in 2015 led to significant dry conditions, which likely contributed to increased vegetation fire activity, especially peat land fire (Khan et al. 2020, Khoir et al. 2021). El Niño event in 2015 affected precipitation patterns, particularly causing dry conditions during June, July, and August. These dry conditions can enhance the likelihood of vegetation fires due to the lack of moisture and higher temperatures (Tangang et al. 2017). The BOMBA and MODIS hotspots data show March and April as the highest months for vegetation fire activity, it is believed that the dry spell may have started earlier or persisted into the beginning of the year, creating conducive conditions for fires (Ashâ et al. 2014). The influence of El Niño could have started affecting Malaysia's weather patterns before the peak dry months of June, July, and August, potentially leading to increased fire activity in March 2015. El Niño increased vegetation fire cases and contributed to haze from August to November 2015 (Samsuddin et al. 2018). Therefore, the 2015 El Niño event significantly impacted dry conditions in Malaysia, which would have contributed to the heightened vegetation fire activity observed in March, June, July, and August.

From the data analysed Forest and Agriculture land use is chosen to observe the fire activity according to the type of Forest and Agriculture. Tropical Forests and Wetland Forest recorded the most frequent fire activity in BOMBA, especially in March. According to BOMBA and MODIS hotspots, peatland recorded the highest number of incidents in March compared to other months. Oil Pam, Rubber, and Paddy fields show the most frequent fire activity especially recorded in BOMBA and MODIS hotspots. The details analysis is shown in Figure 2 and Figure 3.

Table 2. Number of Vegetation Fire Incidents according to land, B : BOMBA, M : MODIS

	Number of Vegetation Fire Incidents									
Type of Landuse	Forest		Agriculture		Coastal Area		Empty Land		Mixed Grassland	
Month/ Data Sources	B	M	B	M	B	M	B	M	B	M
January	29	38	170	37	2	2	98	8	1193	41
February	59	81	381	128	3	6	149	12	2172	58
March	109	283	483	211	4	6	161	20	2223	67
April	34	306	127	101	1	2	49	22	597	74
May	25	128	104	63	1	0	39	13	602	62
June	29	118	137	93	2	0	58	6	720	31
July	31	295	159	119	2	0	69	6	937	42
August	22	89	132	45	3	0	60	7	733	44
September	16	106	120	43	1	0	32	6	507	33
October	22	60	159	32	2	0	61	2	695	42
November	14	4	53	19	1	0	30	9	347	55
December	18	16	87	20	1	0	38	2	521	20

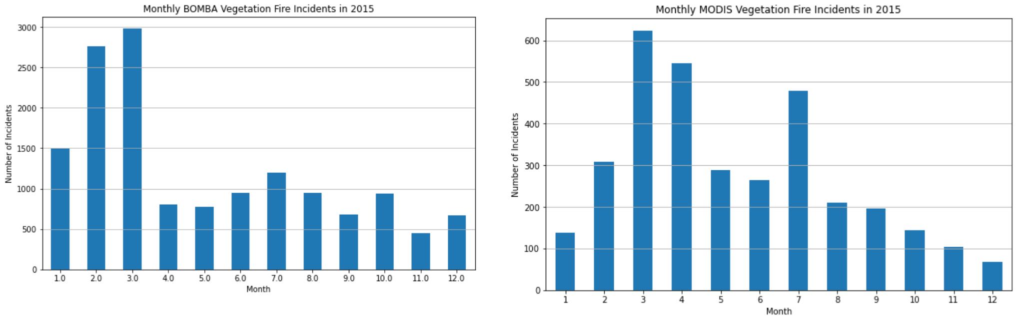
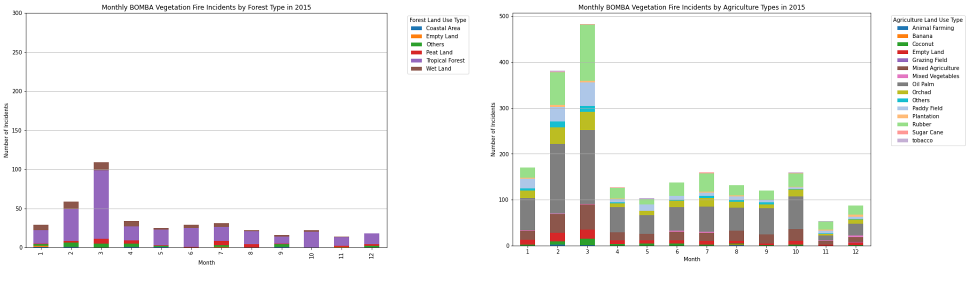


Fig. 1. Number of Vegetation Fire Incidents by Months



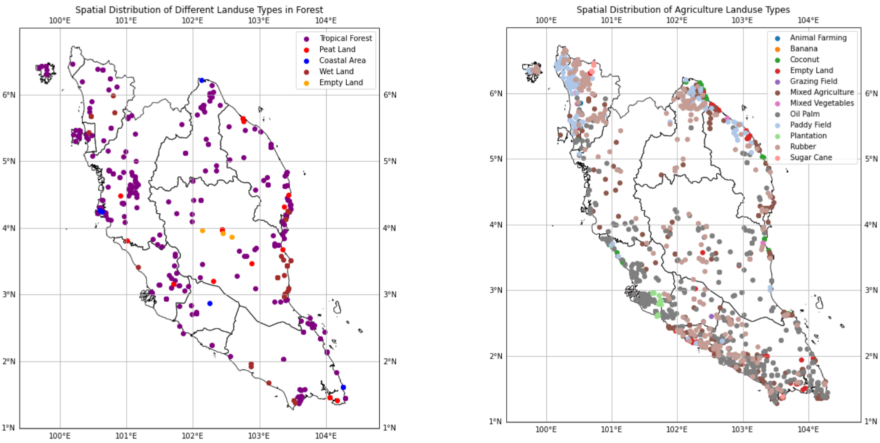


Fig. 2. Number of BOMBA Vegetation Fire Incidents by Forest and Agriculture Land Use Type

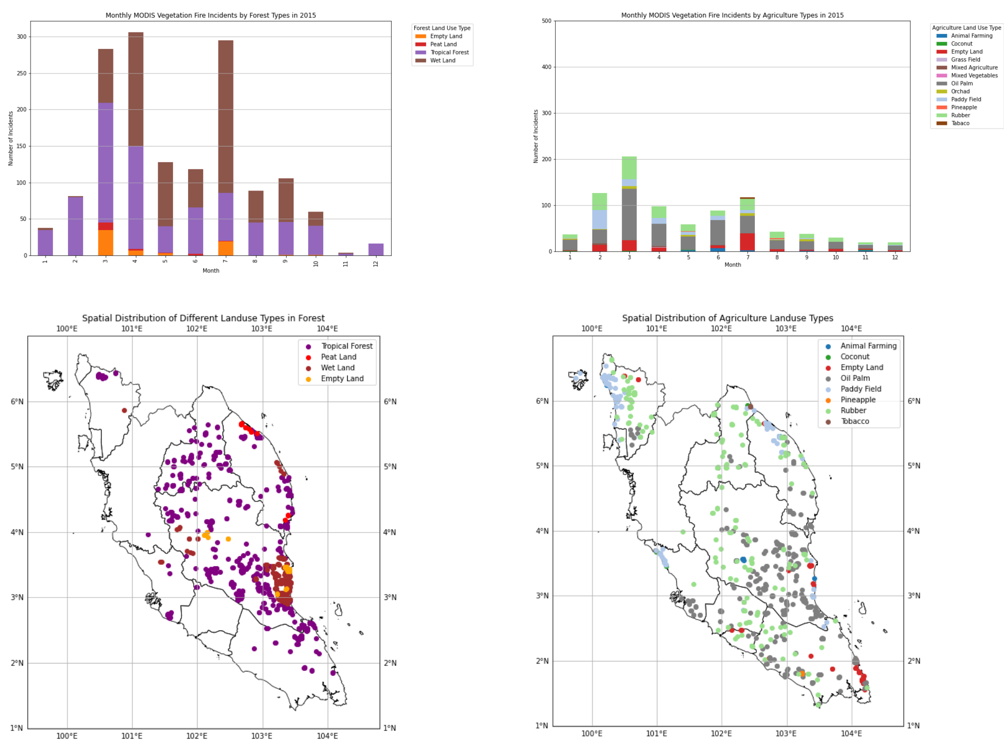


Fig. 3. Number of MODIS Vegetation Fire Incidents by Forest and Agriculture Land Use Type

According to Table 2, Figure 2, and Figure 3, the MODIS demonstrates a higher frequency of fire detection in forested areas than BOMBA, indicating its effectiveness in identifying large-scale fires in the remote forested area. Conversely, BOMBA reports more incidents in precise areas such as agricultural lands, coastal regions, and mixed grasslands, likely due to the proximity of these locations to human activities. The trend is almost similar between the MODIS system and BOMBA except for April as it recorded the highest number of Forest (283) in MODIS incidents.

Throughout 2015, the MODIS system detected a total of 3,369 fire points in Peninsular Malaysia, whereas the BOMBA recorded a significantly higher number of fire cases, totaling 14,634 incidents. This highlights a stark discrepancy, with MODIS detections accounting for only 23.03% of the BOMBA-recorded incidents. The substantial underestimation by the satellite data may be attributed to limitations such as temporal resolution, cloud cover interference, and differing sensitivities and detection criteria between the two systems. The comparative analysis of data sources shows notable differences. Out of 14,634 BOMBA fire cases, 3,369 MODIS detections, and 149 matched cases, 1.02% of BOMBA cases were matched with MODIS detections, while 4.42% of MODIS detections were matched with BOMBA cases. Figure 4 shows the distribution of similarities in case detection according to date and location.

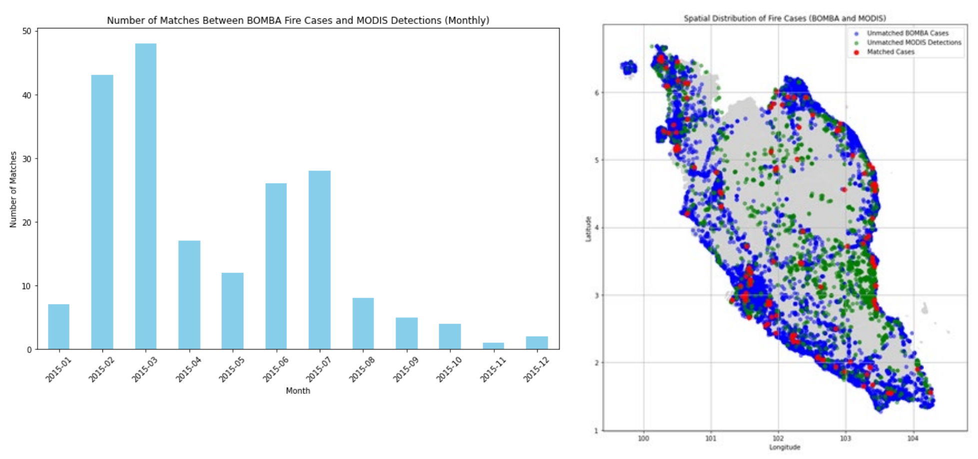


Fig. 4. Trend and Distribution of Matching Records of BOMBA and MODIS Hotspot in 2015 by month, time and location

BOMBA data shows that the burn areas are considerably smaller and remain consistent across all months. The average burn area detected for BOMBA in 2015 was 0.69 hectares. However, MCD64A1 could detect big-area fire incidents. It could detect from 24 hectares to 548 hectares of vegetation fires. Figure 5 shows that both systems detected that July lost the most burning vegetation land. The stark difference in the size of detected areas between the two sources highlights potential discrepancies or variations in measurement methodologies or event occurrences. This information is crucial for understanding land use impacts and planning effective resource management and fire control strategies. This could show that the differences between the two data detection areas and focusing areas are different where BOMBA mostly detected areas near human activity areas while MCD64A1 could cover some data sets that have big fires and couldn't be treated by BOMBA.

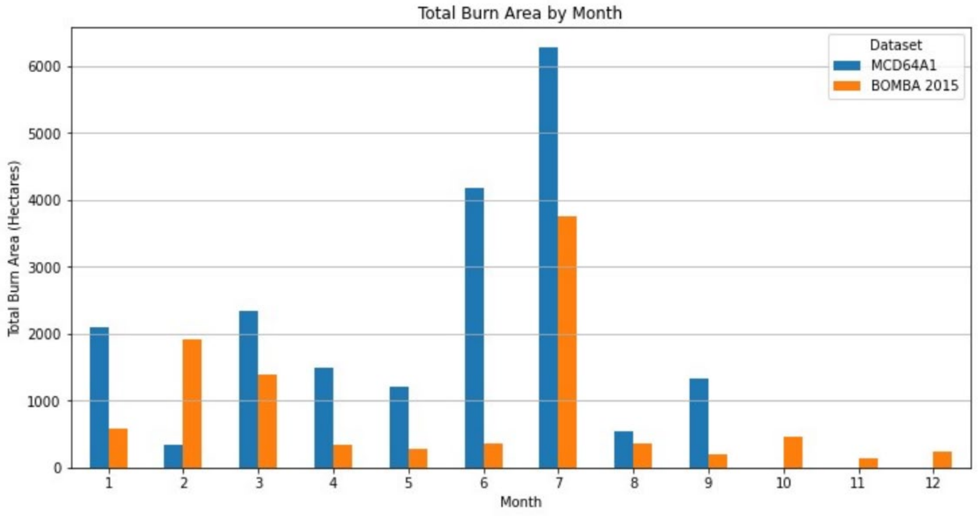


Fig. 5. Comparison of BOMBA detected area and burn area data from MCD64A1.

4 Conclusions

In 2015, Peninsular Malaysia experienced vegetation fires, with the highest number of incidents happening in March. This fire increase was closely related to the El Niño event which caused less rainfall and very dry conditions. These dry spells started early in the year and got worse by June, July, and August, making it easier for fires to start and spread. The data from the BOMBA and satellite-based MODIS hotspots showed that March had the most fire incidents. This suggests that the dry conditions caused by El Niño began earlier in the year, leading to more fires in March.

Besides, there were differences between the number of fires recorded by BOMBA and those detected by satellites, with BOMBA reporting many more incidents. This shows that satellites might miss smaller or less intense fires, which are still important to track. The vegetation fire emissions caused severe haze, worsening air quality and affecting public health. These findings highlight the need for better fire monitoring systems that combine satellite data with ground observations to improve fire detection and management. Addressing these differences in fire detection is important for developing effective strategies to reduce the harmful effects of vegetation fires on air quality and health. The impact of the 2015 El Niño event on vegetation fires in Peninsular Malaysia shows the importance of strong fire management plans for similar events.

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