Faculty of Resource Science and Technology

THE INFLUENCE OF FOREST FIRES ON LAND USE TREND IN MALAYSIA

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Master of Environmental Science
(Land Use and Water Resource Management)
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AUTHOR'S DECLARATION

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The Influence of Forest Fires on Land Use Trend in Malaysia

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ABSTRACT

Forest fires also known as wildfires are catastrophic events that can burn over a large area of forest in a short period, impacts tremendously on public safety, property, forest resources, and forest ecosystems. The study on the influence of forest fire in Malaysia are limited. Forest fire had become more intense at global scale due to climate changes and it is important to understand the impacts to Malaysia which have large proportion of forest. The purposes of the research are to examine the relationships between forest fire with the agriculture plantation area in Malaysia, forested area in Peninsular Malaysia, API in Malaysia, rainfall in Malaysia, forest fire convictions in Sarawak and other supplementary data within year 2002 to 2018. The data in this research were collected from various government agencies, organisation and open source data online. The data were then analysed via boxplot, descriptive analysis and regression analysis by using Microsoft Excel. The result found out forest fire had negative correlation with the agricultural land area and rainfall while had positive correlation with forested area, API, fire compound, permitted open burning by NREB. The study also discovered the impacts of El Ninõ events which greatly affected different parts of Malaysia.

Key words: Forest fires, forest land, agriculture land, fire convictions, human activities.

ABSTRAK

Kebakaran hutan adalah bencana alam yang boleh membakar kawasan hutan berskala besar dalam masa yang singkat, memberi impak besar kepada keselamatan awam, harta benda, sumber hutan, dan ekosistem hutan. Kajian mengenai pengaruh kebakaran hutan di Malaysia sangat terhad. Kebakaran hutan menjadi lebih serius pada skala global disebabkan oleh perubahan iklim dan memahami impak kebakaran hutan di Malaysia sangat penting keran Malaysia mempunyai kawasan hutan yang besar. Tujuan kajian ini adalah untuk mengkaji hubungan antara kebakaran hutan dengan kawasan perladangan pertanian di Malaysia, kawasan hutan di Semenanjung Malaysia, API di Malaysia, kadar hujan di Malaysia, pendakwaan atas kebakaran hutan di Sarawak dan data tambahan lain dalam lingkungan tahun 2002 hingga 2018. Data dalam kajian ini telah dikumpulkan dari agensi kerajaan, organisasi dan laman web berkenaan. Data tersebut dianalisis melalui kotak plot, analisis deskriptif dan analisis regresi dengan menggunakan Microsoft Excel. Kajian mendapati kebakaran hutan mempunyai korelasi negatif dengan kawasan tanah pertanian dan hujan manakala mempunyai korelasi positif dengan kawasan hutan, API, kompaun kebakaran, kebakaran yang dibenarkan oleh NREB. Kajian itu juga mendapati bahawa kejadian El Ninõ mempunyai impak dan pengaruh yang besar di sekitar Malaysia.

Kata kunci: Kebakaran hutan, kawasan hutan, kawasan perladangan, kebakaran hutan yang disabitkan kesalahan, aktiviti manusia.

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LIST OF ABBREVIATIONS

DOE	Department of Environment
DOSM	Department of Statistics Malaysia
EQA	Environmental Quality Act
GFW Fires	Global Forest Watch Fires
MPOB	Malaysia Palm Oil Board
Modis	Moderate Resolution Imaging Spectroradiometer
NAHRIM	National Hydraulic Research Institute of Malaysia
NREO	Natural Resources and Environment Ordinance
NREB	Natural Resources and Environment Board
ONI	Ocean Nino index
RSPO	Roundtable on Sustainable Palm Oil
VIIRS	Visible Infrared Imaging Radiometer Suite
WDTA	World Database on Protected Areas

1 INTRODUCTION

Forest fires also known as wildfires are devastating events that can burn over a large area of forest in a short period of time. According to Graham's study (as cited in Finney, 2005), large fires can involve adjacent patches of hundreds of square kilometers of complete mortality which would is not known within long fire history records. The area will be difficult and costly for the recovery of watershed and restoration of forest growth. The burns can leave tremendous impacts on public safety, property, forest resources, and forest ecosystems. Forest fires can affect country's economy whereby it requires a lot of money to cope with forest fire as well as recover it. A 64-year study period done by Collins et al. (2016) showed that over 85% of the 7,430 houses were destroyed by wildfires where the one third of the fire started by powerlines, 25% from undetermined causes, 22% from deliberately ignited fires and 11% by lightning strikes.

Forest fires can give significant impact on the timber harvest schedules which resulted in fluctuation to the economic value of timber supply (Martell, 2001). According to studies done by Dennis and Colfer (2006), fire risk increased and a positive feedback loop is created in and around the forest area whereby fire-affected forest becomes more prone to repeat fire damage as a result of increased logging activities and large-scale agro-industrial developments in tropical rainforests in addition to the contributing El Niño drought conditions. Forest is an important natural asset that provide people with job opportunities and the livelihood strategy of the rural community. The loss of these assets due to forest fire may resulted people to lose their jobs and force people who live nearby to move as the area became unfavourable for subsistence.

Forest fires also caused significant damage to the habitat of the wildlife living in or around the burned area. According to Gleason (as cited in Romeo, 2018), cases that wild animals died in forest fires are seldom especially the larger or matured wildlife as they can sense the threat of a fire before humans where mammals will retreat to other areas, birds can fly away whereas the amphibians and reptiles will hide in wet area or under logs and rocks. However, the fires will change the original habitat of the burned area such as the food resources, introduction of invasive species and alteration of the soil condition. Some part of the forest is served as winter home for the migratory birds where they depend on the forest resources for food supply and fuel for their long-distance travel.

Fire is used for large scale land clearing for agricultural purposes. The main agricultural development in Malaysia is oil palm plantation which was established in the early years of 20th century (Carr, 2011). Malaysia is the second largest exporter for palm oil which worth USD9.7 billion or 29% in the total palm oil export in year 2017 (Daniel, 2018). According to Tom (2011), report from Wetlands International claims that about 353,000 hectares of peat swamp forests were cleared largely for palm oil production between year 2005 and 2010 in Malaysia. The use of fires for land preparation for palm oil can be reduced by improving the governance of palm oil value chains through fair value-added distribution, market transparency and green certification (Purnomo et al., 2018). Beside oil palm, rubber industry which started in 1970s is another main contributor to the economic growth in Malaysia even though the export of natural rubber has been inconsistent (Hassan et al., 2013). The production of natural rubber as raw material enabled the development of forward linkage activities through technological discoveries and establishment of downstream rubber goods industries which offered alternative employment for estate labour (Goldthorpe, 2015). Hence, government play an important role to control the use of fires for land preparation for various agricultural activities.

Human subsistence depends very much on a healthy environment where the natural resources and the thriving ecosystems from the environment are the main drive for country's economy. Environmental laws help to protect and balance the environment and the economy of a country. Effective environmental laws should restrict the projects approval by the decision-makers that could hurt the communities, environment and economy in the long-term as it is not synonymous with creating economic stability for a country by rushing to approve projects that provide temporary jobs and export our natural resources to the lowest bidder (Page, 2015). In Malaysia, forest fire is known as an environmental crime under Environmental Quality Act 1974 with fine not exceeding RM500,000 or imprisonment for a term not exceeding 5 years or both. Environmental laws in Sarawak and Sabah will be under legislation of Natural Resource and Environment Ordinance 1958 and Environment Protection Enactment 2002 respectively.

Environmental crime usually has relatively low risks of detection as most individual does not see it as a crime due to the its nature (Mustafa, 2015). Despite the heavy fine and jail, people especially the agriculture managers and developers are willing to pay the fine to clear the forested land using fire as it is cheaper and more effective (Purnomo et al., 2018). Human-caused forest fire is very severe in Malaysia but not all of them are reported due to poor detection or ignorance by the public. Even if the fires are reported, most of the offender are not convicted for their doing due to lack of evidences.

Conclusively, forest fire is caused mainly by human activities and people from all aspects have the responsibility to it. Policy makers have to take forest fire into consideration when planning on development projects in the forest or around the forest area. Public and private organisations need to be educated the precautionary steps when carry out any activities which are related to burning or located in the forest or around the forest area such as shifting cultivation, open burning or development projects. Each individual has to cooperate and work together with relevant agencies on forest fire by learning to identify the sign of forest fire and report the fire as soon as possible.

1.1 Problem Statement

Forest fires can happen anywhere and harm homes, agriculture, humans, and animals in their path which change the original land use pattern of the land. Oil palm is the main agricultural plantation in Malaysia where the total area for oil palm total plantation is increasing each year. Global warming and El Niño phenomenon make the climate warmer and alter the precipitation levels, turning wet areas wetter and dry areas drier ("Union of Concerned Scientists", 2017). This situation turns the environment to become more favourable for forest fire to take place, increasing the rate of forest fires occurrence.

There is no research done on the impact of forest fire on agriculture activities and the forested area in Malaysia from year 2008 to 2017. There were many forest fires occur in Malaysia but its relationship with the number of reported fires and number of convictions for causing the fires is not known. Human activities are the main causes of forest fires and the research will evaluate the efficiency of fines or confinements to individual who caused the fire.

The burning of forest tends to release hazardous gaseous into the atmosphere such as carbon dioxide, methane, nitrous oxide, carbon monoxide, nitrogen oxides, and fine and coarse particulate matter which can impact the air quality. However, there is no study being done on the impact of forest fire to the air quality in Malaysia.

Malaysia is a tropical country with sufficient rainfall throughout the year. Rainfall or precipitation is one of the natural hydrological events which can increase the relative humidity on the land surface. However, the likelihood of rainfall to decrease the fire alerts is not known. On the other hand, extensive forest fire may affect the original hydrological cycle of the area such as destruction of river basin which altered the rainfall pattern in Malaysia.

1.2 Objectives

The main objective of the study is to determine the relationships between forest fire and agricultural plantation area from year 2002 to 2017 in Malaysia. The specific objectives are:

- To investigate the relationship between forest fire with the forested area from year 2007 to 2017 in Peninsular Malaysia,
- To investigate the relationship between forest fire with the air pollution index from year 2007 to 2016 in Malaysia, and
- To investigate the relationship between forest fire with the rainfall from year 2008 to 2014 in Malaysia.

2 LITERATURE REVIEW

2.1 Forest Fire Background

Forest fire usually occurred in places where hot summer weather dries out dense vegetation especially during the droughts season (Anita, 2006). According to Finney (2005), area with likelihood of fire burning is dependent on ignitions occurring off-site and the topography, fuels, weather, and relative fire direction which enable each fire to reach that location. Hence, there are high probability for forest fire to happen in Malaysia. Forest fires generally started naturally through lightning or spontaneous combustion of dry fuel such as sawdust and leaves. Other than that, forest fires are started by human activities such as smoking, recreation, equipment, and miscellaneous where human-caused fires constitute higher percentage of forest fires. According to Collins et al. (2016) study on 7,430 houses from year 1951 to 2015, over 85% of them were destroyed by wildfires where the one third of the fire started by powerlines, 25% from undetermined cause, 22% from deliberately ignited fires and 11% by lightning strikes as shown in Table 2.1. Human-caused fires are usually detected early in their duration, and therefore they are usually contained easily whereas natural fires can burn for hours before being detected by firefighting authorities. Obviously, it will be much easier to extinguish a fire that is detected in its early stages than a fire that has been burning for period of time but has only just been detected because of lack of communication.

Table 2.1: The number of wildfires that destroyed houses and the number of houses destroyed from 1951 to 2015 by ignition cause (Collin et al., 2016)

Ignition cause	**No. of wildfires that destroyed houses**	**No. of houses destroyed**
Deliberate	61	1663
Powerlines	30	2513
Lightning	29	843
Other known	35	580
Undetermined	95	1831
Total	**250**	**7430**

2.2 Fire History in Malaysia

Malaysia experienced one of the most severe forest fire episodes in history within year 1997 and 1998 as a result of extended dry seasons following the El Niño phenomenon. Incidences of forest fires were reported in almost all states, which was unprecedented. Forest fires consumed the most in Sabah, accounting for 73% of the total land area (Isa, 2001).

According to the fire-monitoring platform Global Forest Watch Fires (as cited in Mei, 2017), Sarawak is the state in Malaysia with the highest number of forest and land fires with a record of 860 Modis (Moderate Resolution Imaging Spectroradiometer) fire alerts from beginning of the year 2017 until August of the year. GFW Fires reported that the number of fire alerts in Malaysia has decreased by 70% in year 2017 compared with previous year (Mei, 2017).

Table 2.2 and Table 2.3 show the area affected by forest fires in 1998 by State and forest type respectively in Malaysia and the probable causes of the forest fires. The results showed that the most probable causes for forest fires is land clearing by local farmers and unknown causes.

Table 2.2: Area affected by Forest Fires in 1998 by State (Isa, 2001)

Location	Area (Hectares)	Probable Causes
Kelantan	605	Snapped electrical transmission lines and land cleaning by farmers
Selangor	255	Land clearing by farmers and disposed cigarettes
Perak	100	Hunting and other unknown causes
Johor	56	Campers and other unknown causes
Kedah	41	Land clearing by farmers
Terengganu	1,315	Land clearing by farmers and other unknown causes
Pahang	427	Land clearing by indigenous people and local farmers nearby, and other unknown causes
Sabah	47,500	Land clearing by local farmers
Sarawak	14,200	Land clearing by local farmers
Total	64,499	

Table 2.3: Area of Forest Type burned in 1998 (Isa, 2001)

Forest Type	Area (Hectares)	Probable Causes
Peat Forest	63,331	Land clearing by farmers and indigenous people, hunting and other unknown causes
Secondary Forest	432	Land clearing by farmers and other unknown causes
Degraded Heat Forest	310	Land clearing by farmers
Health Forest	250	Unidentified
Logged-over forest	120	Unidentified
Forest plantation	26	Snapped electrical transmission lines, cigarettes and other unknown causes
Montane forest	15	Camper
Coastal swap forest	15	Cleaning by fishing villagers
Total	64,499	

2.3 Climate Changes

In the 9th and 10th months of year 2015, the most intense biomass burning episodes had occurred in Equatorial Asia over the past two decades as a result of the supremely dry weather corresponding with the occurrence of strong El Ninõ conditions (Mead et al., 2018). Fires not only affect carbon sequestration by forests, but release greenhouse gases which create positive feedback that potentially impact the climate (Amiro et al., 2001). According to "Union of Concerned Scientists" (2017), global warming and El Niño events changes the moisture and precipitation rate with wetter wet land areas and drier dry land areas. Thus, increasing the risk of forest fire when the forest is struck by lightning or human fraud. According to Calder et al (as cited in Wine & Cadol, 2016), conditions conducive to large wildfires will continue after the examination of historical periods of climate warming as Earth's climate warms further. Beside the frequency and size of forest fire, climate change will set up stage for more disease, insects, and invasive species to move in (Struzik, 2017).

2.3.1 Global Warming

According to CBC Radio (2018), research by Dr. Kurz in British Columbia showed that carbon emission from forest fire is two to three times of the carbon emission from fossil fuel burning. Other than that, the post-fire effects can cause an additional loss of carbon via decomposition which cause changes to the condition of forest sink (Amiro et al., 2001). Research done by Kurz and Apps (1994) showed that increasing area burned by a factor of three decreases the total forest carbon budget by only 6% over 100 years. However, it is clear that carbon budget can be easily driven down after several years with greater amounts of fire, even causing a situation where the forest is a net carbon source.

2.3.2 El Ninõ phenomenon

El Ninõ occurred when the Ocean Nino index (ONI) rises above the 0.5 threshold for consecutive months which resulted in a prolonged warming of the Pacific Ocean sea surface temperature (Chu, n.d.). However, the effects of the impacts take place in very slow pace which will affect the agricultural productions especially oil palm in Malaysia and Indonesia as the main oil palm producing countries. Beside the El Ninõ, the Indian Ocean Dipole (IOD) also known as the Indian Ninõ also have great impact to Malaysia where the negative IOD can result in longer drought with decreased rainfall whereas positive IOD can increase the rainfall, result in prolonged wet season (Chu, n.d.). The combine effects of the El Ninõ and Indian Ninõ will further strengthened the impacts of the climates in Malaysia. In Malaysia, the occurrence of El Ninõ is usually forecasted to fall between June to August where eastern part of Peninsular Malaysia, Sabah, and Sarawak are more prominent to the impact of El Ninõ (Chu, n.d.) as shown in Figure 2.2. La Niña in contrary is the cooling phase of El Ninõ which will bring in more rainfall and reduce the global average temperatures (Lamansky, 2016). The timeline of El

Ninõ and La Niña events with its corresponding ONI index from year 1950 to 2015 are as shown in Figure 2.1.

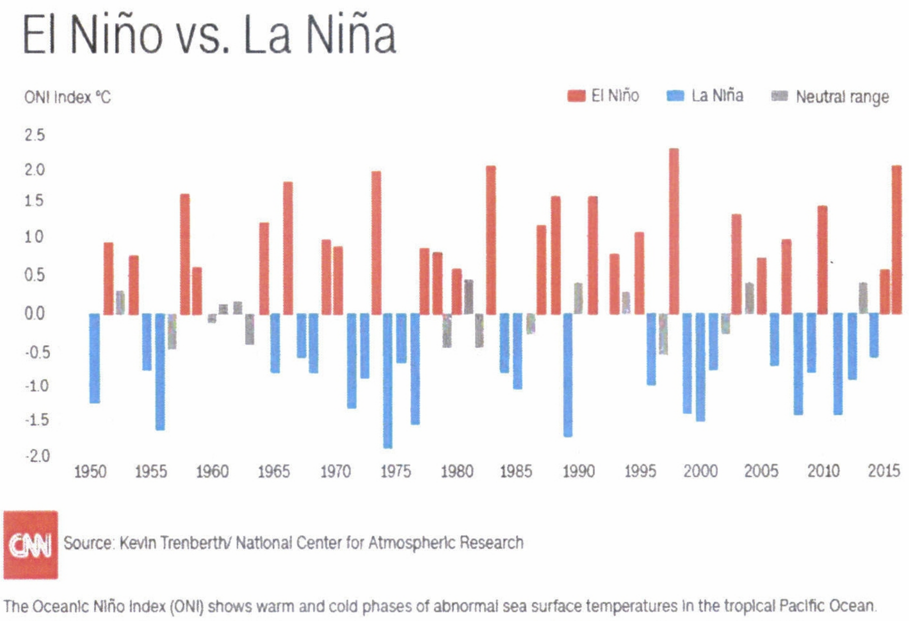

Figure 2.1: Timeline of El Ninõ events since year 1950 (Trenberth, 2016).

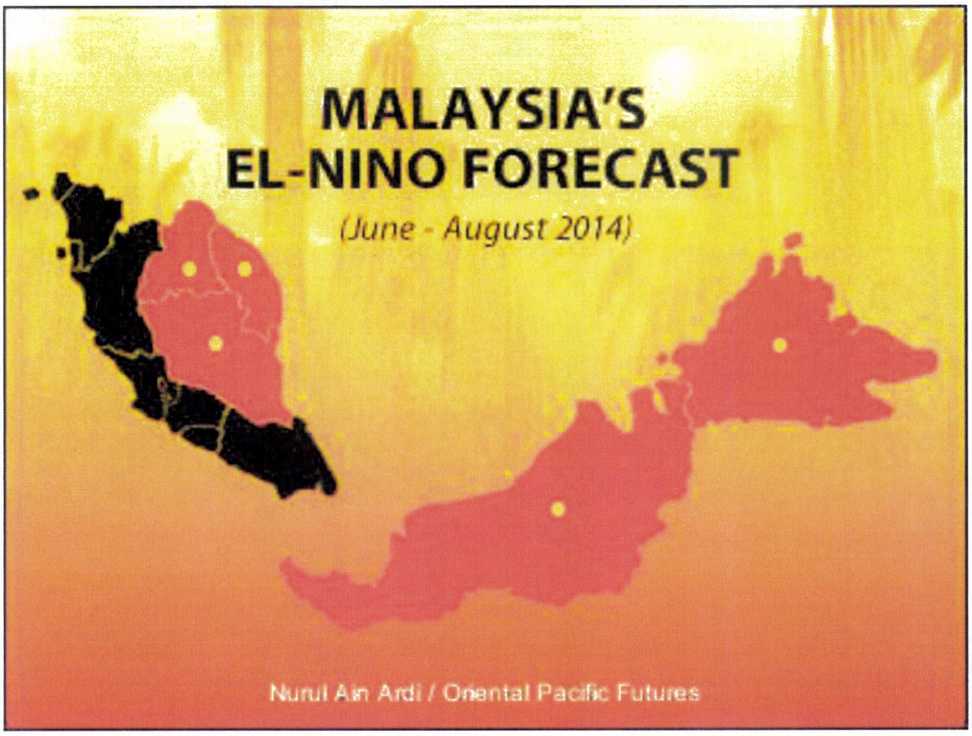

Figure 2.2: Impacts of El-Nino on Malaysia (sources: Chu, n.d.).

2.4 Law and Enforcement of Forest Fire

According to Page (2015), "we depend on governments to use laws and other tools to protect our health, the environment and the economy and we don't need them to act as an advocate for one interest (industry) over another (people)." He further stated that Environmental laws should ensure that the projects designed by companies cause the least amount of environmental damage and make the best use of the available resources while companies must pay for the costs of preventing or repairing damage to the environment, rather than downloading them to taxpayers as clean-up costs or healthcare expenses. Therefore, every companies are responsible to take care of the environment under the environmental laws and regulation as part of the price of doing business.

According to Section 29A in Environmental Quality Act 1974 (Appendix 1) on prohibition on open burning, no person shall allow or cause open burning on any premises. Any person who contravenes the prohibition shall be convicted and liable to a fine not exceeding RM500,000 or imprisonment for a term not exceeding 5 years or both. Open burning is defined as any fire, combustion or smouldering that occurs in the open air and which is not directed there through a chimney or stack (EQA 1974). According to Section 29AA, no person shall allow or cause fire, combustion or smouldering to occur in any area if the Director General notifies, by such means and in such manner as he thinks expedient that the air quality in the area has reached an unhealthy level; and that the fire, combustion or smouldering for the purpose of any activity other than those specified in the notification would be hazardous to the environment.

Natural Resources and Environment Ordinance (NREO) is laws of Sarawak aim to consolidate and amend the law relating to conservation of natural resources and the management of the environment. According to NREO, any fire which is ignited or lighted in the open air onto any refuse, wastes, vegetation or other combustible materials whatsoever is regards as environmental crime while activities such as burning of materials in any incinerator, any burning of materials in connection with the performance of religious rites and ceremonies, and funerals; or any fire used in connection with preparation or cooking of food are excluded. Under section 5-f(vii) in NREO, the Board of NREO function to provide rules, guidelines and directions for the protection and enhancement of the environment in clearance and burning of vegetation and the Board have power to prohibit, restrict or control of the burning of vegetation under section 10-2b in the ordinance. The powers and duties on the compliance of this Ordinance are imposed upon the Environmental Authority which refer to any local authority, statutory body or department of the State or Federal Government or such other authority, officer or person duly directed by the Board under the Ordinance. Any person who fail to comply without reasonable cause shall be guilty of an offence with imprisonment for one year and a fine of ten thousand ringgits for first offence and imprisonment for two years and a fine of twenty thousand ringgits for second or subsequent offence. A court in addition to any penalty imposed shall also make an order requiring the person guilty of the offence, to comply with the order of the Controller within such times as the court may specify. Under Section 30 in NREO, any person who, without the written permission of the Controller carries out or causes or permits to be carried out open burning of refuse or other combustible materials on any land as well as any person who burns vegetation in any area which is not Native Customary Land or Native Area Land, shall be guilty of an offence with a fine of twenty thousand ringgit and imprisonment for three years and a fine of thirty thousand ringgit and imprisonment for three years respectively.

Forest fires are usually reported through the public or through the regular monitoring by related agencies such as the Department of Environment, the Forestry Department, the Police

Air Wing, and the Fire & Rescue Department (Isa, 2001). Rapport and responsibilities of all relevance agencies is important for the preventive and control measures of forest fires.

List of relevance government agencies and their role on the forest fire are as shown in Table 2.4. A total ban on the burning of agriculture waste imposed on the plantation companies by Sarawak Natural Resources and Environment Board and monitored by Sarawak Fire and Rescue Department in northern Sarawak was effective in stopping wildfires and haze issues in the northern Sarawak (Then, 2018). Forest fires is occurring in Malaysia from time to time but not all fires are reported due to poor detection or ignorance by the public. Even if the fires are reported, most of the offender are not convicted for their doing due to lack of evidences. Environmental crime does not fit in to the customary kind of criminal offences due to the nature of its crime and these types of crimes usually have relatively low risks of detection but can cause significant damage to the environment (Mustafa, 2015).

Table 2.4: Responsible agencies for forest fire in Malaysia (Isa, 2001)

Government Agencies	Responsibilities
National Security Division	Serves as Secretariat to the National Disaster Committee and coordinates forest fire fighting efforts and training for all relevant agencies
Royal Malaysian Police	Reports forest fires through routine air surveillance; establishes control posts at the site of forest fires; ensures public order and safety of property, and carries out investigation, if necessary.
Fire and Rescue Service Department	Carries out fire suppression and control; ensures safety of all personnel and the public; provides aerial fire suppression services when required; carries out information gathering and post-fire reporting, and provides training to other agencies and voluntary bodies.
Armed Forces	Provide personnel, transportation and machinery when needed; offer medical, engineering, and transportation services; assist in search and rescue mission, and give air ambulance service for emergency transportation.
Forestry Department	Provides personnel in ground fire suppression; assists in search and rescue operation; gives technical assistance relating to conditions of the forest, topography, forest, ecotypes, sources of water, etc.; helps in the assessment and post-fire evaluation; offers equipment and transportation, and secures assistance from logging companies, if needed.
Public Works Department	Provides machinery, equipment and engineering expertise; offers temporary accommodation for firefighting personnel as well as for victims of the fire, and coordinates all engineering and civil works.
Department of Environment	Serves as the first agency to receive report on fire incidence through its air surveillance unit and through public information; carries out enforcement of low against open burning; monitors air quality index; provides information to the public as well as directly to the relevant agencies, and serves as coordinating agency for early detection of forest fire and haze occurrences.
Meteorological Services Department	Provides meteorological information to the public as well as relevant agencies for early warning of potential of forest fires, and assists in weather forecast during large-scale forest fires.
Malaysian Remote Sensing Centre	Receives and evaluates real-time information on incidence of forest fires through satellite imagery, and cooperates with international agencies through exchange of satellite information in assisting early detection of forest fires in Malaysia as well as around the region.
Wildlife and National Parks Department	Provides information on endangered wildlife affected by the forest fires and assists in the translocation of affected species, their safety, and rehabilitation of habitat, if necessary
Social and Welfare Department	Establishes temporary shelter for affected fire victims; provides immediate assistance in terms of food, shelter, medical and subsistence allowance for affected fire victims; and facilitates registration of fire victims for government aids.
St. John Ambulance Malaysia and Malaysian Red Crescent Society	Assists the Welfare Department in the administration of the shelter, aids the Health Department in providing emergency medical care, and organizes volunteers to provide first-aid to fire victims and as fire fighters.

2.5 Environmental Impacts by Forest Fire

2.5.1 Impacts to Air Quality

Haze is another environmental issue arise as a result of forest fire. The haze can cause transboundary pollution where the polluted air originated in one country can be transported across hundreds and even thousands of kilometers to another country can destroy their environment. Example of transboundary pollution as a result of forest fires can be seen in Malaysia as a resulted of forest fire in Indonesia. According to studies done by Mead et al. (2018), Malaysia experiences recurring haze events annually especially during the dry season when south-easterly winds transported the emissions from forest and agricultural fires in Malaysia and Indonesian Sumatra to the densely populated urban areas such as Kuala Lumpur and the surrounding of Klang Valley area. Mead et al. (2018) also found out that over 60% of the population living in the Greater Klang Valley was systematically exposed to unhealthy air quality conditions associated with the increased pollutant concentrations from during September and October 2015. The air pollution can health problem by exacerbate lung diseases and causing breathing difficulties in affected population.

Haze or air pollution has raised concerns around the world and Malaysia established Malaysian Air Quality Guidelines, the Air Pollution Index, and the Haze Action Plan in order to prevent air pollutions and improve the air quality of the country (Afroz & Ibrahim, 2003). In 10th June 2002, Malaysia and other Southeast Asian Nations signed the ASEAN Agreement on Transboundary Haze Pollution in order to reduce haze pollution in Southeast Asia which were ratified in September 2014. This agreement aims to prevent and monitor transboundary haze pollution as a result of land or forest fires which should be mitigated, through concerted national efforts and intensified regional and international co-operation (ASEAN Agreement on Transboundary Haze Pollution, 2002).

2.5.2 Impacts to Water Quality

Fire has been observed to impact many aspects of the streamflow regime, including peak flow, base flow, and water. Streamflow is defined as the discharge or the volume of water that moves over a designated point over a fixed period of time and it is an important determinant of water quality and aquatic habitat conditions. Research done by Bart (2016) showed that post fire will increase the annual streamflow by 134% (within 82% to 200%) at a regional scale during the first postfire year assuming 100% area burned and average annual wetness conditions. The increase in post fire streamflow is due to the reduced soil infiltration capacity and reduced transpiration. According to the study carried by Wine and Cadol (2016), soil water repellency increased as the live plant canopy cover and leaf litter were burned by wildfire whereby the burned leaf litter layer promotes surface sealing, and reduces infiltration. Hence, the hydrological dynamic is altered and produce high chances flash flooding.

Bart (2016) also found out that annual wetness conditions will affect the annual streamflow response to fire where the postfire response is low during dry years and high during wet years. The post fire response on increase streamflow will be reduced after the vegetation is recovered in subsequent years while large wildfire can enhance annual river flow for at least 5 years (Hallema et al., 2018). The complete recovery of soil-hydraulic properties such as the headwater catchment and infiltration mechanism in the burned area will take at least 3 years (Ebel et al., 2016). The recovery process needs to be constantly monitored as the rapid vegetation growth can produces massive amounts of fuels susceptible to fire (Hallema et al., 2018). However, researches carried out in New Mexico and Colorado showed that the post fire increased streamflow can be maintained for numerous years (Hallema et al., 2018).

2.5.3 Impacts to Biodiversity

According to Gleason (as cited in Romeo, 2018), most wildlife will survive in wildfires as they can sense the threat of a fire before humans where mammals will retreat to other areas, birds can fly away whereas the amphibians and reptiles will hide in wet area or under logs and rocks. Yellowstone fires in 1988 reported that only around 350 elk died from the estimated population of 50,000 (Romeo, 2018). After the wildfire recedes, the species diversity and population in the burned area will not be the same as before. Foraging mammals such as mouse deer, will take immediate advantage of the newly created habitat which provide them abundant food resources from the massive seed bank of the dead trees following fire (Nappi et al., 2004). One of the most striking examples is the Black-backed Woodpecker (*Picoides arcticus*), one of the species in North America which is found to be highly abundant during the first years following fire due to the large amount of wood-boring (*Cerambycidae* and *Buprestidae*) and bark (*Scolytidae*) beetles on standing dead trees (Nappi et al., 2004).

Birds are important species in the ecology of forest where their role include pollinators for plants, predators of parasites and some of them are keystone species in particular ecosystem. Malaysia provide winter homes for most birds around the world and the migratory birds which are stopping at Malaysia is decreasing especially at the Perak coast with a decline up to 86% (Krishnamoorthy, 2007). According to ornithologist Wells (as cited in Struzik, 2017), birds are the hidden part of rich biodiversity and the migration pattern of the birds rely very much on the forest for their survival. Wildfires force birds to flee while some of the weaker birds such as the nestlings will be killed in the fire. Even if the birds escaped the fire, they would also affect by the smoke produced by forest fires and study on captive birds by veterinarians and poultry scientists found that smoke can cause damage to lung tissue and the animals become susceptible to potentially lethal respiratory infections (McGlashen, 2017). According to Doucette (as cited in Correia, 2017), the cases of birds flying into windows and getting injured is increasing as the wildfires affected their migration patterns, pushing them to the coast. Besides that, the number of tagged birds is decreased from around 1,800 to 1,000 at the service's tracking station in the Chilcotin region which was hit heavily by wildfires (Easton as cited in Correia, 2017).

2.6 Ecological Benefits of Forest Fire

Forest fire can provide ecological benefits within an ecological frame but at the same time it is completely incompatible with human values. According to Finney (2005), studies done by Keeley et al. on crown fires in chaparral shrub lands and Agee's study in coastal and subalpine forests are normal of those fire regimes while the fire provide periodic renewal for the plant communities. Fire cleans the forest floor or detritus and eliminates low-growing underbrush which allow sunlight to come in and sustains the soil at the same time enable the trees to grow stronger and healthier as the competition for nutrients and spaces is reduced. ("Cal Fire", n.d.). However, human often do not perceive crown fires near cities or in municipal watersheds as they may ruin or damage human-managed systems. Despite the conflicts or mutual responses between ecology and human values to a given fire, the important concern for risk assessment is that wildland fires are certain to happen.

Large damaging wildfires that spread out of control can be avoided by clearing brush from the forest floor with low intensity flames at the same time the burned weak trees will return the nutrient to the forest. According to "Cal Fire" (n.d.), low intensity fire only causes little damage to trees as it remains on the ground burning grasses and vegetation. Research done by Neary et al. (1999) indicated that low-impact burning can facilitate growth of herbaceous flora, increasing plant available nutrients, thinning of over-crowded forests, and hence enabled healthy systems whereas severe fires can cause changes in successional rates, alter above and belowground species composition, produce rapid or decreased mineralization rates, alter C : N ratios, produce volatilization of nutrients and ash entrainment in smoke columns, and result in subsequent nutrient losses through accelerated erosion, leaching or denitrification.

A little of fire disturbance is beneficial for many wildlife species in the forest and even the intense one could leave behind a mosaic of habitat patches due to uneven burning (McGlashen, 2017). Forest provide the wildlife and birds with habitat and shelter but some part of the forest is not suitable due to the absent of food and unfavourable environment such as occurrence of diseases and pest insects. Fire clears wildlands intact with heavy bush and provide spaces for vegetation, herbs and food for the many wildlife species. According to "Cal Fire" (n.d.), the water supply is increased when fire removes a thick stand of water hungry shrubs that dominated all the water supply in certain area. As water stream are fuller, more species of plants or animals will grow or come and settle down around the area. Compare with forest fire, more trees die each year from disease and insect infestation while the diseases and insects that prey on trees will be annihilated by fire, keeping the forest healthy ("Cal Fire", n.d.). Some flora need heat to open and release seeds for regeneration as well as for seed germination in Chaparral plants like manzanita, chamise and scrub oak and these flora species will extinct as no new generation is developed.

Therefore, forest fire played its role to keep the forest healthy and sustain the timber resources and biodiversity within. As for the policies makers and environmental committee, broad-scale effects of natural disturbance are required to take into consideration when developing ecosystem management policies and prioritising objectives when planning for multiple resources use (Fall et al., 2004).

2.7 Forests in Malaysia

Malaysia is one of the countries with high percentage of forested land among developing countries. Due to its significant topographic variations, Malaysia has distinct topographic variations and various type of rainforests in nature which include lowland and highland rainforests, peat swamp forests and mangrove forests. Forest diversity in Malaysia serve as home of countless unique mammal and bird species such as Malayan Tigers, Proboscis Monkeys, Orang Utans, Hornbills and Malayan Tapirs. Global demand and high profits of oil palm had threatened more and more lowland tropical forests being converted into oil palm plantation (Abram et al., 2014).

2.8 Agriculture in Malaysia

2.8.1 Oil Palm Plantation

Oil palm is contributing the world with 33% of vegetable oil and 45% of edible oil even though it is planted on 5% of the total world vegetable oil acreage (Singh, 2013). Oil palm plantation is the main agricultural activities in Malaysia established in the early years of 20^{th} century and become one of the largest palm oils producing countries with Indonesia and Thailand in Southeast Asia where these three countries dominated 90% of the world's total palm oil production (Carr, 2011; Chu, n.d.). *Elaeis guineensis* Jacq is the oil palm tree introduced into Malaysia from West Africa by the British in early 1870's as ornamental tree and commercialised to palm oil industry in 1917.

Statistic in year 2017 showed that Malaysia is the second largest exporter for palm oil which worth USD9.7 billion or 29% in the total palm oil export (Daniel, 2018). The climatic condition in Malaysia with annual rainfall of at least 2000 mm, mean maximum air temperatures of 29–33°C and mean minimum air temperatures of 22–24°C throughout the year, relative humidity above 85%, and bright sunshine averaging 5 h d^{-1} throughout the year provide favourable condition for oil palm plantation to generate high yield of palm oil products (Carr, 2011). Oil palm need three years to produce its first ripen fruits after the planting and the yields will rise for the next few years and then slowly decline due to interplant competition (Carr, 2011).

Mesocarp in the palm oil fruit is the main economic product while the other parts can be used for various applications. For example, extracted kernel oil can be processed into kernel cake as animal feeds, the sap can provide raw material for sugar and alcoholic beverages, the palms can be used as source of building materials, and some of the tissues are important sources of fibre (Carr, 2011). Study done by Singh et al. (2013) on the genetic sequence of oil palm showed that oil palm contains oil biosynthesis genes and homologues of WRINKLED1 which can help to achieve sustainability for biofuels and edible oils.

Expansion of oil palm plantations particularly in Malaysia and Indonesia is concerned by many environmentalists and scientists on the impacts to tropical forests and biodiversity (Koh & Wilcove, 2009). During the years between 2005 and 2010, about 353,000 hectares of peat swamp forests were cleared largely for palm oil production in Malaysia as reported by Wetlands International (Tom, 2011). No doubt that fire is the most effective and cheapest way to clear huge forested area into agricultural land especially for palm oil plantation in Malaysia at the cost of environmental issues (Purnomo et al., 2018). Fire can cause surface sealing and reduce infiltration of soil which may affect the yield of oil palm due to competition for water where for every 100 mm increase in the soil water deficit can result in a yield loss of about 10% (Carr, 2011; Wine & Cadol, 2016). The use of fires for land preparation for palm oil can be reduced by improving the governance of palm oil value chains through fair value-added distribution, market transparency and green certification (Purnomo et al., 2018).

According to Koh and Wilcove (2009), Malaysian Palm Oil Council (MPOC) claimed that oil palm expansion in Malaysia is mainly converted from former rubber, cocoa and coconut cultivation since 1990 where the protected forests and forest reserves is banned for oil palm plantations. Hence, the expansion of oil palm is claimed to be no threat to biodiversity.

2.8.2 Rubber Plantation

Rubber industry which started in 1970s is another main contributor to the economic growth in Malaysia even though the export of natural rubber has been inconsistent nowadays (Hassan et al., 2013). Malaysia is an ideal location for large scale rubber plantation due to the equatorial climate of the land and the sparsely populated condition (Goldthorpe, 2015). Rubber plantation is one of the firm industrial foundation for rapid expansion of the manufacturing sector after independence in Malaysia. The production of natural rubber as raw material enabled the development of forward linkage activities through technological discoveries and establishment of downstream rubber goods industries which offered alternative employment for estate labour (Goldthorpe, 2015). The rubber-based companies in Malaysia namely Top Glove Corporation Berhad, Supermx Corporation Berhad, Kossan Rubber Industries Berhad, and Hartalega Holding Berhad were accounted to produce an annual output of around 120 billion units of gloves which were estimated to be consumed by 57% of the world in 2016 ("Asia Equity Research", 2017).

3 MATERIALS AND METHODS

3.1 Data Collection

The data are collected from secondary data sources from government agencies and relevant institute or organisation as shown in Table 3.1. The government agencies included the Department of Statistics Malaysia, Forestry Department Peninsular Malaysia, Department of Environment, and NREB while other organisation included Global Forest Watch Fire, MPOB, and OR Technologies Malaysia.

Table 3.1: Data collection and the sources

Data	**Official Data**
Annual MODIS Fires alerts by States Monthly MODIS Fire alerts by States Annual heatmaps by States Type of forest affected by fire	Global Forest Watch Fires
Oil palm plantation area Oil palm production Rubber plantation area Rubber production	Department of Statistics Malaysia
Oil palm plantation area by States	MPOB
Forested area Peninsular Malaysia Forest production in Peninsular Malaysia	Forestry Department Peninsular Malaysia
Monthly Air Pollution index by States	Department of Environment
Monthly rainfall in Malaysia Annual rainfall in Malaysia	OR Technologies Malaysia (NAHRIM)
Open burning convictions in Sarawak Open burning approval in Sarawak Open burning compounds for agriculture in Sarawak	NREB

3.1.1 MODIS Fires Alerts

Global Forest Watch Fires (GFW Fires) is an online platform which provide open data to monitor forest and land fires and empower people to better combat harmful fires before they burn out of control via combination of real-time satellite data from NASA's Active Fires system, high resolution satellite imagery, detailed maps of land cover and concessions for key commodities such as palm oil and wood pulp, weather conditions and air quality data to track fire activity and related impacts in the South East Asia region.

The yearly time series data on MODIS fires alerts in Malaysia was collected from year 2002 to 2018 and the annual heat maps on MODIS fires in Malaysia at district level from year 2007 to 2018 was extracted from GFW fire reports (Appendix 2 on page 75). The monthly time series data on MODIS fires alerts in Malaysia and Sarawak was collected from year 2007 to 2018. The monthly time series data on MODIS fires alerts in Malaysia by States was collected from year 2013 to 2015.

The monthly time series data on MODIS fire alerts from WDPA protected areas, intact forest, RSPO palm oil concessions, peatland, plantation areas and wood fiber areas in Malaysia and Sarawak was collected from year 2013 to 2018.

3.1.2 Agriculture Activities in Malaysia

3.1.2.1 Oil Palm Plantation

The yearly time series data on total planted oil palm was collected from DOSM in association with MPOB from year 2000 to 2016. The collected data included total planted area (hectare), total harvested area (hectare), total production of fresh fruit brunches (tonne) and yield per hectare (tonne). The data includes estates and independent smallholdings excluding FELDA, FELCRA, RISDA and State Agency.

The time series data on the area of matured oil palm planted area and immature oil palm planted area in Malaysia by States from year 2013 to 2018 was collected from MPOB. The data of the oil palm planted area is inclusive of private estates, state schemes or government agencies, FELCRA, RISDA, independent smallholders, and FELDA.

3.1.2.2 Rubber Plantation

The yearly time series data on total planted oil palm was retrieved from DOSM in association with Rubber Board Malaysia in Malaysia from year 2000 to 2016. The collected data included total planted area (hectare), total tapped area (hectare), total production of natural rubber (tonne) and yield per hectare (tonne). The collected data was solely base on the estates only.

3.1.3 Forest Land and Production

Forested land and production were analysed base on Peninsular Malaysia only due to lack of data on Sabah and Sarawak. The time series data on the land area, forested land area, permanent reserved forest area and forest production of every States in Peninsular Malaysia is obtained from the annual reports of Forestry Department Peninsular Malaysia from year 2007 to 2017. The permanent reserved forest area was divided into 4 forest type namely inland forest, peat swamp forest, mangrove forest, and forest plantation. Forest products included sawn timber, plywood, veneer and moulding measured in cubic metre.

3.1.4 Air Pollution Index (API)

The monthly time series data on air pollution index (API) were collected from DOE from year 2000 to 2016 in Malaysia by States and Sarawak by division. For every States in Malaysia, the average API index were obtained by dividing the API index by the number of API stations in respective states.

3.1.5 Rainfall in Malaysia

The monthly time series data on rainfall in millimeters were collected from OR Technologies Malaysia from year 2008 to 2014. The collected data include 27 rainfall stations from Peninsular Malaysia; 8 stations in Sarawak; and 5 stations in Sabah (Appendix 5). The average annual and monthly rainfall data were obtained by dividing the collected data with respective rainfall stations.

3.2 Data Analysis

Microsoft Excel are used in the study to perform the regression analysis and boxplot, and charts. Boxplot are used to find out the shape of distributions, central value and the variability of the data base on 5 quartiles. Regression analysis can determine the correlation of forest fire with the studied variables. Regression analysis was conducted on annual MODIS fire a year after on the oil palm plantation area and rubber plantation area in Malaysia; inland forest, peat swamp forest, mangrove forest and forest plantation in Peninsular Malaysia; API in Malaysia; Rainfall in Malaysia; fire compounds and permitted open burning by NREB in Sarawak.

4 RESULTS AND DISCUSSION

4.1 MODIS Fire Alerts

MODIS stands for Moderate Resolution Imaging Spectroradiometer, monitored by instruments on board NASA's Earth Observing System (EOS) Terra (EOS AM) and Aqua (EOS PM) satellites. The orbit of the Terra satellite goes from north to south across the equator in the morning and Aqua passes south to north over the equator in the afternoon resulting in global coverage every 1 to 2 days (NASA, 2018). From time to time, the data on MODIS fire alerts will be constantly being calibrated in Global Forest Watch. Therefore, the MODIS fire alerts retrieved in the future may increase slightly from the data collected in the project.

VIIRS fires is another measurement on active fire data which complement with MODIS fire but with the improved spatial resolution of 375m data compared to MODIS fire (1km data). The smaller scaled spatial resolution allowed VIIRS to detect fires over relatively small areas. However, the VIIRS data are only available from year 2016 to the present in Malaysia.

A total of 109,445 MODIS fire and VIIRS fire alerts were recorded in GWF Fires in Malaysia from year 2007 to 2018 as shown in Figure 4.1. The States included Melaka, Johor, Kedah, Kelantan, Kuala Lumpur, Labuan, Pahang, Perak, Perlis, Putrajaya, Sabah, Sarawak, Selangor, Terengganu, Negeri Sembilan, and Pulau Pinang with the top 10 States with the most fire alerts as shown in right table of Figure 4.1. Sarawak is the States with the most fire alerts with 41,571 fires being detected followed by Pahang (20,272 fire alerts) and Sabah (19,112 fire alerts). Sarawak is the largest States in Malaysia with total size of 12.4451 million hectares which accounted for the high number fire alerts being reported.

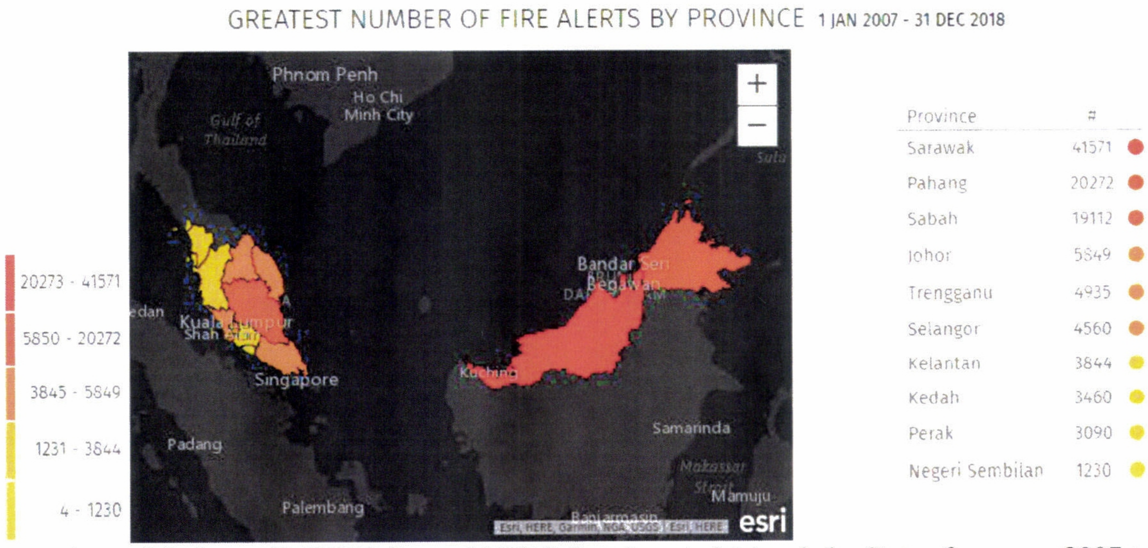

Figure 4.1: Sum of MODIS fire and VIIRS fire alerts in Malaysia by States from year 2007 to 2018 (sources: GWF Fires).

The district with the highest number of fire alerts is Pekan (9694 fire alerts) from Pahang from year 2007 to 2018 as shown in Figure 4.2. From the map, there were more fire alerts reported in eastern part of Peninsular Malaysia compared with the western part. One of the factors is because of the impacts El Ninõ events which have prominent effects on the eastern side of Peninsular Malaysia, Sabah and Sarawak (refer to Figure 2.2 on page 10).

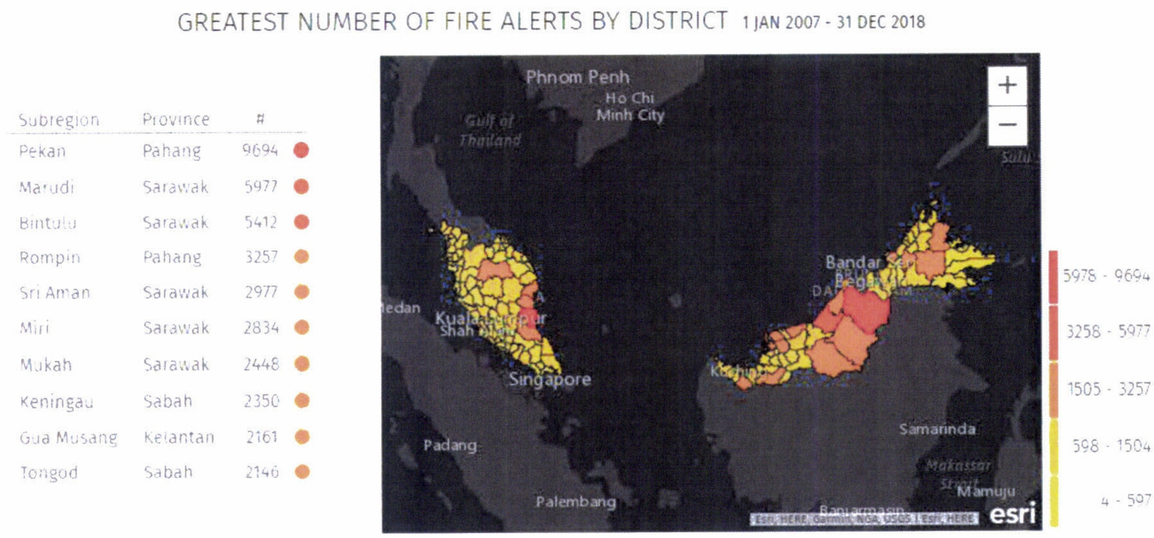

Figure 4.2: Sum of MODIS fire and VIIRS fire alerts in Malaysia by Districts from year 2007 to 2018 (sources: GWF Fires).

4.1.1 Annual Fire Alerts in Malaysia

The total annual MODIS fires in Malaysia from year 2007 to 2018 have standard deviation of 1933.96 and standard error mean of 558.29. Year 2009 had the highest total number of fire alerts with 8,852 MODIS fires recorded as shown in Figure 4.3 while the lowest fire alerts were recorded with 2,108 MODIS fire in year 2017 as shown in Figure 4.3. Year 2009 and year 2014 had an extreme outlier recorded at 3,610 fire alerts and 2,657 fire alerts respectively. There was drastic increase in the total number of MODIS fire between year 2008 to 2009 (100.68% increment) and year 2013 to 2014 (85.68% increment). One of the potential factors is the occurrence of El Ninõ event during the years (refer El Ninõ timelines in Figure 2.1 on page 10). The total number of MODIS fire were fluctuated over the 12 years with significant increase between year 2008 (4,422 MODIS fire) to 2009 (8,852 MODIS fire) and 2013 (4,575 MODIS fire) to 2014 (8,495 MODIS fire). Overall, the trend of the total number of MODIS fire were in a declining stage over the 12 years.

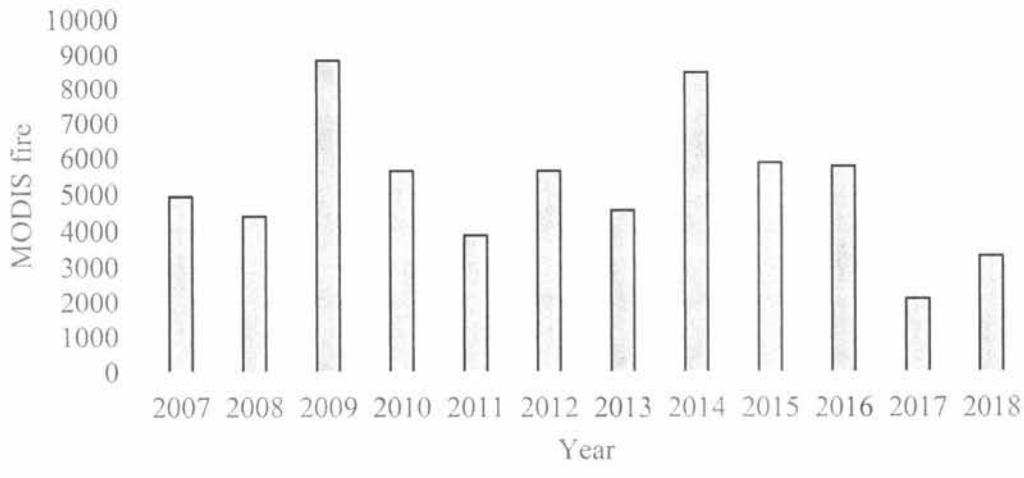

Figure 4.3: Total annual MODIS fires in Malaysia from 2007 to 2018.

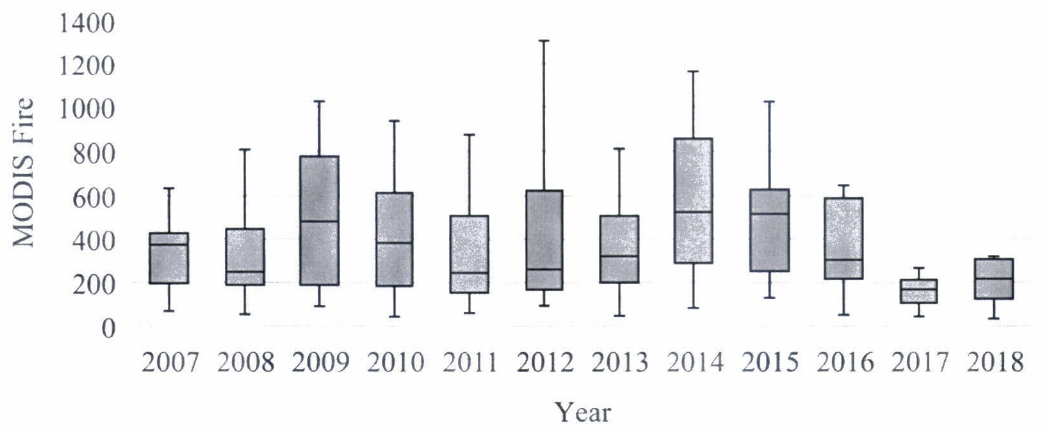

Figure 4.4: Annual MODIS fire in Malaysia from year 2007 to 2018.

Sarawak had the highest number of annual MODIS fire with 6,034 alerts in year 2009 while Peninsular Malaysia had the highest number of annual MODIS fire with 5,735 alerts in year 2014 as shown in Figure 4.5. At the same time, Sarawak had an extreme outlier recorded at 3,033 MODIS fire in year 2009 in August while Peninsular Malaysia had two outliers recorded at 961 and 2,297 MODIS fire in year 2014 in February and March respectively as shown in Figure 4.6. Sarawak, Sabah and Peninsular Malaysia had the lowest annual MODIS fire alerts in year 2017 with 875 alerts, 1,077 alerts and 155 alerts respectively. Sarawak had contributed 68% of the total MODIS fire in Malaysia during year 2009 while Peninsular Malaysia had contributed 67.51% of the total MODIS fire in Malaysia during year 2014. The result showed that Sarawak was impacted from the El Ninõ events in year 2009 whereas Peninsular Malaysia was impacted from El Ninõ event in year 2014 to 2016.

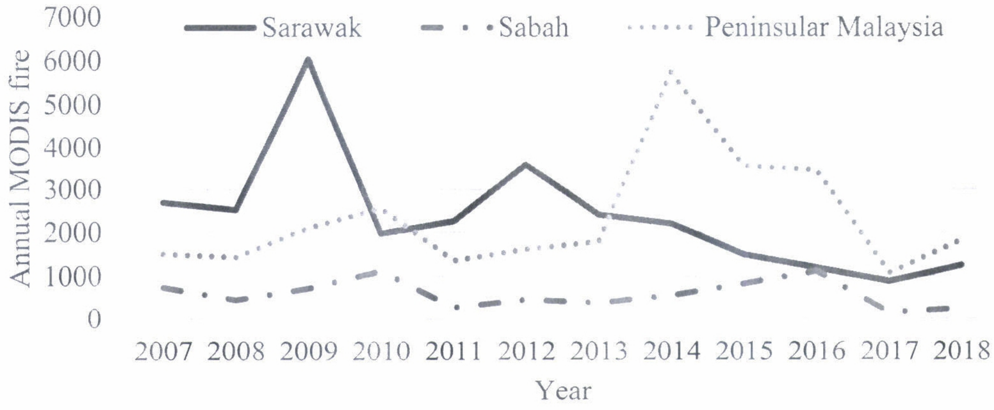

Figure 4.5: Annual MODIS Fires by Sarawak, Sabah and Peninsular Malaysia from year 2007 to 2018.

As shown in Figure 4.6, Sarawak had inconsistent fire alerts from year 2007 to 2009 and 2011 to 2012 with high range value but it was getting more consistent and lower fire risk from year after. On the other hand, Peninsular Malaysia had inconsistent fire risk within year 2014 to 2016 which Sabah had lowest MODIS fire alerts throughout the year with a more consistent rate. The standard deviation and standard error mean of the monthly MODIS Fires from year 2007 to 2018 is recorded at 319.292 and 26.608 respectively in Sarawak; 64.866 and 5.405 respectively in Sabah; and 237.126 and 19.76 respectively in Peninsular Malaysia as shown in Table 4.1.

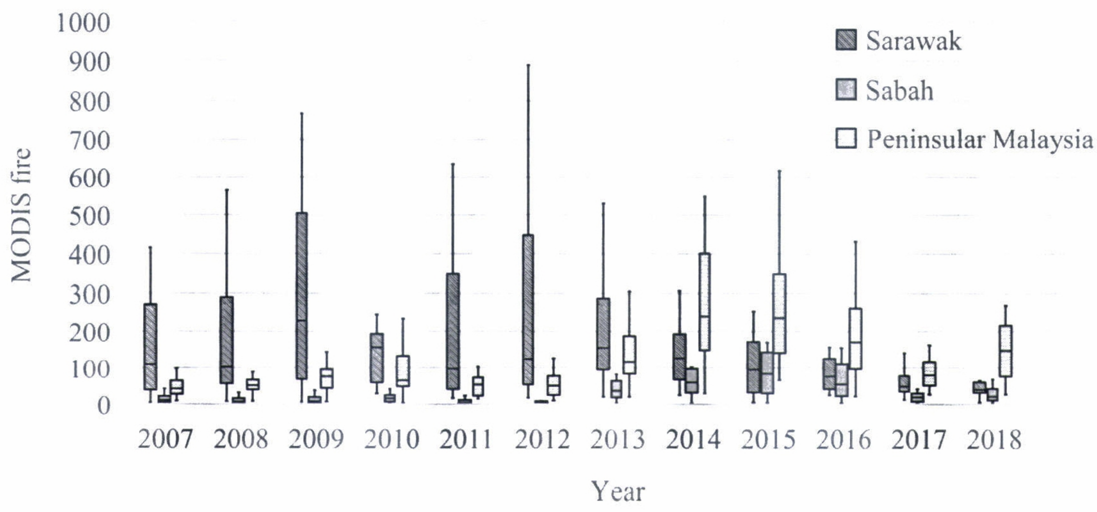

Figure 4.6: Annual MODIS Fires by Sarawak, Sabah and Peninsular Malaysia from year 2007 to 2018.

Table 4.1: Overall data analysis of monthly MODIS fire in Sarawak, Sabah and Peninsular Malaysia from year 2007 to 2018

	Sarawak	Sabah	Peninsular Malaysia
Minimum	4	0	3
First Quartile	40.75	5	43
median	105.5	16	77
Third Quartile	237.75	41	174.5
Maximum	3033	491	2297
Mean	197.8472	36.29861	146.7014
Range	3029	491	2294
Standard deviation	319.292	64.86577	237.1256
Standard error	26.60766	5.40548	19.76047

The annual heat maps on MODIS fires in Malaysia from year 2007 to 2018 (refer Appendix 2 in page 75) were obtained from GFW fires reports. The maps encompassed the fire alerts at district level in all states in Malaysia on the respective years.

4.1.2 Monthly fire alerts in Malaysia

Month August is the month with the highest count of average MODIS fires alerts (1,050.25 fire alerts) followed by March (659.33 fire alerts) in Malaysia from year 2007 to 2018 as shown in Figure 4.7. As approaching to the end of the year starting from November until January on the following year, the average MODIS fires alerts count is the lowest (less than

200 MODIS Fire alerts). One of the factors for the results is due to the changes of precipitation level in Malaysia. As a tropical country, Malaysia face two monsoon winds seasons namely Southwest Monsoon from April to September and the Northeast Monsoon from October to March where March and October form transitions between the two monsoons (Malaysian Meteorological Department, 2008). The monsoon functions as the primary delivery mechanism for fresh water which affects the environment, agriculture, society, hydro-power production, and geography of the country. The Northeast Monsoon also known as rainy season in Malaysia where it will bring in more rainfall starting from October and ending in March (Malaysian Meteorological Department, 2008). Northeast Monsoon originates from China and the north Pacific while the southwest monsoon originates from the deserts of Australia (Malaysian Meteorological Department, 2008). Months with high rainfall tend to have a smaller number of MODIS fire detected compared to the other months.

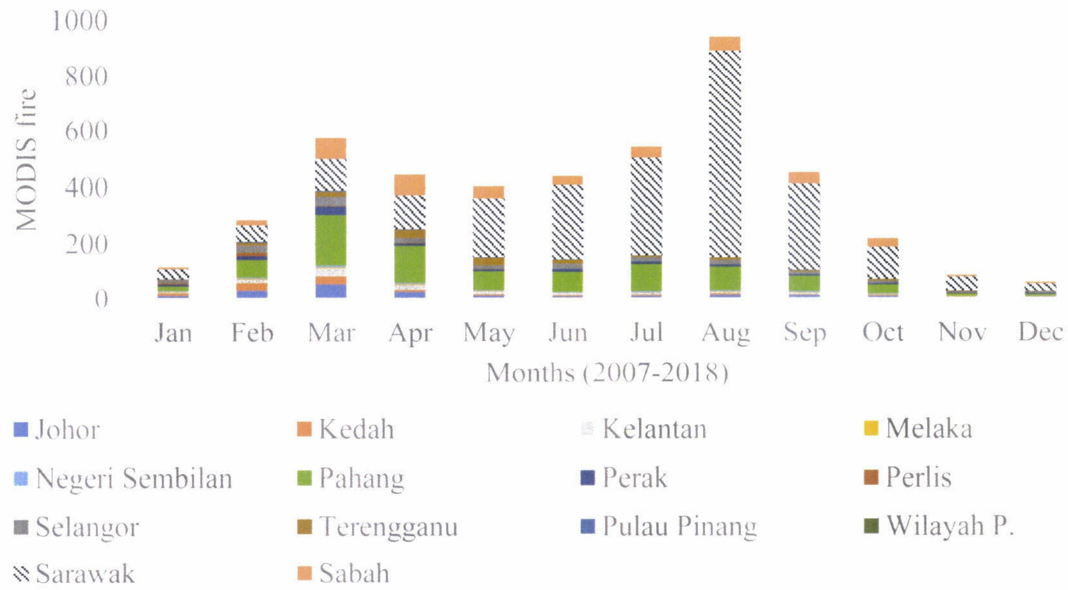

Figure 4.7: Average monthly MODIS fires in Malaysia by States from 2007 to 2018.

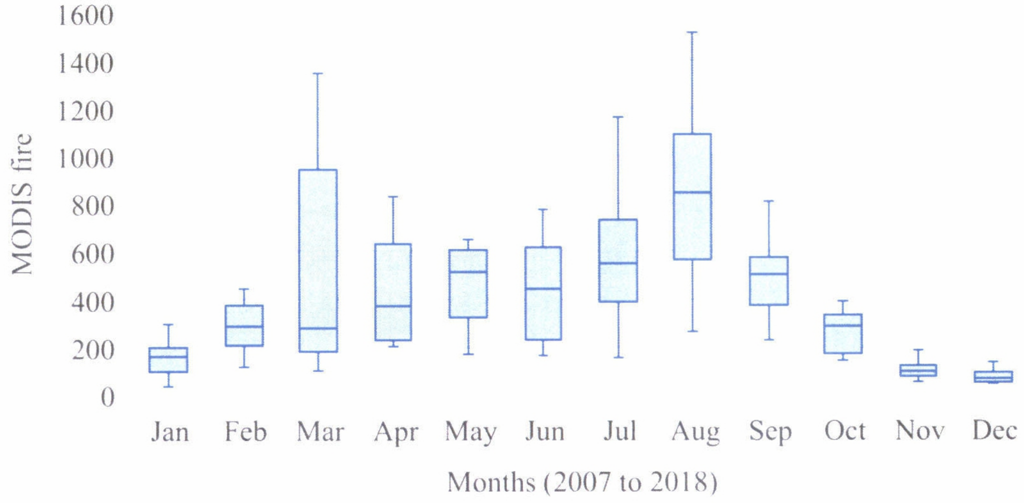

Figure 4.8: Boxplot on MODIS fires in Malaysia from year 2007 to 2018.

Table 4.2 indicated the data analysis on monthly MODIS fire in Malaysia which were sort from the by States with the most fire risk to the States with low fire risk from year 2007 to 2018. Sarawak had the most monthly MODIS fire alerts with average of 197.85 fires per month with standard deviation of 319.29 and standard error of 26.61 from year 2007 to 2018. May to September were the months with high MODIS fire alerts in Sarawak with more than 200 fire alerts per months. The highest count was in August with 738.08 MODIS fire in average over the 12 years. Pahang was the second States in Malaysia with the highest MODIS fire alerts recorded at average of 69.35 MODIS fire with standard deviation of 120.48 and standard error of 10.04 in similar years. The months with the most fire in Pahang were March and April with average of 181.17 MODIS fire and 135.25 MODIS fire respectively. Pahang was a big States located at the east coast of Peninsular Malaysia which was vulnerable to El Nino events. The third goes to Sabah average 36.3 MODIS fire alerts per months within the years. Wilayah Persekutuan was comprised of Kuala Lumpur, Labuan and Putrajaya and it had the least fire alerts throughout the year with 2 or less fire alerts each month. Boxplot had plotted on every States in Malaysia from year 2007 to 2018 (refer to Appendix 3 in page 78).

Table 4.2: Data analysis of monthly MODIS fire in Malaysia by States from year 2007 to 2018

	Range	**Mean**	**Standard deviation**	**Standard error**
Sarawak	3029	197.85	319.29	26.61
Pahang	1141	69.35	120.48	10.04
Sabah	491	36.30	64.87	5.41
Johor	392	16.92	38.39	3.20
Terengganu	155	10.99	22.85	1.90
Selangor	235	14.76	25.94	2.16
Kelantan	138	8.85	17.79	1.48
Kedah	106	7.92	16.05	1.34
Perak	176	9.06	17.01	1.42
Negeri Sembilan	19	2.90	3.62	0.30
Melaka	14	1.95	2.46	0.21
Perlis	26	2.11	4.68	0.39
Pulau Pinang	8	1.76	1.80	0.15
Wilayah P.	2	0.12	0.40	0.03

4.1.3 Fire alerts in Sarawak

In Sarawak, months with the most average MODIS fires fall within months July to September (more than 300 average MODIS fires) with the highest average MODIS fires count in August (738.08 average MODIS fires) as shown in Figure 4.9 and Figure 4.10 which contributed to 70.28% of the average MODIS fires in Malaysia during the month as shown in Figure 4.7. The annual rainfall in Sarawak is varies between 330cm and 460cm with constantly high humidity exceeding 68% throughout the year (State Planning Unit Sarawak, 2011). Sarawak is accommodated by majority of Dayak ethnic group which also subdivided into Iban, Bidayuh and Orang Ulu (Borneo Post Online, 2014). According to Hatch (1980), shifting cultivation has been the traditional method on the growing of hill paddy for food production for the Dayaks and Ibans of Sarawak for generations. The cycle of shifting cultivation usually begins at months July or August after the Gawai festival by the local community in Sarawak, contributing to high MODIS fires alerts. Increasing population will pressure the traditional cycle of cutting, burning and taking one crop of hill paddy which caused the fallow period to decline significantly.

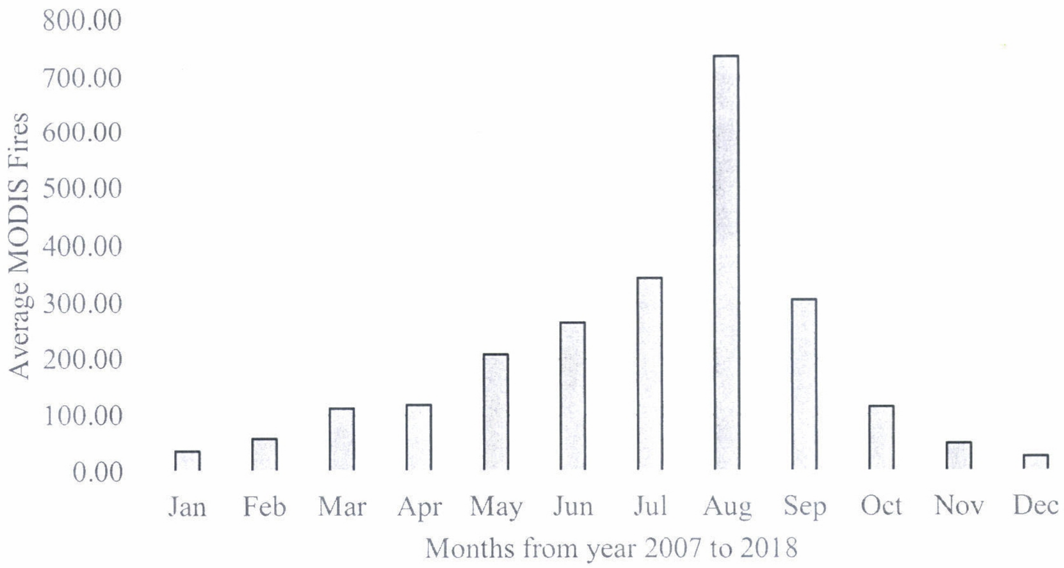

Figure 4.9: Average monthly MODIS fires in Sarawak from 2007 to 2018.

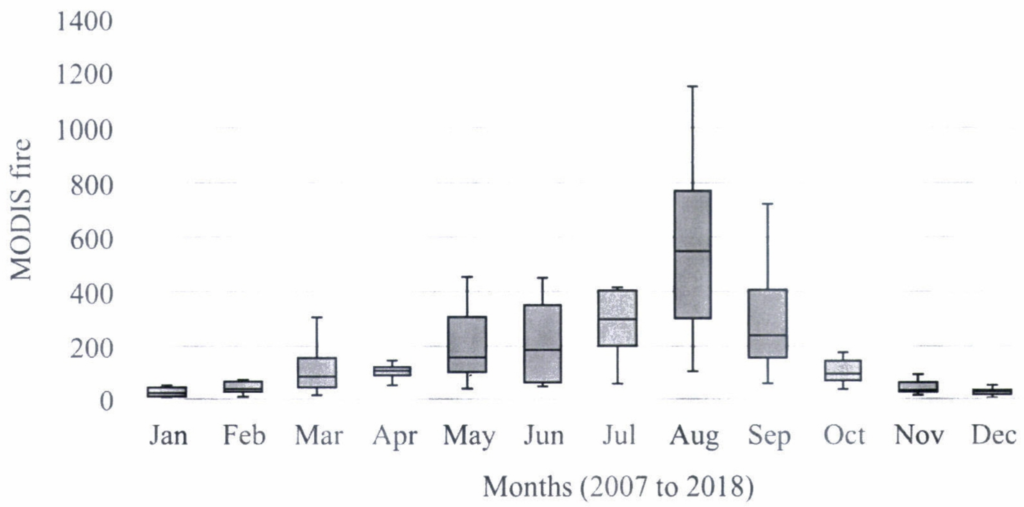

Figure 4.10: Boxplot on monthly MODIS fire in Sarawak from year 2007 to 2018.

Open burning is an activity that can contributed to the increased of fire risks and other environmental issues. In Sarawak, open burning is prohibited unless acquire approval from NREB with compliance with the Fire Danger Rating System Order 2004 (Appendix 4). The approved open burning is only applied to particular purposes such as clearing, sanitizing and preparing sites for reforestation, oil palm and other plantations; reducing hazardous fuel accumulations to prevent uncontrolled and haze producing wildfires during period of extended drought. The surrounding environment conditions will be assessed such as the drought code should not higher than 75, API does not exceed 100, all smoke must be eliminated within 24 daylight hours, separate burns of up to 50 ha, burning area should not exceed 30% of total area etc (Natural Resources and Environment (Fire Danger Rating System) order, 2004).

There were two cases of open burning convictions reported in NREB in year 2014 and 2018 in Sarawak as shown in Table 4.3. The convictions mainly due to allegation of the Fire Danger Rating System order 2004. The low number of open burning conviction is a result of low enforcement or weak fire detection system. It is a difficult task to confine the culprit who started the fire due to the difficulty in collecting the evident. The number of permitted open burning by NREB over the State of Sarawak are as shown in Figure 4.11. The results showed that the number of permitted open burning by NREB have significant impact on the MODIS fire alerts in Sarawak starting from year 2012 to 2018.

Table 4.3: Open burning cases filed and convicted in Sarawak by NREB

Year	**Open burning cases filed**	**Open burning convictions**
2014	2	2
2018	2	2

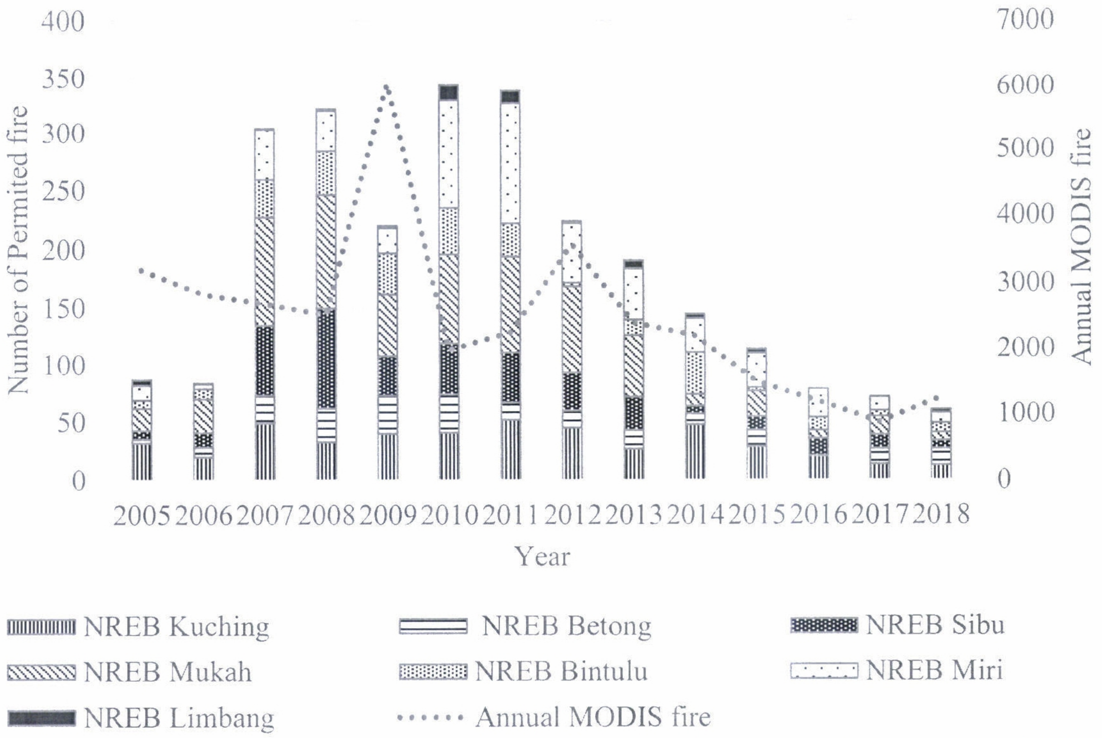

Figure 4.11: Number of the permitted open burning in Sarawak on the annual MODIS fire alerts.

The R^2 value of the scatter plot on number of permitted open burning by NREB on the annual MODIS fire in Sarawak from 2005 to 2018 is 0.0854 as shown in Figure 4.12. A simple linear regression was calculated to predict number of permitted open burning based on MODIS fire alerts in Sarawak from year 2005 to 2018 as shown in Table 4.4. A non-significant regression equation was found ($F(1,12) = 1.1205$, $p > 0.3106$), with R^2 of 0.0854. The predicted number of permitted open burning is equal to 124.6138 + 0.0244 MODIS fire alerts. The number of permitted open burning increased 0.0244 for each MODIS fire alerts in Sarawak from year 2005 to 2018.

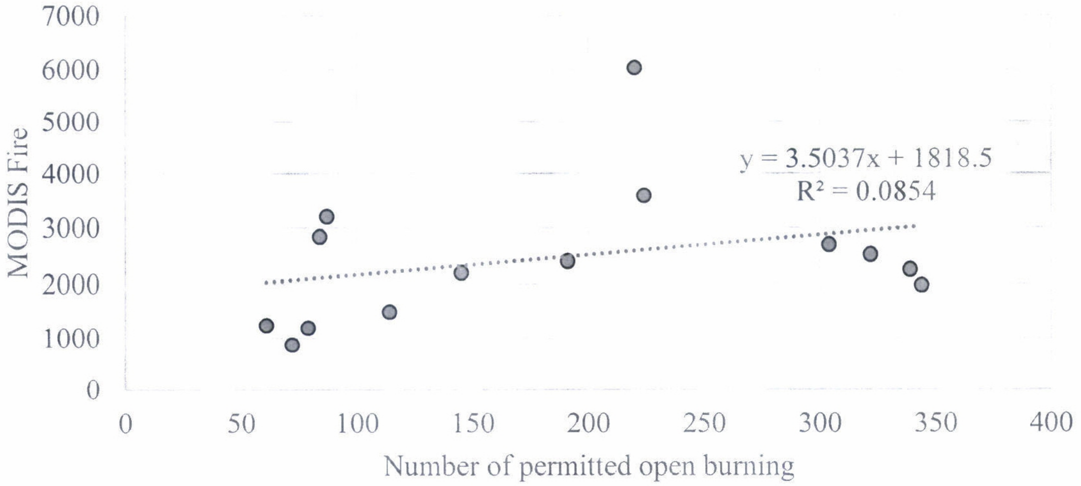

Figure 4.12: Regression analysis on number of permitted open burning by NREB on the annual MODIS fire in Sarawak from 2005 to 2018.

Table 4.4: Summary output of regression analysis on number of permitted open burning by NREB on the annual MODIS fire in Sarawak from 2005 to 2018

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.2922
R Square	0.0854
Adjusted R Square	0.0092
Standard Error	107.1131
Observations	14.0000

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	12856.2296	12856.2296	1.1205	0.3106
Residual	12	137678.6276	11473.2190		
Total	13	150534.8571			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	124.6138	63.5847	1.9598	0.0737	-13.9253	263.1529
Annual MODIS fire	0.0244	0.0230	1.0586	0.3106	-0.0258	0.0745

The compounds on open burning in agriculture had weak and positive correlation with the MODIS fire in Sarawak from 2002 to 2018 with R^2 value of 0.0966 as shown in Figure 4.13. A simple linear regression was calculated to predict compounds in open burning in agriculture based on MODIS fire alerts in Sarawak from year 2002 to 2018 as shown in Table 4.5. A non-significant regression equation was found ($F(1,15) = 1.6032$, $p > 0.2248$), with an R^2 of 0.0966. The predicted open burning compounds in agriculture is equal to 2.5563 + 0.0021 compounds when MODIS fire is measured in MODIS fire alerts. The compounds on open burning in agriculture increased 0.0021 for each MODIS fire alerts in Sarawak from year 2002 to 2018.

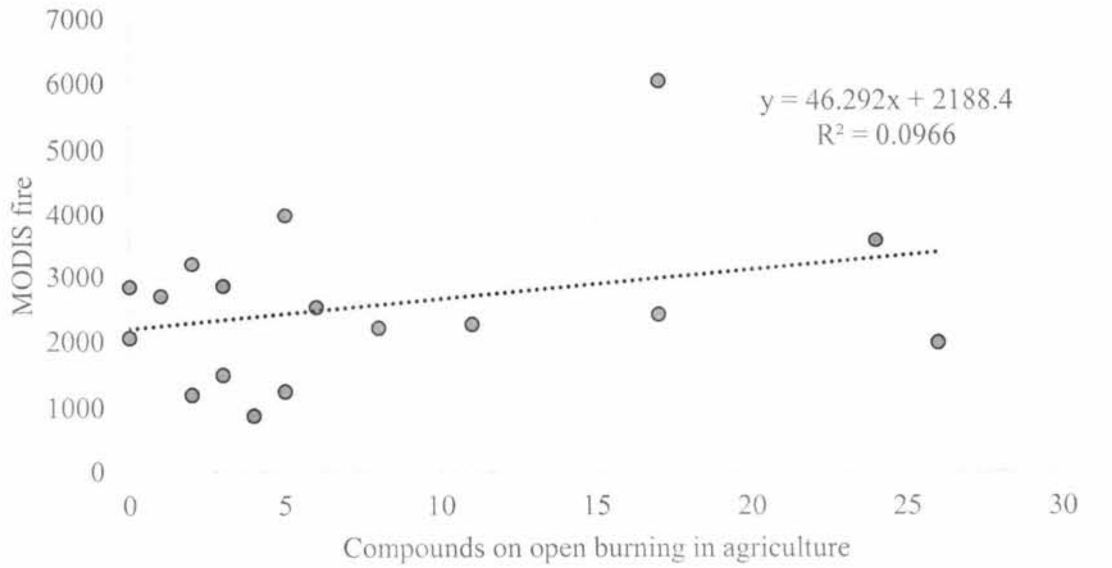

Figure 4.13: Regression analysis on number open burning compounds in agriculture with the annual MODIS fire in Sarawak from 2002 to 2018.

Table 4.5: Summary output of regression analysis on number open burning compounds in agriculture with the annual MODIS fire in Sarawak from 2002 to 2018

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.310743
R Square	0.096561
Adjusted R Square	0.036332
Standard Error	8.09415
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	1	105.0357	105.0357	1.603225	0.224758
Residual	15	982.729	65.51527		
Total	16	1087.765			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.556382	4.641864	0.550723	0.589932	-7.33752	12.45028
MODIS fire Sarawak	0.002086	0.001647	1.266185	0.224758	-0.00143	0.005597

4.2 Agriculture activities

4.2.1 Oil palm

The planted area and harvested area of oil palm plantation in Malaysia were in the increasing trend from year 2000 to 2016 due to the global demand. On the other hand, the production of oil palm was increased from year 2000 to year 2015 then decreased drastically in year 2016. According to Plantation Industries and Commodities Minister Datuk Mah Siew Keong (Star Online, 2016), palm oil production in Malaysia drop 10% in year 2016 after 2015-2016 El Nino cut yields in the first half which is about supply of 17.96 million tonnes as shown in Figure 4.14.

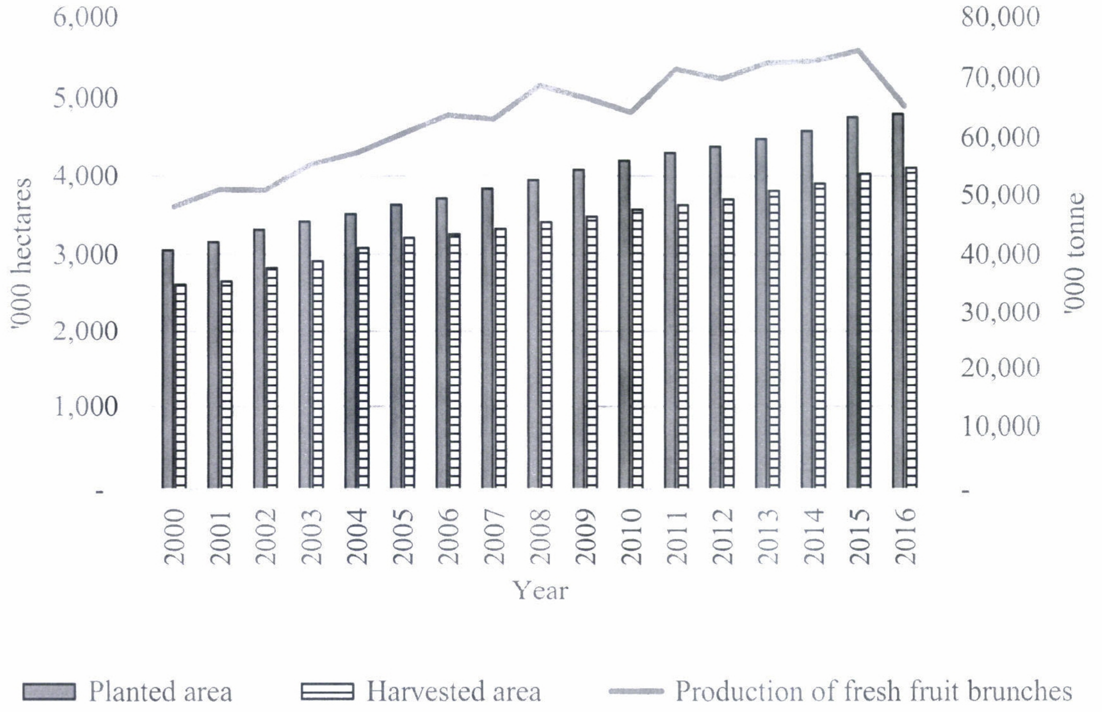

Figure 4.14: Planted area, harvested area and production of oil palm in Malaysia from year 2000 to 2016.

The R^2 value of the scatter plot on the annual MODIS fire on the planted area of oil palm after planted a year from 2002 to 2016 is 0.1058 as shown in Figure 4.15. A simple linear regression was calculated to predict annual MODIS fire based on the oil palm plantation area in Malaysia from year 2000 to 2016 as shown in Table 4.6. A non-significant regression equation was found ($F(1,13) = 1.5, p > 0.2$), with an R^2 of 0.1058. The predicted annual MODIS fire is equal to 11104.1004 – 1.2988 (Oil palm plantation area), where oil palm plantation area is measured in '000 hectares. Modis fire alerts decreased 1.2988 fire alerts for each '000 hectares of oil palm plantation in Malaysia from year 2002 to 2016.

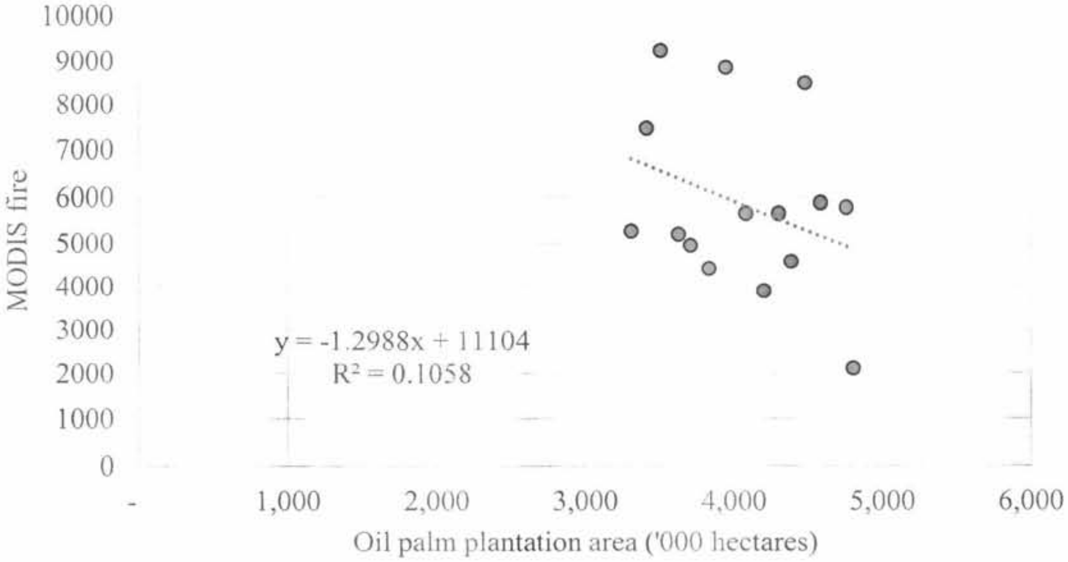

Figure 4.15: Regression analysis on oil palm plantation area with MODIS fire after one year in Malaysia from 2002 to 2016.

Table 4.6: Summary output of regression analysis on oil palm plantation area with MODIS fire after one year in Malaysia from 2002 to 2016

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.3252
R Square	0.1058
Adjusted R Square	0.0370
Standard Error	1913.2258
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	1	5629074.5	5629074.5	1.5	0.2
Residual	13	47585627.9	3660432.9		
Total	14	53214702.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	11104.1004	4284.6440	2.5916	0.0224	1847.6899	20360.5110
Oil Palm	-1.2988	1.0473	-1.2401	0.2369	-3.5614	0.9638

MODIS fire had weak negative correlation with oil palm production in Malaysia from year 2002 to 2016 with R^2 of 0.0678 as shown in Figure 4.16. Hence, MODIS fire can reduce the oil palm production in Malaysia but the impacts are not significant.

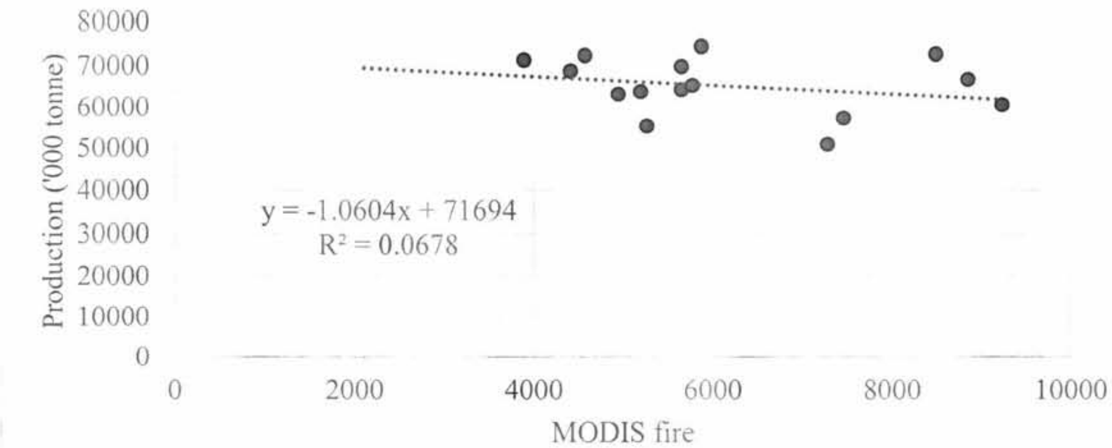

Figure 4.16: Scatter plots on MODIS fire with oil palm production in Malaysia from year 2002 to 2016.

Sabah and Sarawak were the States in Malaysia with the most hectarage area of oil palm plantation while Perlis and Pulau Pinang were the States in Malaysia with the least size of oil palm plantation from year 2013 to 2018 as shown in Figure 4.17. The oil palm plantation area in Sarawak increased the most (35.45%) among the other States from 1,160,898 hectares in year 2013 to 1,572,477 hectares in year 2018.

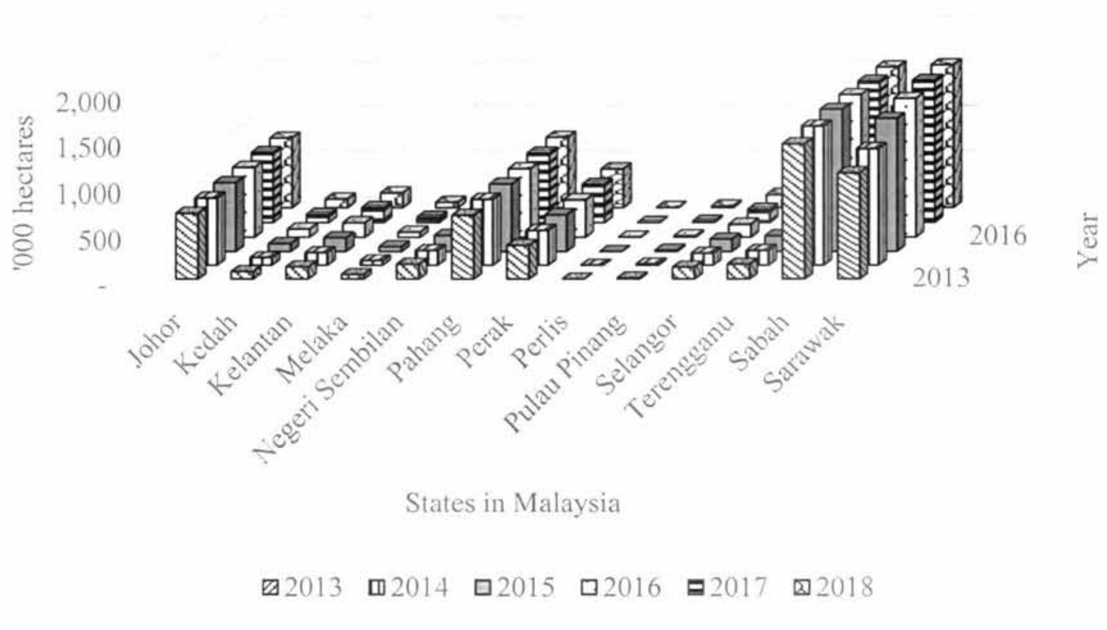

Figure 4.17: Area of oil palm planted area in Malaysia by States from year 2013 to 2018.

The MODIS fire one year after the oil palm plantation and the oil palm plantation area approved by NREB from year 2010 to 2017 in Sarawak are in a decreasing trend as shown in Figure 4.18. Therefore, NREB approval on the oil palm plantation area had somehow affected the MODIS fire counts in Sarawak.

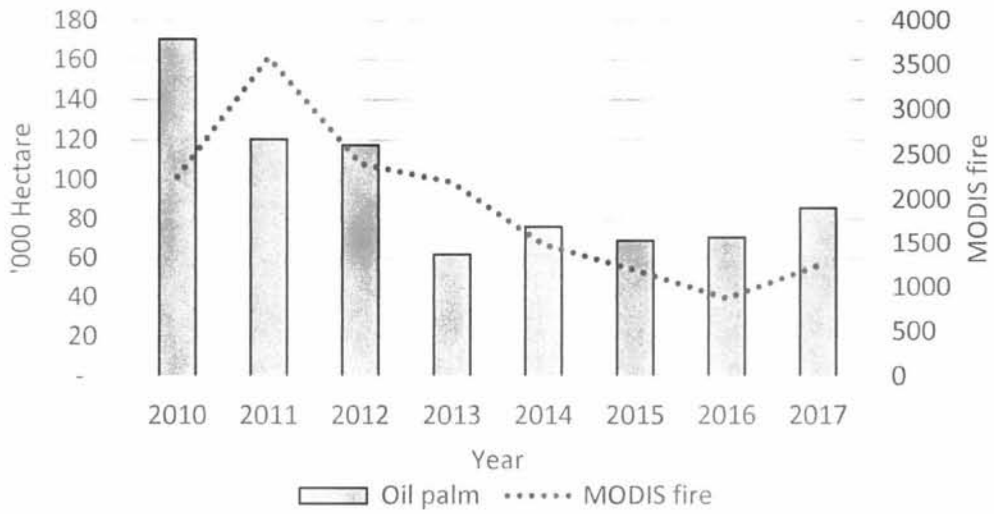

Figure 4.18: Area of oil palm plantation projects approved by NREB and total MODIS fire alerts a year after the plantation in Sarawak from year 2010 to 2017.

The area of oil palm plantation approved by NREB had weak positive correlation with MODIS fire after one year of plantation in Sarawak from 2010 to 2017 with R^2 value of 0.312 as shown in Figure 4.19. A simple linear regression was calculated to predict MODIS fire alerts based on the oil palm plantation area approved by NREB as shown in Table 4.7. A non-significant regression equation was found ($F(1,6) = 2.722$, $p < 0.15$), with R^2 of 0.312. The predicted MODIS fire alerts in Sarawak is equal to 627.017 + 13.261(Oil palm plantation approved by NREB), where oil palm approved by NREB is measured in '000 hectares. The MODIS fire alerts in Sarawak increased 13.261 fire alert counts for each '000 hectares of oil palm plantation approved by NREB. Oil palm plantation approved by NREB was not significant predictors of MODIS fire alerts.

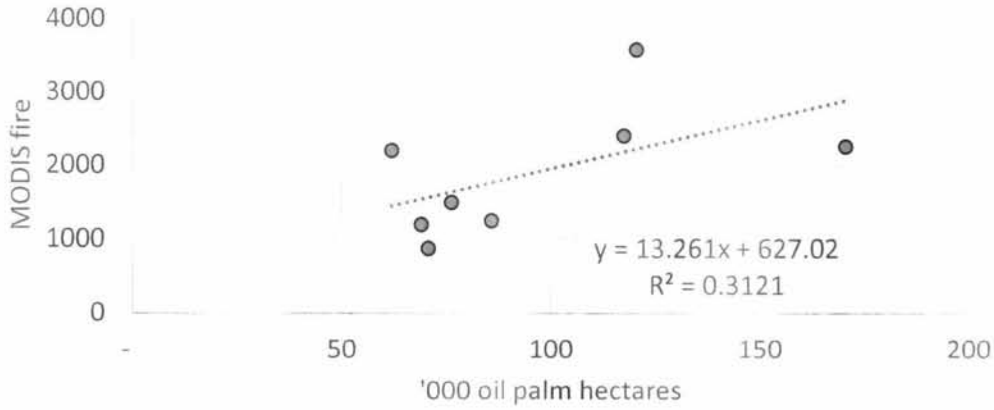

Figure 4.19: Regression analysis on the area of oil palm plantation approved by NREB with annual MODIS fire one year after plantation in Sarawak from 2010 to 2017.

Table 4.7. Summary output of regression analysis on the area of oil palm plantation approved by NREB with annual MODIS fire one year after plantation in Sarawak from 2010 to 2017

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.559
R Square	0.312
Adjusted R Square	0.197
Standard Error	789.097
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	1	1695116.813	1695116.813	2.722	0.150
Residual	6	3736043.187	622673.865		
Total	7	5431160.000			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	627.017	824.414	0.761	0.476	-1390.250	2644.285
Oil palm	13.261	8.037	1.650	0.150	-6.405	32.927

4.2.2 Rubber

Rubber plantation area in estate had declined since year 2000 until year 2011 before it started to increase from year 2012 as shown in Figure 4.20. The area of the tapped area and the natural rubber production have declined over the 18 years. According to Hays (2008), declining prices of natural rubber resulted in large area of rubber plantations were abandoned or converted into a more lucrative oil palm plantation between 1999 and 2004. The increasing of the planted area for rubber in year 2012 is due to the positive outlook for natural rubber due to issue on climate changes and growing preference for renewable materials. Synthetic rubber, a petroleum-based product is the main competitors of natural rubber. However, petroleum is on a declining supply trend as well as the global fight on climate change would favour the production of natural rubber compared with the synthetic rubber regardless the higher cost of natural rubber (Ahmad Ibrahim, 2018). Considering the climate change, natural rubber is one of the alternative fuels that can replace the usage of petroleum and fossil fuel.

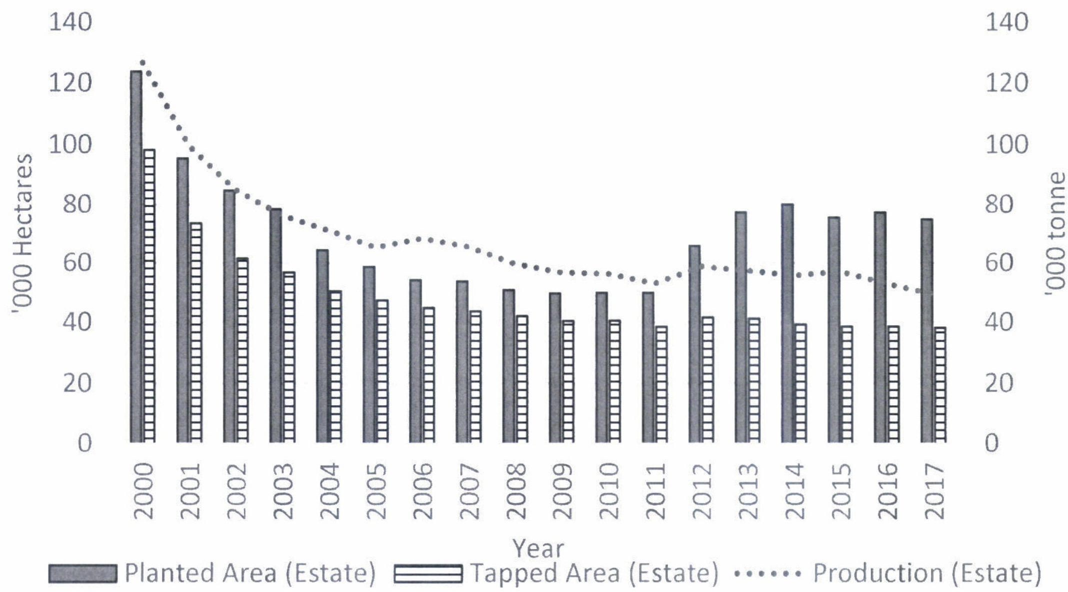

Figure 4.20: Planted area, harvested area and production of rubber in Malaysia from year 2000 to 2016.

The production of natural rubber is decreased dramatically from year 2000 (126.7 thousand tonnes) to 2005 (65.3 thousand tonnes) then slowly decreased to 49.3 thousand tonnes in year 2017 as shown in Figure 4.20. The substantial decrease of the natural rubber production in the early year is resulted from the low market prices of natural rubber where most of the rubber plantation were abandoned. Natural rubber is a crop that can only grow in tropical climates which made Malaysia as the world 3rd producers and world 1st exporters in 1988 before the invention of synthetic rubber (Hays, 2008; Labbe, 2017). As in year 2012 onward, the increasing area of rubber plantation do not seem to increase the production of natural rubber. One of the possible reasons is due wide spread of leaf blight disease caused by *Fusicoccum* species on the rubber tress especially *Hevea brasiliensis* which is the main rubber plantation tree species in Malaysia (Ngobisa et al., 2013).

The area of rubber planted area had weak and negative correlation with MODIS fire alerts in Malaysia from year 2002 to 2017 with R^2 of 0.0004 as shown in Figure 4.21. A simple linear regression was calculated to predict MODIS fire alerts based on rubber planted area in Malaysia from year 2002 to 2017 as shown in Table 4.8. A non-significant regression equation was found ($F(1,14) = 0.0062$, $p > 0.9384$), with an R^2 of 0.0004. The predicted MODIS fire alerts is equal to 5881.169 – 3.231 thousand hectares of rubber planted area. The MODIS fire alerts decreased 3.231 MODIS fire alerts for each thousand hectares of rubber planted area.in Malaysia from 2002 to 2017.

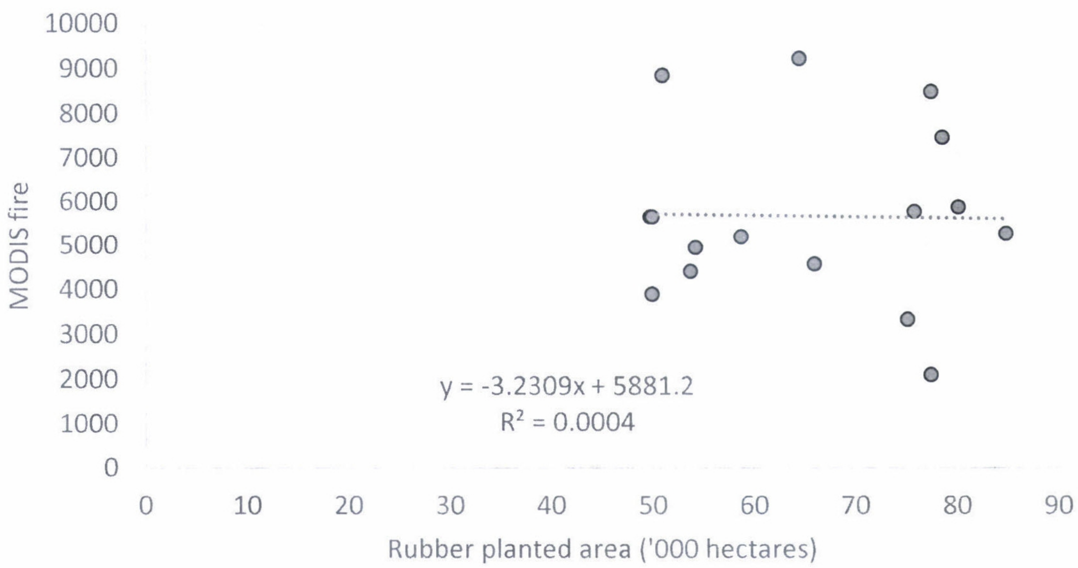

Figure 4.21: Regression analysis on rubber planted area with MODIS fire after one year in Malaysia from 2002 to 2017.

Table 4.8: Summary output of regression analysis on rubber planted area with MODIS fire after one year in Malaysia from 2002 to 2017

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.0210
R Square	0.0004
Adjusted R Square	-0.0710
Standard Error	2053.805
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	1	26086.28	26086.28	0.0062	0.9384
Residual	14	59053617.47	4218115.53		
Total	15	59079703.75			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5881.169	2735.457	2.150	0.050	14.198	11748.141
Planted Area (Estate)	-3.231	41.085	-0.079	0.938	-91.349	84.887

MODIS fire had weak positive correlation with natural rubber production in Malaysia from year 2002 to 2017 with R^2 of 0.1026 as shown in Figure 4.22. Hence, MODIS fire can increase the natural rubber production in Malaysia but the impacts are not significant.

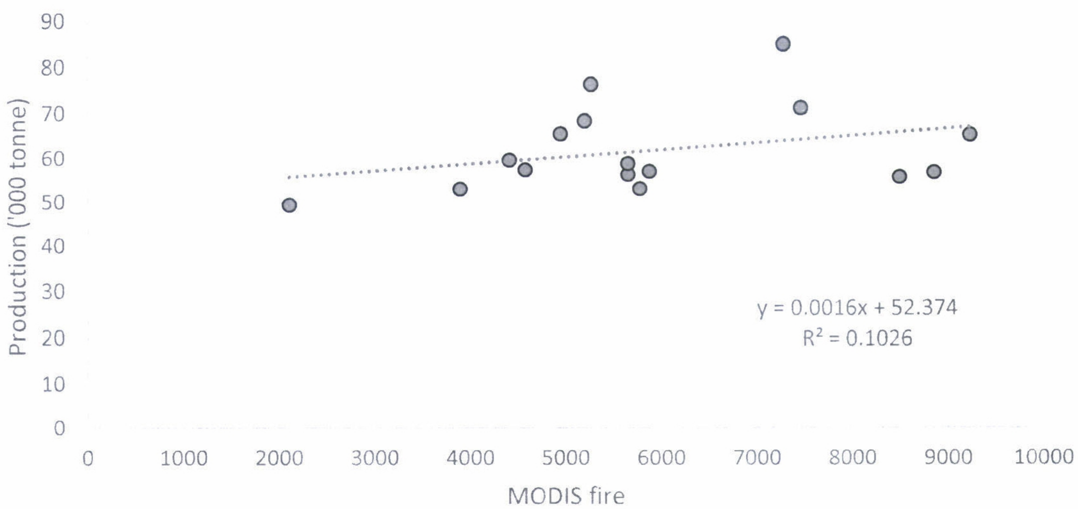

Figure 4.22: Scatter plots on MODIS fire with natural rubber production in Malaysia from year 2002 to 2017.

4.3 Forest land and production

Table 4.9: Percentage of forested land area in Peninsular Malaysia by States from year 2007 to 2017

	Percentage of forested land area in Peninsular						
States	2007	2008	2009	2010	2011	2012	2013
Johor	25.82%	23.27%	25.64%	24.57%	24.55%	24.55%	24.55%
Kedah	36.64%	36.64%	36.64%	36.59%	36.59%	34.77%	36.52%
Kelantan	59.39%	57.77%	57.77%	57.08%	53.77%	53.77%	53.77%
Melaka	3.21%	3.22%	3.22%	3.22%	3.07%	3.27%	3.27%
Negeri Sembilan	23.79%	24.03%	24.21%	23.69%	23.63%	23.80%	23.80%
Pahang	55.09%	57.50%	57.52%	57.52%	57.52%	57.52%	57.52%
Perak	49.96%	49.65%	49.27%	49.08%	49.02%	48.87%	49.85%
Perlis	14.39%	13.66%	13.94%	14.44%	14.43%	14.51%	14.51%
Pulau Pinang	7.57%	7.57%	7.57%	7.57%	7.57%	7.57%	7.54%
Selangor	31.39%	30.74%	31.32%	31.63%	31.63%	31.63%	31.63%
Terengganu	50.66%	50.53%	50.53%	50.53%	50.15%	50.15%	50.58%
Wilayah Persekutuan	0.21%	9.60%	9.65%	6.05%	6.05%	7.02%	7.02%
Peninsular Malaysia	44.38%	44.40%	44.73%	44.48%	44.04%	43.90%	44.23%

The percentage of the forested land area in Peninsular Malaysia from year 2007 to 2017 was

The States with the decreasing trend are Johor, Kedah, Kelantan, Negeri Sembilan, Perak, Pulau

with the increasing trend are Melaka, Pahang, Perlis, Selangor, and Wilayah Persekutuan.

Inland forest was the dominant forest type compare to the other forest types in Peninsular Malaysia from year 2007 to 2017 as shown in Figure 4.23 and Table 4.10. The inland forest area in Peninsular Malaysia was in the declining trend with -26,966 coefficient while the other forest type area was in the increasing in peat swamp forest (1,806 coefficient), mangrove forest (598.47 coefficient), and forest plantations (38,882 coefficient) from year 2007 to 2017. Forest plantation increased dramatically from 104,541 hectares in 2007 to 417,454 hectares in 2017 with an increment of 299.3%.

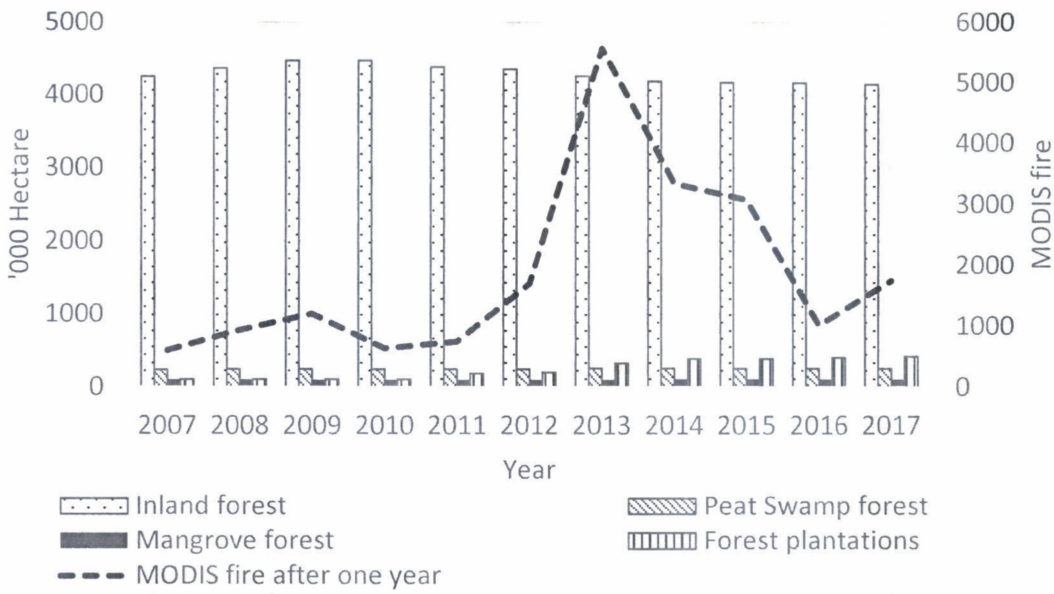

Figure 4.23: Forest type area in Peninsular Malaysia with MODIS fire after a year from year 2007 to 2017.

Table 4.10: Forest type area in Peninsular Malaysia from year 2007 to 2017

	Permanent Reserved Forest Peninsular Malaysia (hectares)			
Year	Inland forest	Peat Swamp forest	Mangrove forest	Forest plantations
2007	4,250,087	237,745	103,257	104,541
2008	4,364,791	241,474	100,752	108,512
2009	4,472,390	241,474	99,915	108,742
2010	4,469,893	242,906	98,229	108,657
2011	4,384,876	242,906	98,858	185,794
2012	4,354,030	242,906	98,848	197,829
2013	4,257,200	254,976	99,697	324,417
2014	4,185,186	255,080	105,693	387,828
2015	4,168,354	253,447	105,693	389,254
2016	4,162,980	253,447	105,726	402,000
2017	4,140,133	253,447	105,824	417,454

Peat swamp forest only available in Johor, Pahang, Selangor, and Terengganu while mangrove forest only available in Johor. Kedah, Melaka, Negeri Sembilan, Pahang, Perak, Pulau Pinang, Selangor, and Terengganu. Forest plantation was available for all the States in Peninsular Malaysia except Pulau Pinang, Wilayah Persekutuan, as well as Melaka since year 2015.

As shown in Figure 4.24 within the year 2007 to 2010, inland forest had a weak negative correlation with the annual MODIS fire after a year in Peninsular Malaysia; Peat swamp forest had a strong positive correlation with the MODIS fire after a year in Peninsular Malaysia; while mangrove forest and forest plantation had weak positive correlation with annual MODIS fire after a year in Peninsular Malaysia.

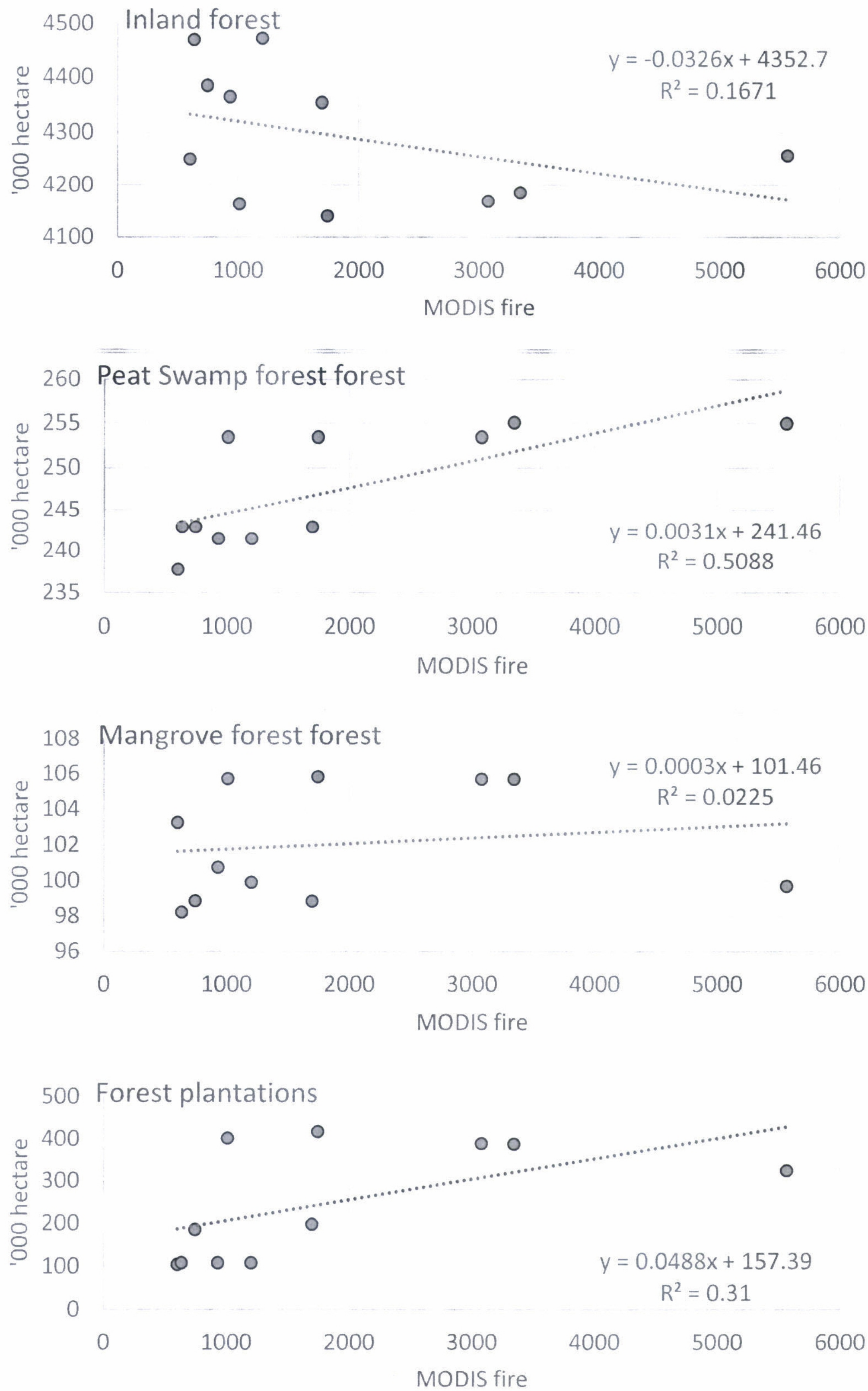

Figure 4.24: Scatter plots on the inland forest, peat swamp forest, mangrove forest and forest plantations with MODIS fire after a year in Peninsular Malaysia from year 2007 to 2017.

As shown in Figure 4.25, peatland in Malaysia is the most vulnerable area to fire risk especially between month March (822 MODIS fires) and April (1033 MODIS fire). March is the transition month of the monsoon season from wet season to dry season in Malaysia. The high temperature and low precipitation will drive the fire risk especially on dry vegetation and peat which are more likely to ignite (Albertson et al. 2009). Other than that, there are likely to be more people on the moors in hot dry weather which further increase rate of fire risk (Albertson et al. 2009). Rapid development, plantation, agriculture activities and dry conditions can increase the vulnerability of the forest to fires. According to Yukili et al., (2016), the opening of large areas for agriculture, logging and construction will result in an increase of the secondary forest plant species, such as *Macaranga pruinosa* (mahang), *Imperata cylindrica* (lalang), *Melastomata malabathricum* (senduduk) and *Dicranopteris linearis* (resam). The presence of these plant species will increase the risk of forest fires because they are more flammable in nature.

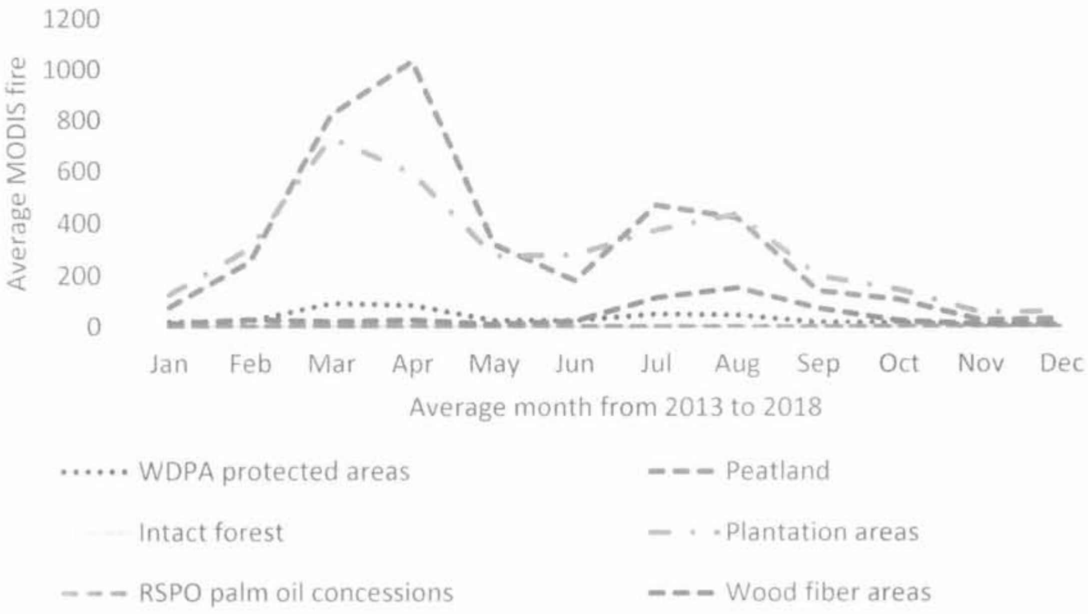

Figure 4.25: Average monthly MODIS fire by WDPA protected areas, intact forest, RSPO palm oil concessions, peatland, plantation areas and wood fiber areas in Malaysia from year 2013 to 2018.

Correlations of MODIS fire alert on forest products in Peninsular Malaysia were analysed on sawn timber, plywood, veneer, and moulding from year 2007 to 2017 as shown in Figure 4.26. MODIS fire had weak positive correlation veneer production in Peninsular Malaysia with R^2 of 0.3609 while had weak negative correlation with production of sawn timber, plywood and moulding with R^2 of 0.0201, 0.1508 and 0.3507 respectively.

Sawn timber in Malaysia are hardwood species such as *Meranti*, *Menggris*, *Kapur*, *Keruing*, *Selangan* and Mixed light hardwood. Forest fire had slight impacts to the production of sawn timber in Malaysia with R^2 of 0.0201 where the production decreased 16.9 m^3 for each MODIS fire alerts in Peninsular Malaysia from year 2007 to 2017.

Malaysia plywood is tropical plywood which is made of mixed species of tropical timber. There is high demand for the plywood in Malaysia where it is exported largely for construction purposes due to its density, strength, evenness of layers, high quality, and low cost. Forest fire had slight impacts to the production of plywood in Malaysia with R^2 of 0.1508 where the production decreased 9.7 m^3 for each MODIS fire alerts in Peninsular Malaysia from year 2007 to 2017.

Veneer is thin slices of wood such as bark which are glued onto core panels to produce flat panels such as doors, parquet floor, and parts of furniture. Forest fire had slight impacts to the production of veneer in Malaysia with R^2 of 0.1508 where the production increased 17.1 m^3 for each MODIS fire alerts in Peninsular Malaysia from year 2007 to 2017.

Moulding is a strip of material with various profiles used to hide and help weather seal natural joints produced in the framing process of building a structure. Forest fire had slight impacts to the production of moulding in Malaysia with R^2 of 0.3507 where the production decreased 30.3 m^3 for each MODIS fire alerts in Peninsular Malaysia from year 2007 to 2017.

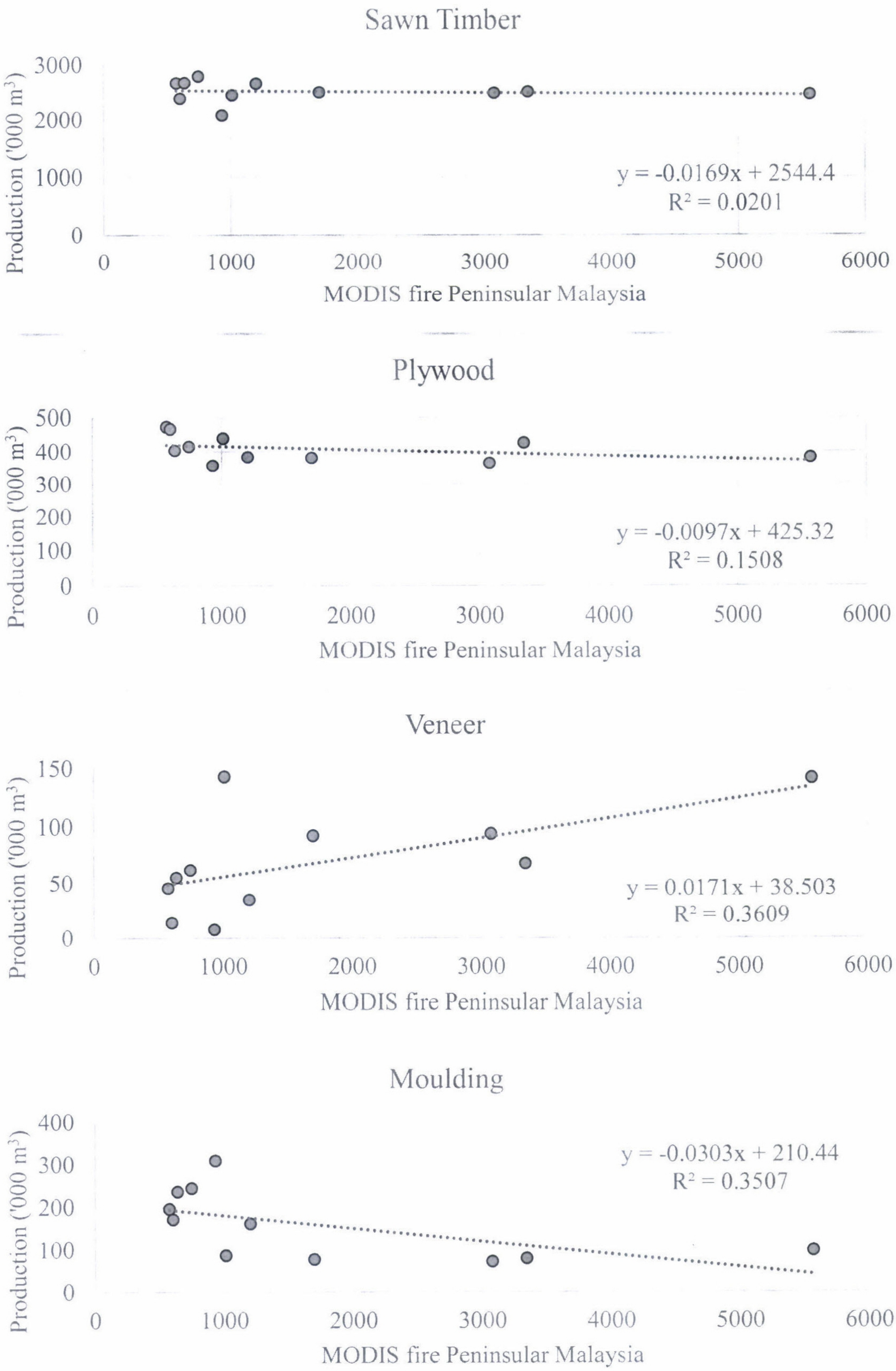

Figure 4.26. Scatter plot for different forest products with MODIS fire alerts in Peninsular Malaysia from year 2007 to 2017.

4.4 Air Pollution Index (API)

4.4.1 Annual API

The highest annual API in Malaysia recorded was in year 2015 at 48.66 API while the lowest was in year 2010 at 39.98 API as shown in Figure 4.27. The high API was due to the 2015 Southeast Asian haze which caused transboundary transfer of the haze from Indonesia as a result of mass illegal burning in the country (Kaos Jr, 2017). The impacts of 2015 Southeast Asian haze were so severe that it caused premature death to estimated 6,500 people in Malaysia and it was considered as the worst haze event in history by NASA scientist (Jenkins, 2015; Agence France-Presse, 2016). The second highest annual average API (47.48 API) in Malaysia during year 2005 was due to 2005 Malaysian haze event which took place majority in the central part of Peninsular Malaysia. However, the overall annual average API level was good from year 2002 to 2016 according to the health classification on API scale used by Malaysia as shown in Table 4.11.

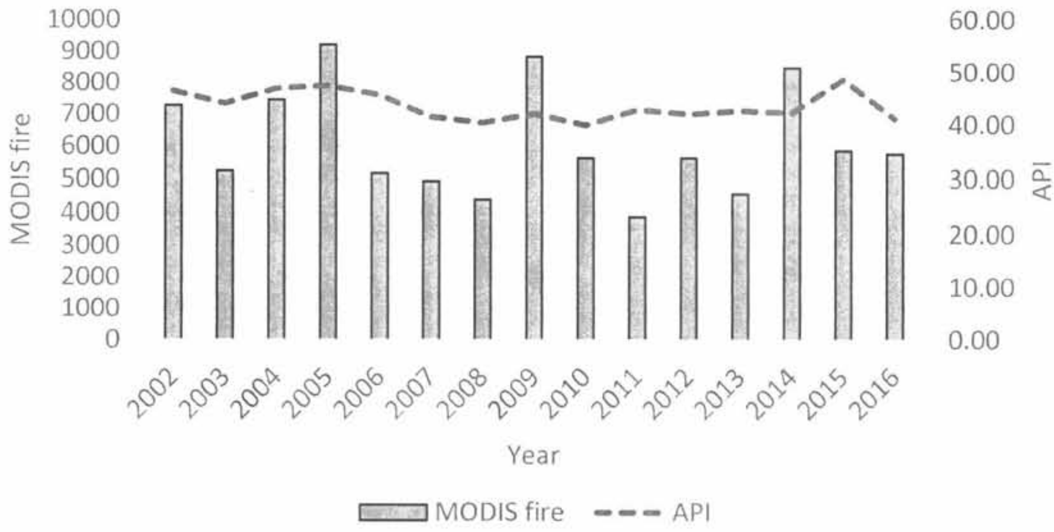

Figure 4.27: Annual MODIS fire on API in Malaysia from year 2002 to 2016.

Table 4.11: Health classification on air pollution index scale used in Malaysian government

Air Pollution Index scale	Health classifications
0 to 50	Good
51 to 100	Moderate
101 to 200	Unhealthy
201 to 300	Very unhealthy
301 and more	Hazardous

The R^2 value of the scatter plot on the annual MODIS fire on annual average API from year 2002 to 2016 is 0.129 with positive coefficient of 0.0006 as shown in Figure 4.28. Hence, the result showed a very weak and positive relationship between the annual MODIS fire on the annual average API in Malaysia from year 2002 to 2016. The equation of the annual API on MODIS fire alerts is 40.046 + 0.0006 where API increased by 0.0006 for each MODIS fire alerts.

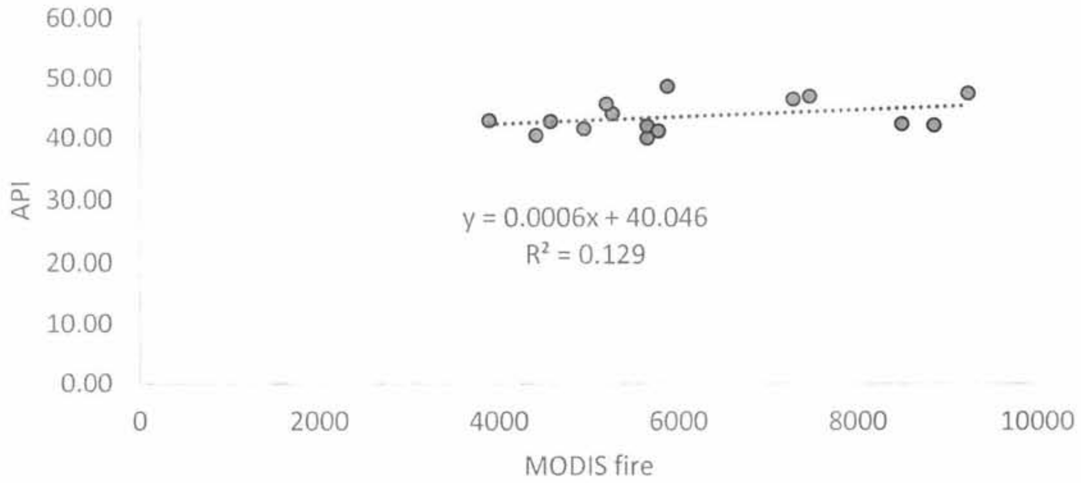

Figure 4.28: Regression analysis of annual MODIS fire on annual average API in Malaysia from year 2002 to 2016.

4.4.2 Monthly API

The monthly average API recorded at high level during the dry season between March to September with the highest monthly average API of 46.12 in June and the lowest at 36.08 in November as shown in Figure 4.29. On the other hand, the monthly average API were maintained at low level during the wet season in Malaysia.

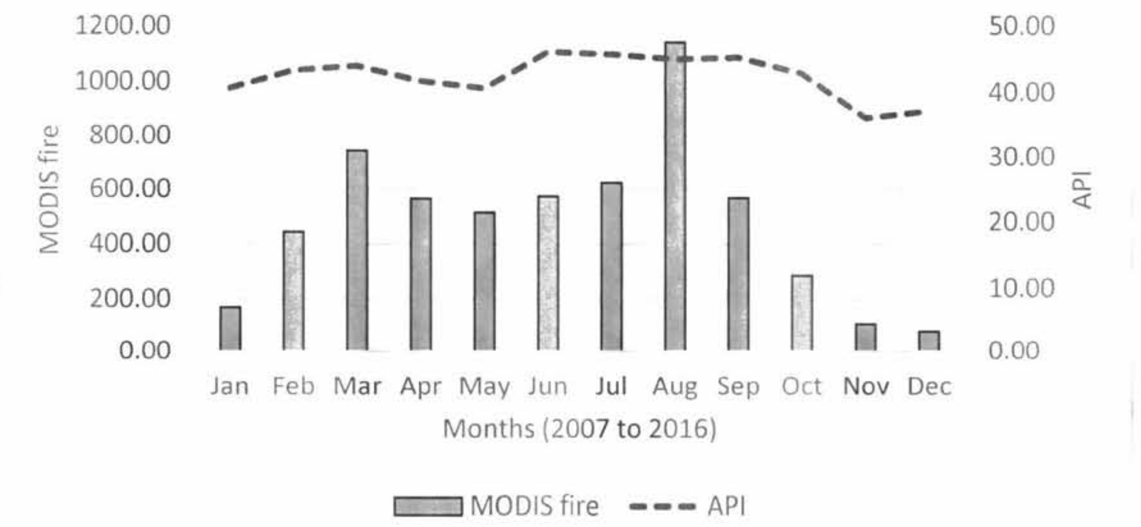

Figure 4.29: Average monthly MODIS fire on average monthly average API in Malaysia from year 2007 to 2016.

The R^2 value of the scatter plot on the monthly average MODIS fire on monthly average API from year 2007 to 2016 is 0.548 with positive coefficient of 0.0081 as shown in Figure 4.30. Hence, the result showed that the monthly average MODIS fire have relatively high and positive relationship on the monthly average API from year 2002 to 2016. The equation of the monthly API on MODIS fire alerts is 38.495 + 0.0081 where the monthly API increased by 0.0081 for each MODIS fire alerts in Malaysia.

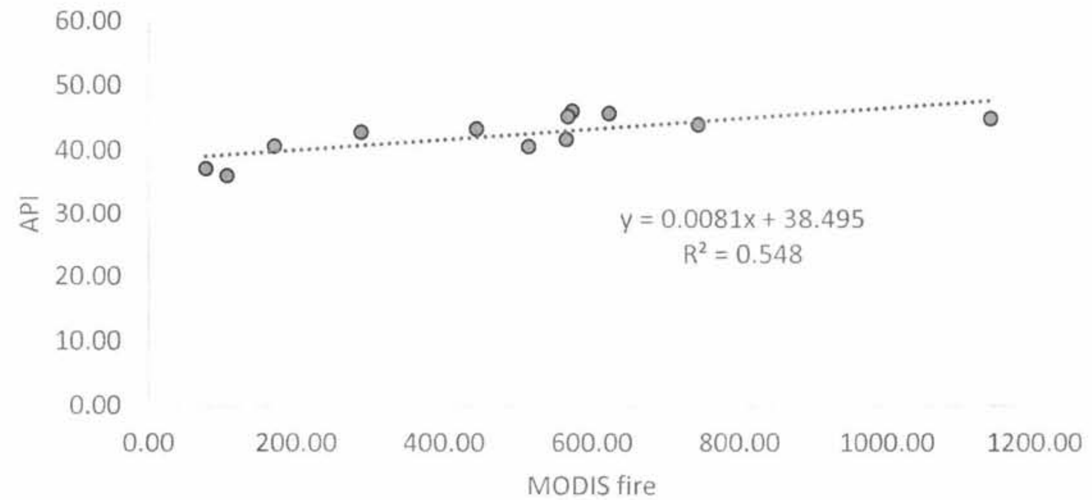

Figure 4.30: Regression analysis of monthly average MODIS fire on monthly average API in Malaysia from year 2007 to 2016.

The highest average monthly API (56.09 API) were recorded at August in Selangor while the lowest average monthly API recorded was 29.59 at December in Sarawak as shown in Figure 4.31 where Sarawak were shown in dotted line. The low API value in Sarawak is mainly due to the low number of API stations (Appendix 5) in Sarawak which cannot effectively detect the air pollution around the State considering Sarawak is the largest States in Malaysia as well as the State which had the highest shifting cultivation activities in the rural communities.

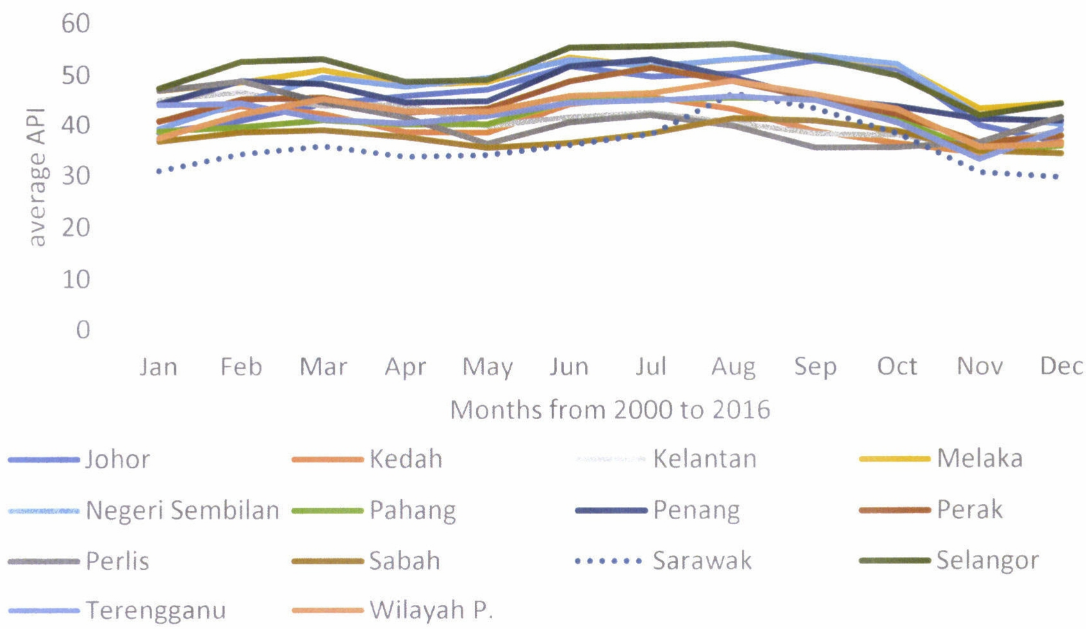

Figure 4.31: Monthly average API by States in Malaysia from year 2000 to 2016.

4.5 Rainfall in Malaysia

Sarawak had the highest rainfall throughout the year compared with Sabah and Peninsular Malaysia as shown in Figure 4.32 and on monthly basis as shown in Figure 4.33. The month with the highest rainfall recorded in Peninsular Malaysia is in November with average 363.23 mm with standard error of 22.04 while the highest rainfall recorded in Sarawak and Sabah is in January with average 487.61 mm with standard error of 67.07 and 370.56 mm with standard error of 59.81 respectively as shown in Table 4.12. Sarawak had rainfall with average 321.92 mm per month and standard error of 13.3329 followed by Sabah with average 247.6 mm per month and standard error of 11.771 then Peninsular Malaysia with average 214.77 mm per month and standard error of 10.0943 as shown in Table 4.13.

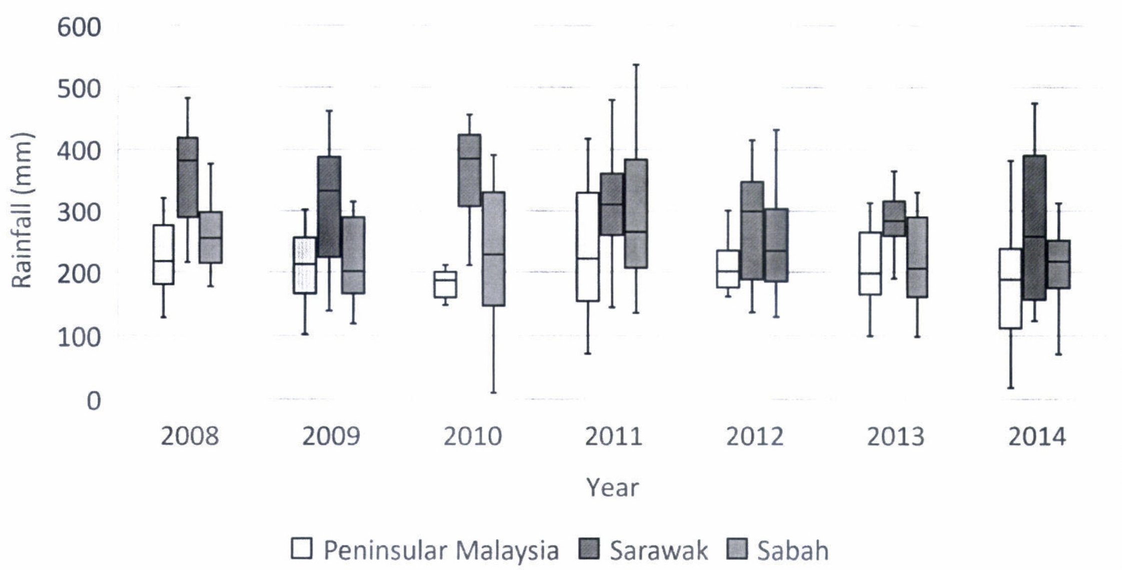

Figure 4.32: Boxplot on annual rainfall data in Malaysia from year 2008 to 2014.

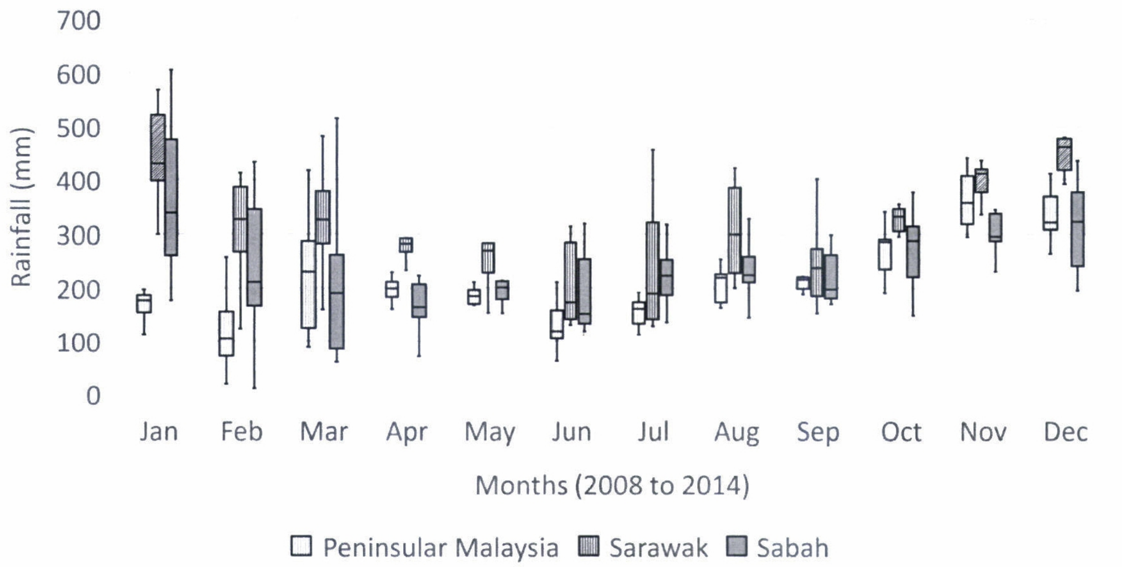

Figure 4.33: Annual rainfall in Peninsular Malaysia, Sarawak, and Sabah from year 2008 to 2014.

Table 4.12: Monthly data analysis on rainfall in Malaysia from year 2014 to 2018

	Rainfall (mm)								
	Peninsular Malaysia			**Sarawak**			**Sabah**		
	Mean	**SD**	**SE**	**Mean**	**SD**	**SE**	**Mean**	**SD**	**SE**
Jan	178.37	50.92	19.25	487.61	177.46	67.07	370.56	158.25	59.81
Feb	119.44	78.92	29.83	309.86	106.16	40.13	239.65	146.29	55.29
Mar	222.85	119.15	45.04	327.09	101.06	38.20	208.73	161.80	61.16
Apr	197.32	24.55	9.28	283.45	35.61	13.46	177.60	72.32	27.33
May	179.54	27.51	10.40	261.01	69.70	26.34	193.17	24.24	9.16
Jun	131.36	50.23	18.99	209.58	80.78	30.53	194.65	79.91	30.20
Jul	154.21	29.18	11.03	242.62	128.03	48.39	222.06	60.66	22.93
Aug	205.08	34.82	13.16	306.62	91.25	34.49	233.45	58.09	21.96
Sep	209.45	14.56	5.50	244.02	85.45	32.30	234.75	81.80	30.92
Oct	267.08	49.91	18.86	329.38	62.74	23.71	268.73	79.25	29.95
Nov	363.23	58.30	22.04	396.60	35.68	13.49	315.25	62.84	23.75
Dec	349.26	82.23	31.08	465.13	74.25	28.07	312.62	91.09	34.43

Table 4.13: Overall data analysis of monthly rainfall in Malaysia from year 2014 to 2018

	Rainfall (mm)			
	Peninsular Malaysia	Sarawak	Sabah	**Malaysia**
Min	18.42	123.25	10.16	**97.79**
Q1	161.14	240.36	176.15	**209.46**
median	198.16	314.52	224.81	**250.99**
Q3	266.32	398.82	313.02	**311.06**
Max	506.50	844.25	606.00	**536.92**
Mean	214.77	321.92	247.60	**261.43**
Standard deviation	92.516	122.198	107.883	**88.457**
Standard error	10.0943	13.3329	11.7710	**9.6515**

4.5.1 Impacts of rainfall on MODIS fire alerts in Malaysia

Rainfall have inverse impacts on MODIS fire in Malaysia from year 2008 to 2014 as shown in Figure 4.34. Therefore, as the rainfall increased, the MODIS fire alerts are decreased. The months with high rainfall usually come with low MODIS fire alerts especially from October to January which also known as raining season of the year.

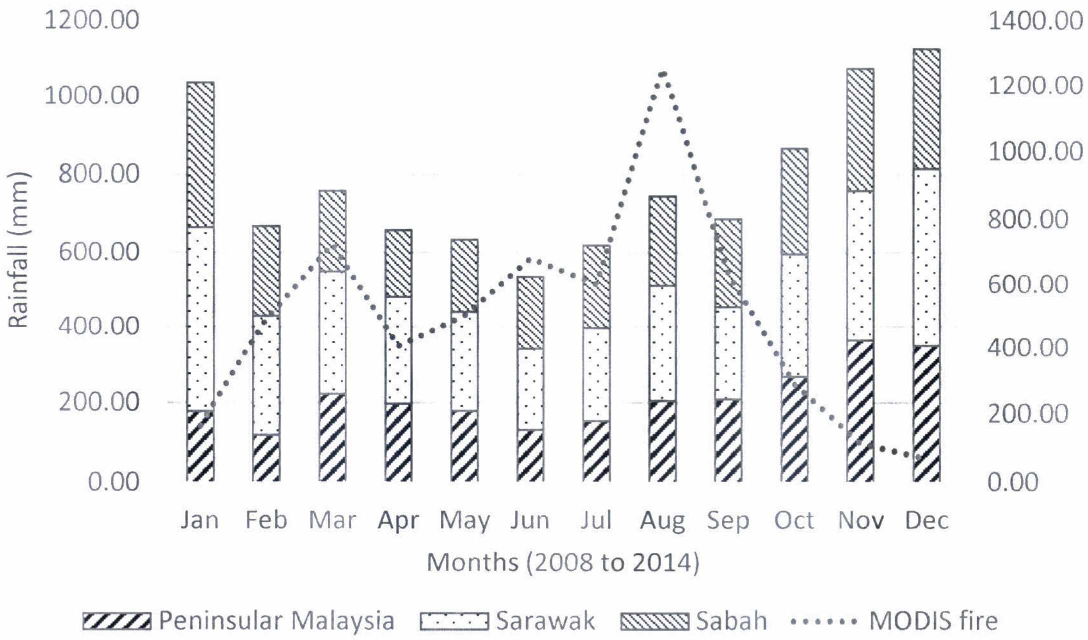

Figure 4.34: Monthly average rainfall data on monthly average MODIS fires in Malaysia from year 2008 to 2014.

The monthly rainfall in Sarawak, Sabah and Peninsular Malaysia had weak and negative correlation with the monthly MODIS fire from year 2008 to 2014 with the R^2 value of 0.1719, 0.1522 and 0.1403 respectively as shown in Figure 4.35. MODIS fire alerts decreased 1.2985 for each millimetre of rainfall in Sarawak; decreased 0.1011 MODIS fire alerts for each millimetre of rainfall in Sabah; and decreased 1.1079 MODIS fire alerts for each millimetre of rainfall in Peninsular Malaysia. The result indicated that the increased in rainfall will slightly decrease the MODIS fire in Malaysia. Rainfall pattern in Sabah are more dispersed compare to Sarawak and Peninsular Malaysia as shown in Figure 4.35, showing that Sabah are experiencing inconsistent rainfall throughout the year.

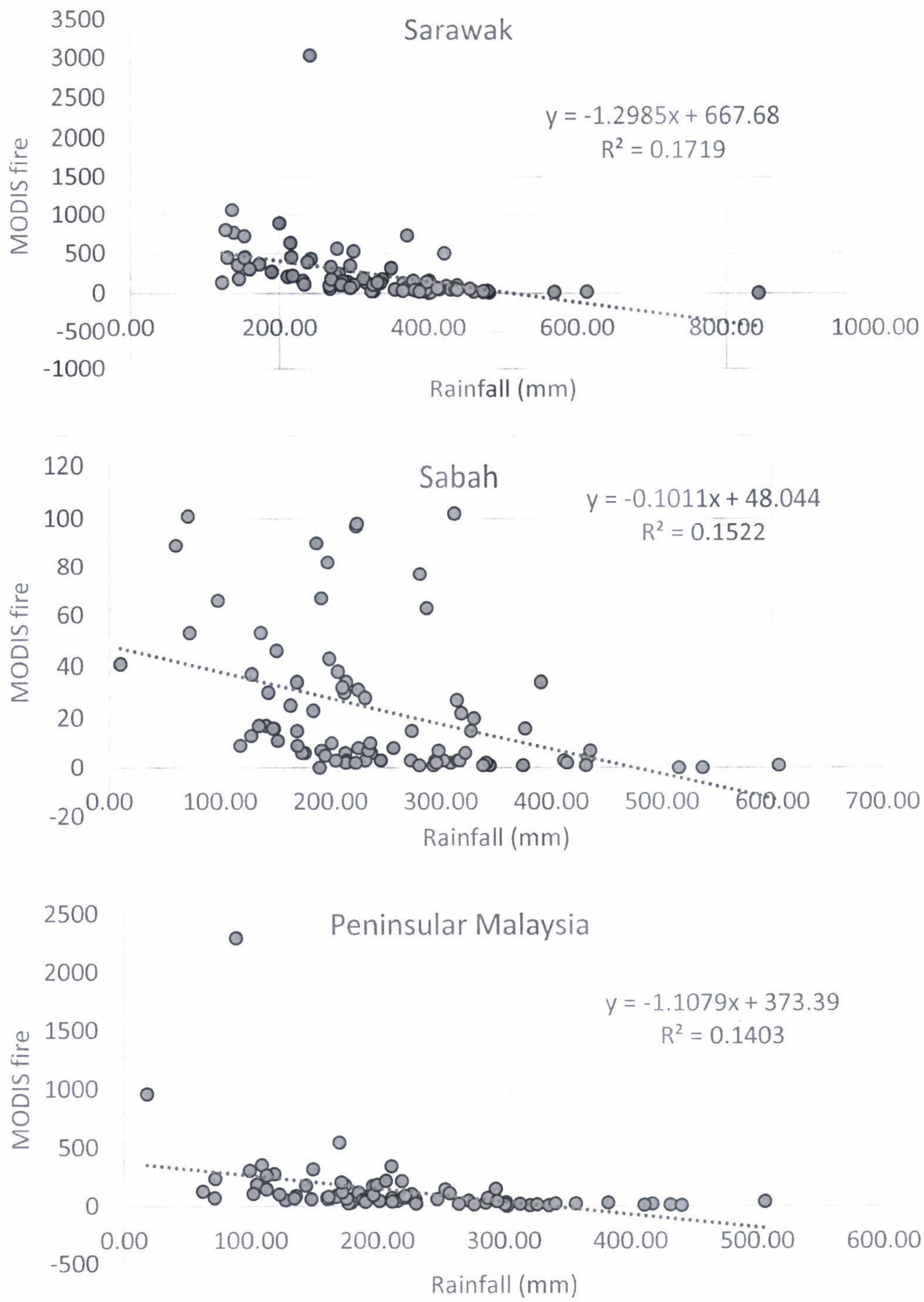

Figure 4.35: Regression analysis of rainfall on MODIS fire in Sarawak, Sabah and Peninsular Malaysia every month from year 2008 to 2014.

6 CONCLUSION

Based on the finding of this study, it is found that the trend of the MODIS fire alerts in Malaysia was decreasing from year 2007 to 2018. Malaysia experienced the highest MODIS fire alerts in year 2009 and August was the months with the most MODIS fire alerts in average among other months. In this study, MODIS fire data was used as detection of forest fire via utilization of orbital remote sensing which allows observation of large areas of land surface every day and repeatedly. However, due to its large spatial resolution of the data, small and smouldering fires are often cannot be detected especially the smouldering of peat fire where it generates a low radiance intensity and a lower temperature than flaming. Further study on forest fire can be done by using VIIRS fire data for fire detection which have better spatial resolution (0.375 km per pixel compare to 1 km per pixel in MODIS fire).

The occurrence of El Ninõ phenomenon had significant impacts on the MODIS fire in Malaysia where it causes drastic increase on the fire alerts during year 2009 and 2014 where Sarawak and Eastern part of Peninsular Malaysia affected the most during the events. Further study can be carried out which base on the El Ninõ events as it is proven to have significant impact on forest fire in Malaysia. The intensity and frequency of the El Ninõ events are increasing as the planet and the warms sea-surface temperatures will increase from about one every 15 years now to every 10 years on average during this century.

Regression analysis showed that the MODIS fire alert did not have much impacts on the plantation of oil palm in year 2002 to 2016 in Malaysia. The same goes to rubber plantation in Malaysia from year 2002 to 2017. MODIS fire had no significant impacts on the oil palm production (2002-2016) and natural rubber production (2002-2017) in Malaysia. Meanwhile, the occurrence of El Ninõ events had decrease the production of oil palm in Malaysia during the 2009 and 2015-16 El Ninõ events. Further study can be done on other agricultural plantation such as paddy, cocoa, pineapple and other crops in Malaysia.

Peatland was the main area which are vulnerable to fire risk in Malaysia especially in the beginning of the drying season in March. The research showed that Peat swamp area had strong positive correlation with the MODIS fire in Peninsular Malaysia from year 2007 to 2017 while having no significant impacts on inland forest, mangrove forest and plantation forest. MODIS fire in Peninsular Malaysia do not have significant impact on the forest production on sawn timber, plywood, veneer and moulding from year 2007 to 2017.

Annual MODIS fire showed a weak positive correlation with the API in Malaysia from year 2002 to 2016 while the monthly MODIS fire showed a strong positive correlation with the monthly API in Malaysia. Further study can be carried out on the carbon emission and other hazardous compounds which are derived from wildfire in Malaysia. Different pollutants required different approaches or methods in order to reduce the resultant impacts.

In this study, rainfall had proven to have negative correlation with forest fire in Malaysia from year 2008 to 2014. If provided with sufficient data, further study can be carried out to look into how forest fire can affect the rainfall patterns in Malaysia. For instance, extensive forest fire may affect the original hydrological cycle of the area such as destruction of river basin which then changing the existing rainfall pattern.

Further research can also be done on the impacts of forest fire towards the changes in forest biodiversity in Malaysia as Malaysia is the top 10 country with vast biodiversity around the globe. Hence, more effective policies and enforcements can be established for wildlife protection when encountered undesired natural causes such as wildfire and El Ninõ phenomenon.

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8 APPENDIX

Appendix 1: EQA 1974 on fire

Section 29A. Prohibition on open burning.

(1) Notwithstanding anything to the contrary contained in this Act, no person shall allow or cause open burning on any premises.

(2) Any person who contravenes subsection (1) shall be guilty of an offence and shall, on conviction, be liable to a fine not exceeding five hundred thousand ringgit or to imprisonment for a term not exceeding five years or to both.

(3) For the purposes of subsection (1) -

"open burning" means any fire, combustion or smouldering that occurs in the open air and which is not directed there through a chimney or stack;

"premises" includes any land.

[Ins. Act A1030:s.3; Am. Act A1102:s.4]

Figure 8.1. EQA 1974: Section 29A. Prohibition on open burning

Section 29AA. Exclusion from "open burning".

(1) The Minister may by order published in the Gazette declare that any fire, combustion or smouldering for the purpose of any activity specified in that order is not open burning as defined in and for the purpose of section 29A so long as such activity is carried out in accordance with or under such conditions as may be specified in the order and not in the place or area specified in the order.

(2) Notwithstanding that any fire, combustion or smouldering is excluded from the definition of open burning under subsection (1) or that it is for the purpose of any activity specified in an order made under subsection (1) , no person shall allow or cause such fire, combustion or smouldering to occur in any area if the Director General notifies, by such means and in such manner as he thinks expedient,-

(a) that the air quality in the area has reached an unhealthy level; and

(b) that the fire, combustion or smouldering for the purpose of any activity other than those specified in the notification would be hazardous to the environment.

(3) In addition to the circumstances referred to in subsection (2) , the Minister may by order published in the *Gazette* specify the circumstances in which no person shall cause any fire, combustion or smouldering for the purpose of any activity specified in the order to occur notwithstanding that it is excluded from the definition of open burning under subsection (1) or that it is for the purpose of any activity specified in an order made under subsection (1).

[Ins. Act A1102:s.5]

Figure 8.2. EQA 1974: Section 29AA Exclusion from "open burning"

Section 29B. Owner or occupier of premises liable for open burning.

If open burning occurs on any premises-

(a) the owner; or

(b) the occupier,

of the premises who has control over such premises shall be deemed to have contravened subsection 29A(1) unless the contrary is proved.

[Ins. Act A1030:s.3]

Figure 8.3. EQA 1974: Section 29B. Owner or occupier of premises liable for open burning

Section 29C. Defence.

In any prosecution under section 29A or 29B, it shall be a defence if the person, owner or occupier of the premises proves -

(*a*) that the open burning occurred outside his control or without his knowledge or connivance or consent; or

(*b*) that he –

(i) took all reasonable precautions; or

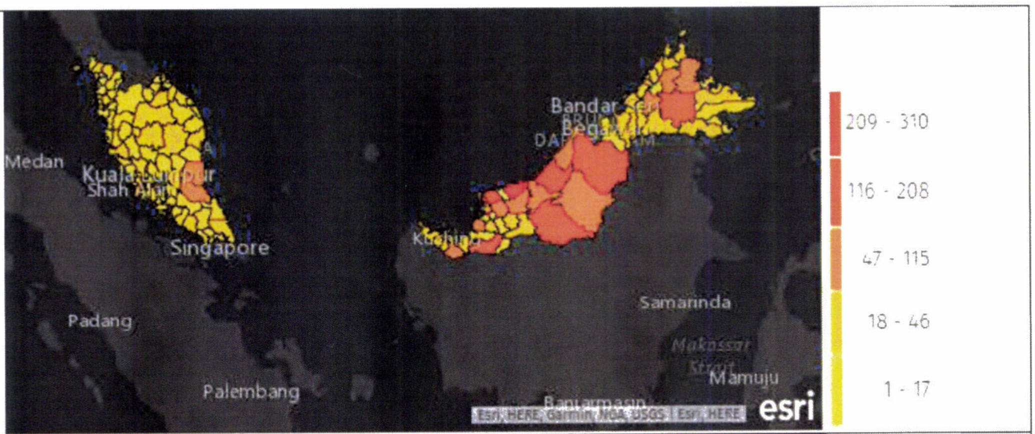
(ii) exercised all due diligence, to prevent the commission of the offence as he ought to have taken and exercised having regard to the nature of his responsibility in that capacity and to all the circumstances.

[Ins. Act A1030:s.3]

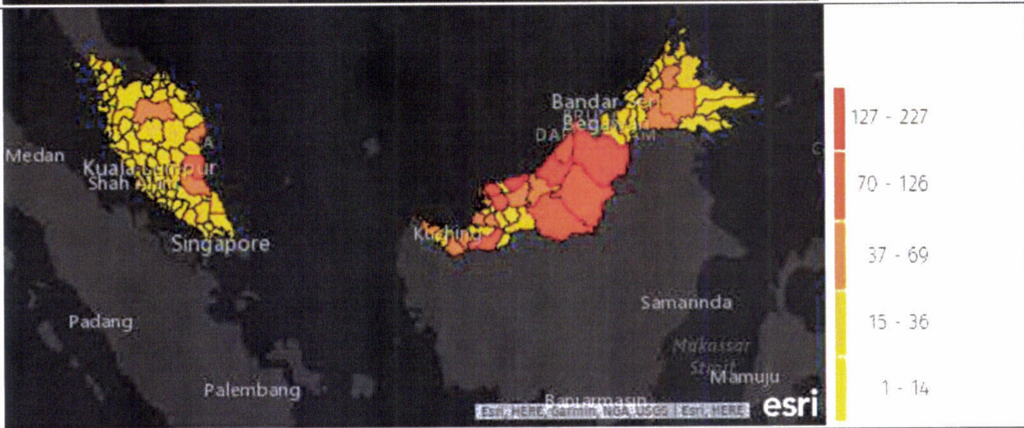
Figure 8.4. EQA 1974: Section 29C. Defence

Appendix 2: Annual heat maps in Malaysia from year 2007 to 2018

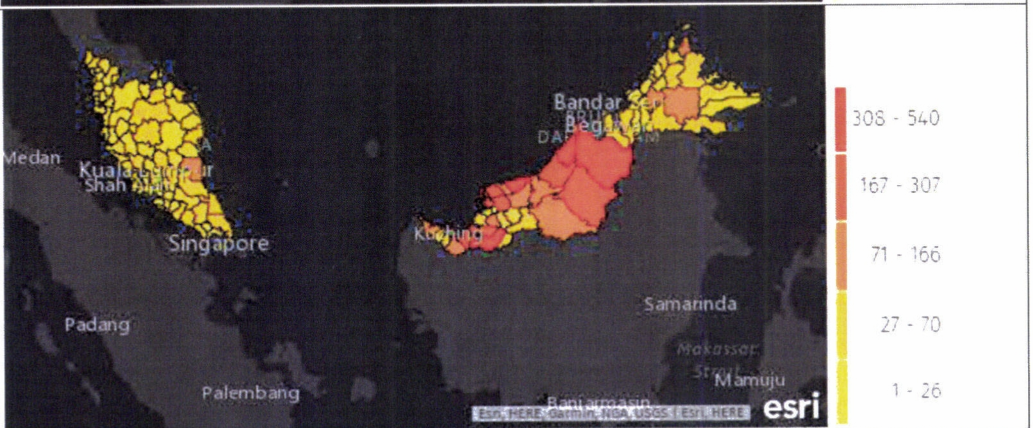
2007



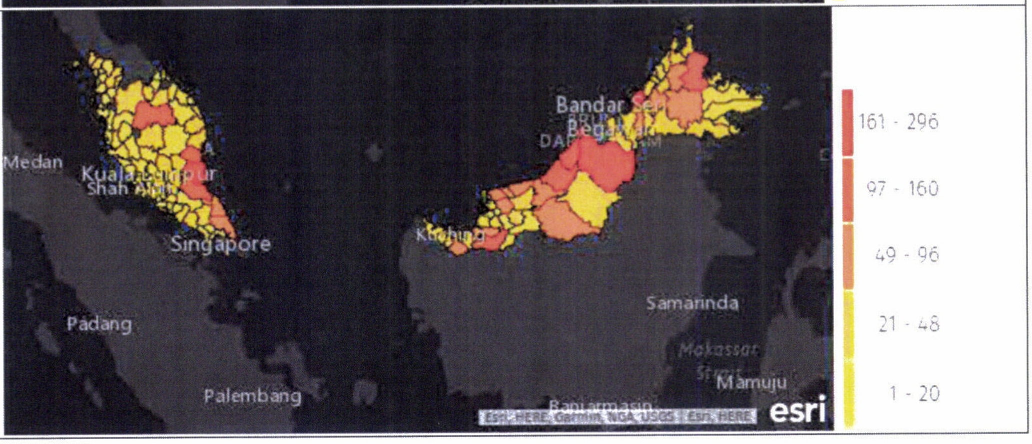
2008



2009



2010



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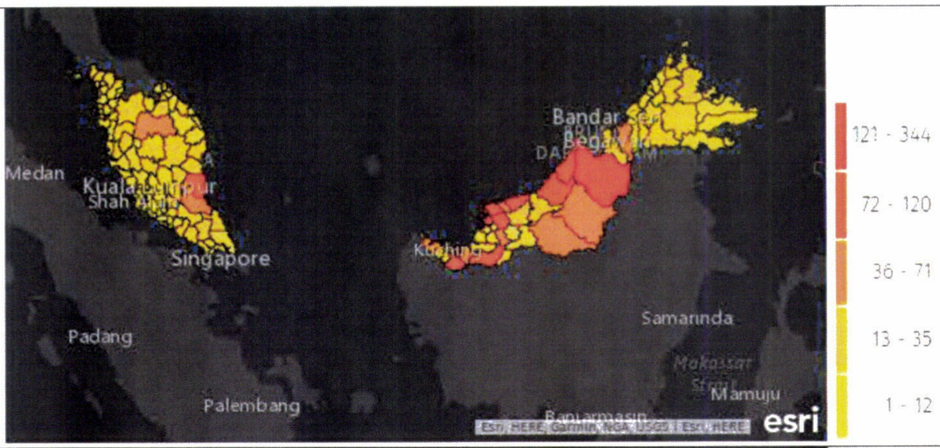

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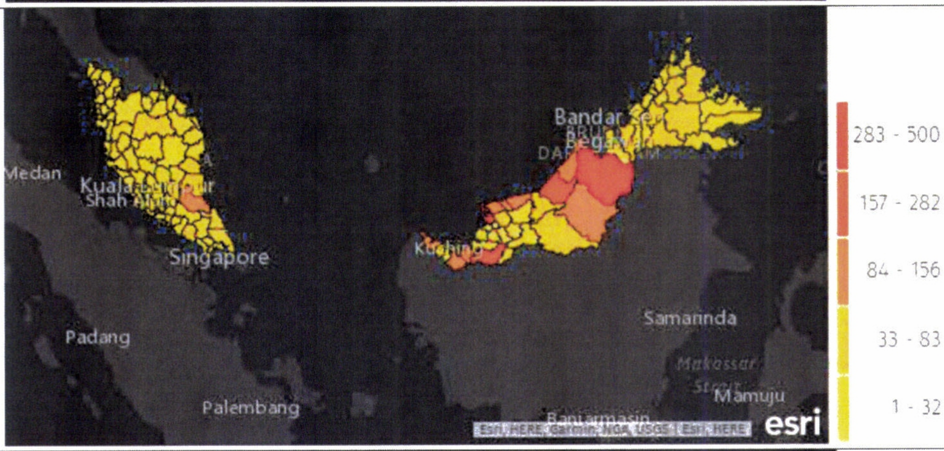

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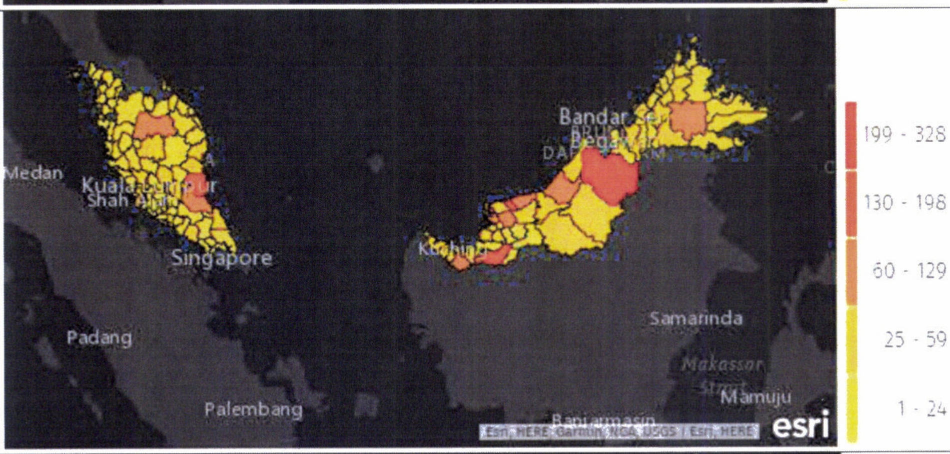

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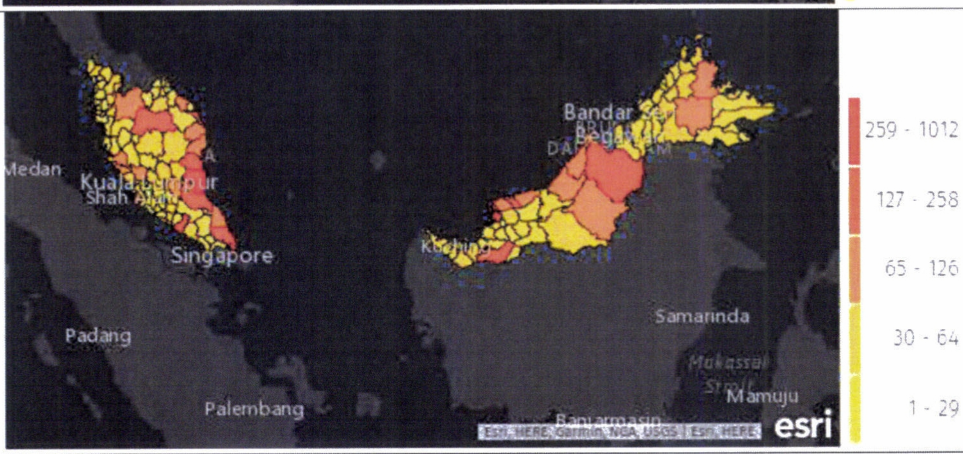

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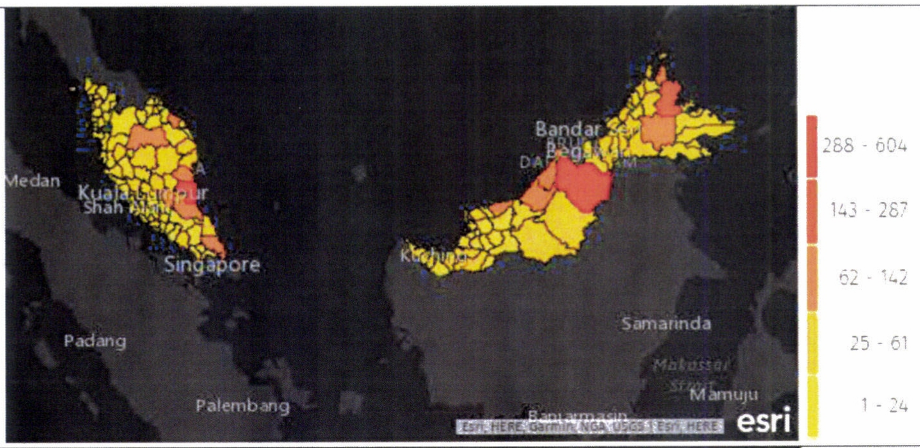

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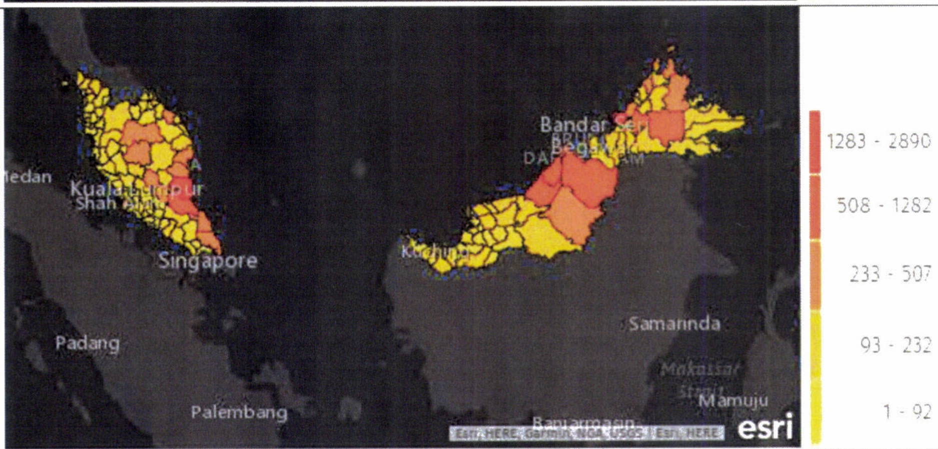

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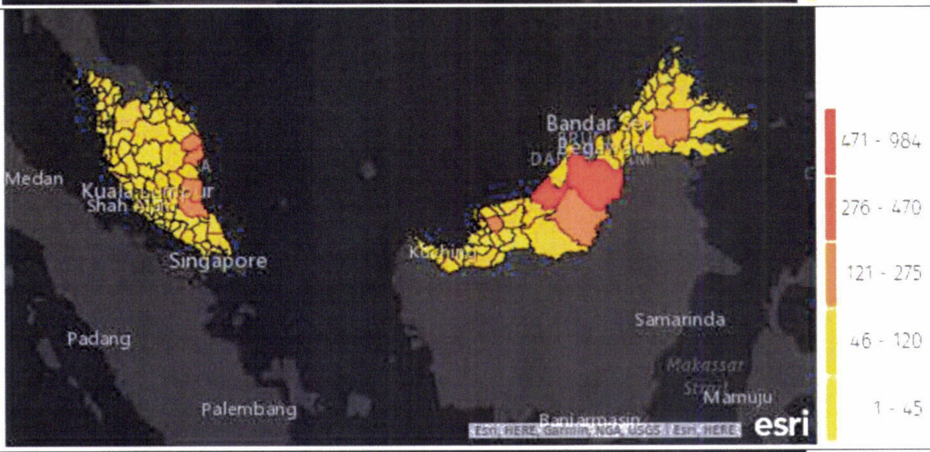

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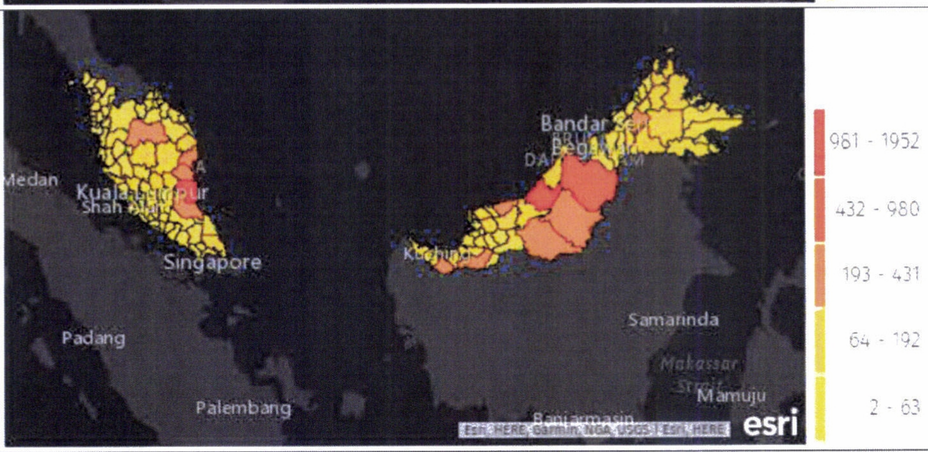
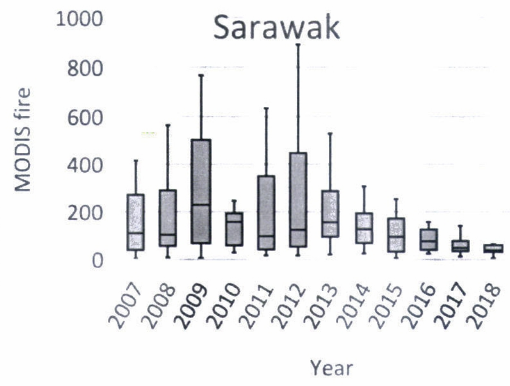
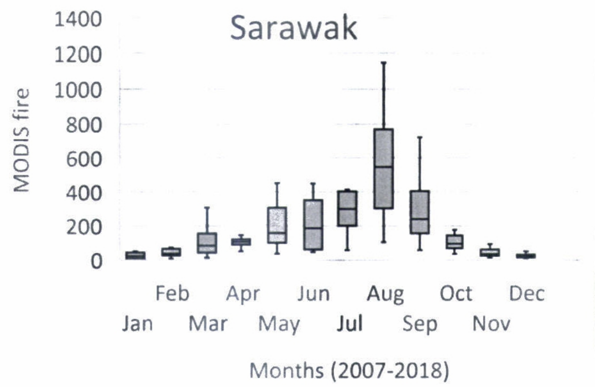
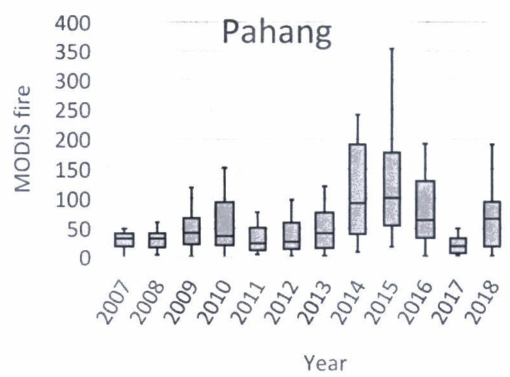
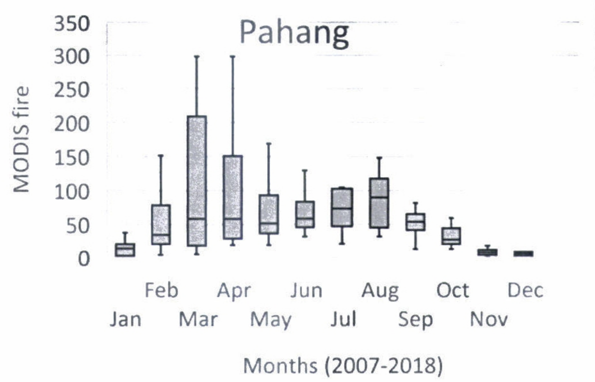
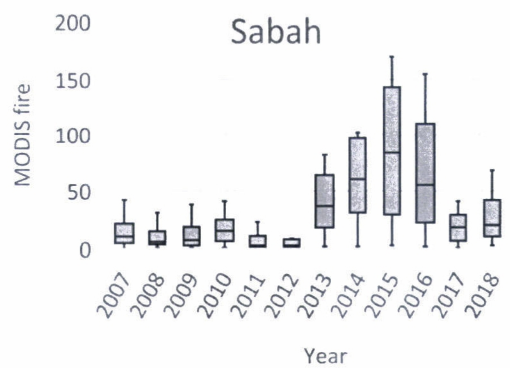
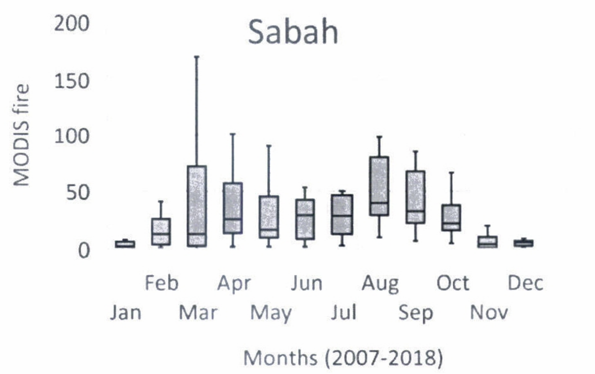
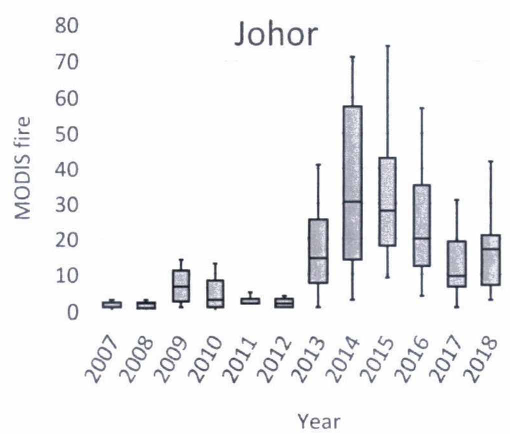
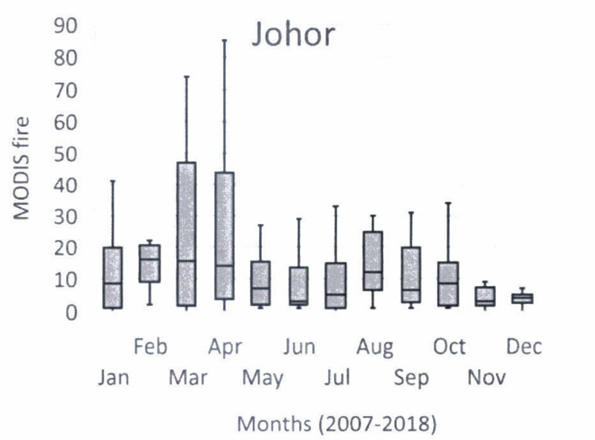
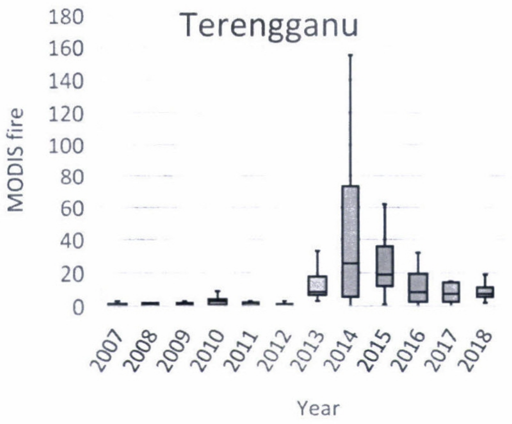
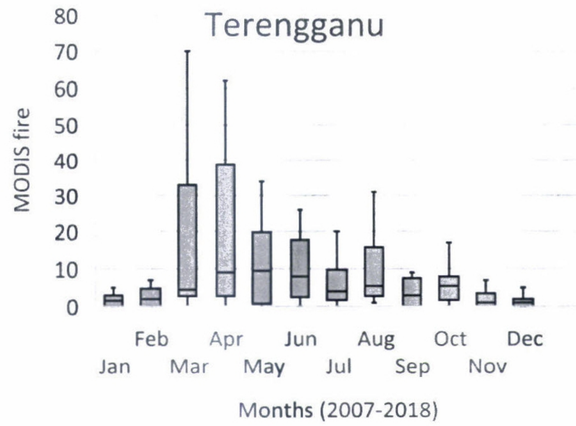
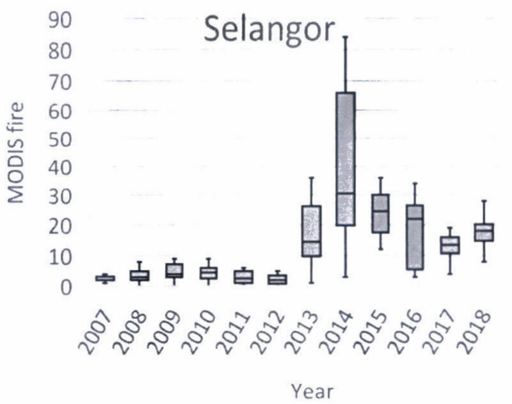


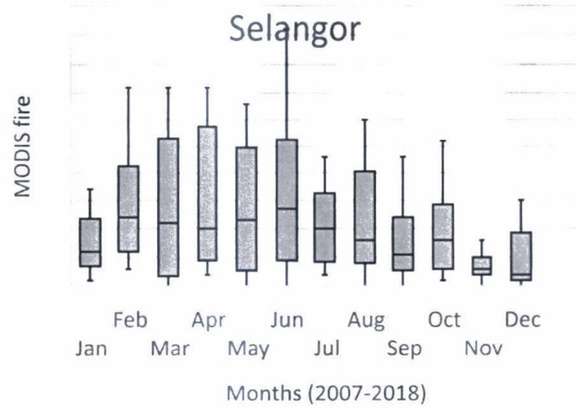
Appendix 3: MODIS fire alerts by States in Malaysia from year 2007 to 2018

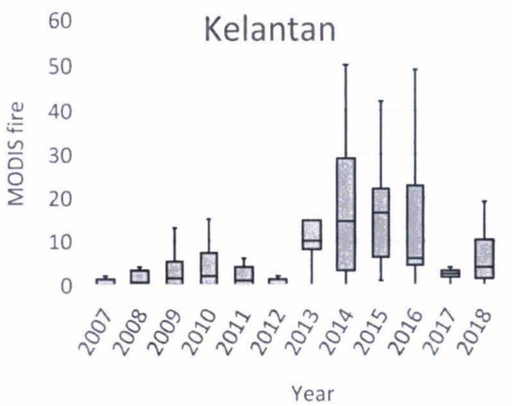
Annual MODIS fire by States	Monthly MODIS fire by States
	
	
	
	

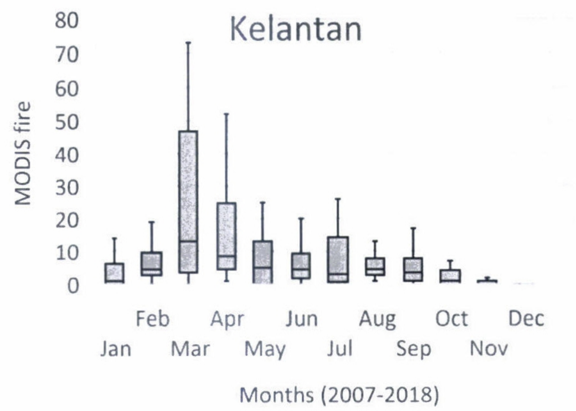

Terengganu
MODIS fire
180
160
140
120
100
80
60
40
20
0
2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year

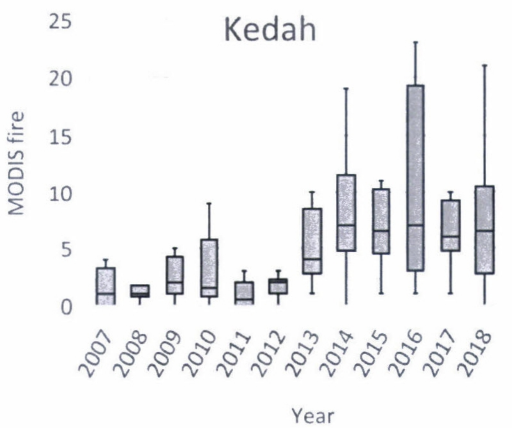

Terengganu
MODIS fire
80
70
60
50
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months (2007-2018)

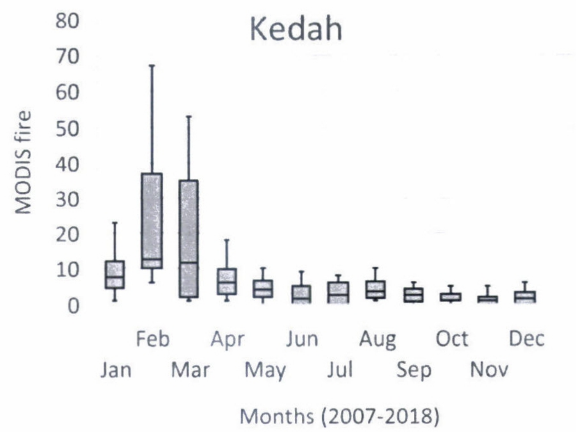

Selangor
MODIS fire
90
80
70
60
50
40
30
20
10
0
2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year

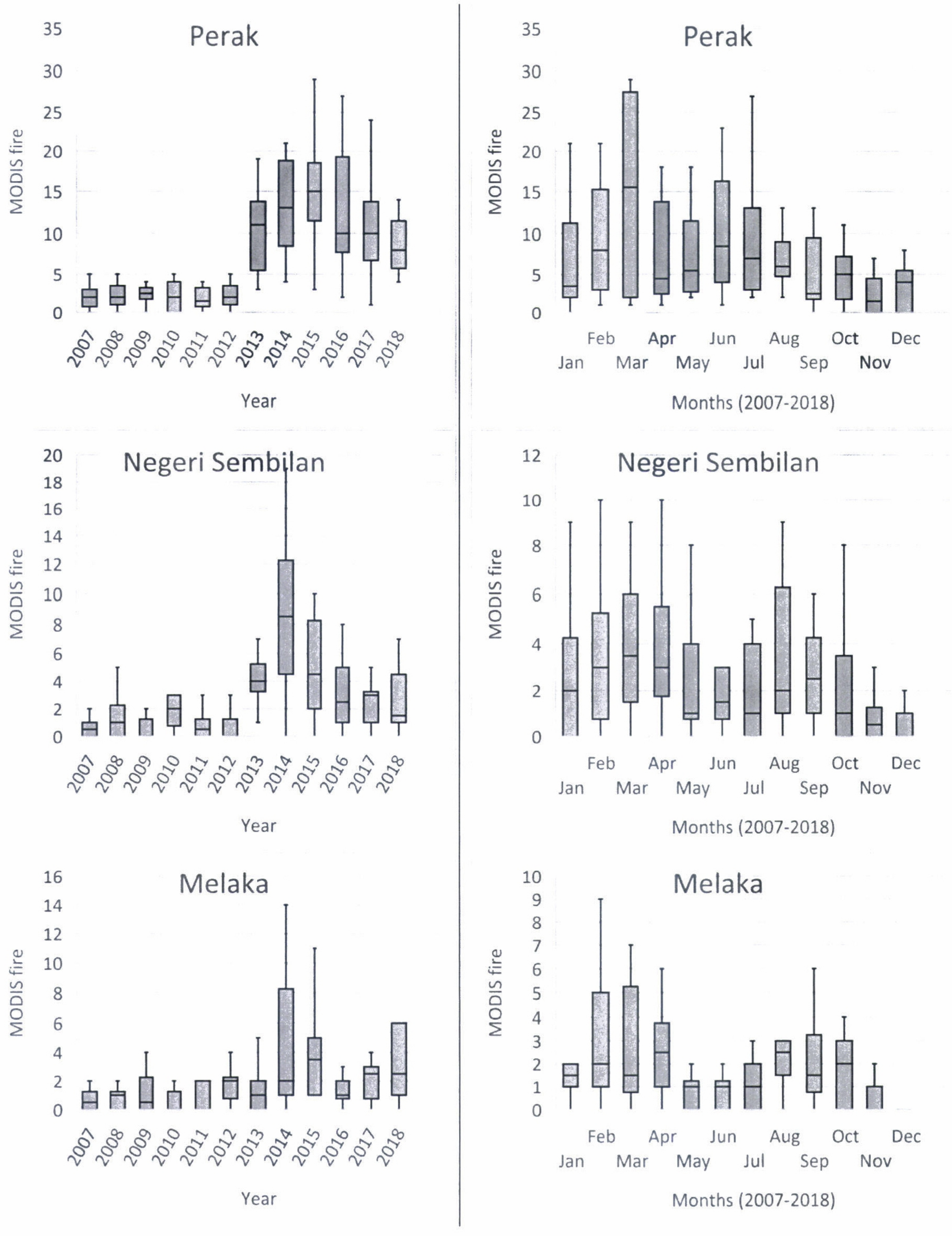

Selangor
MODIS fire
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months (2007-2018)

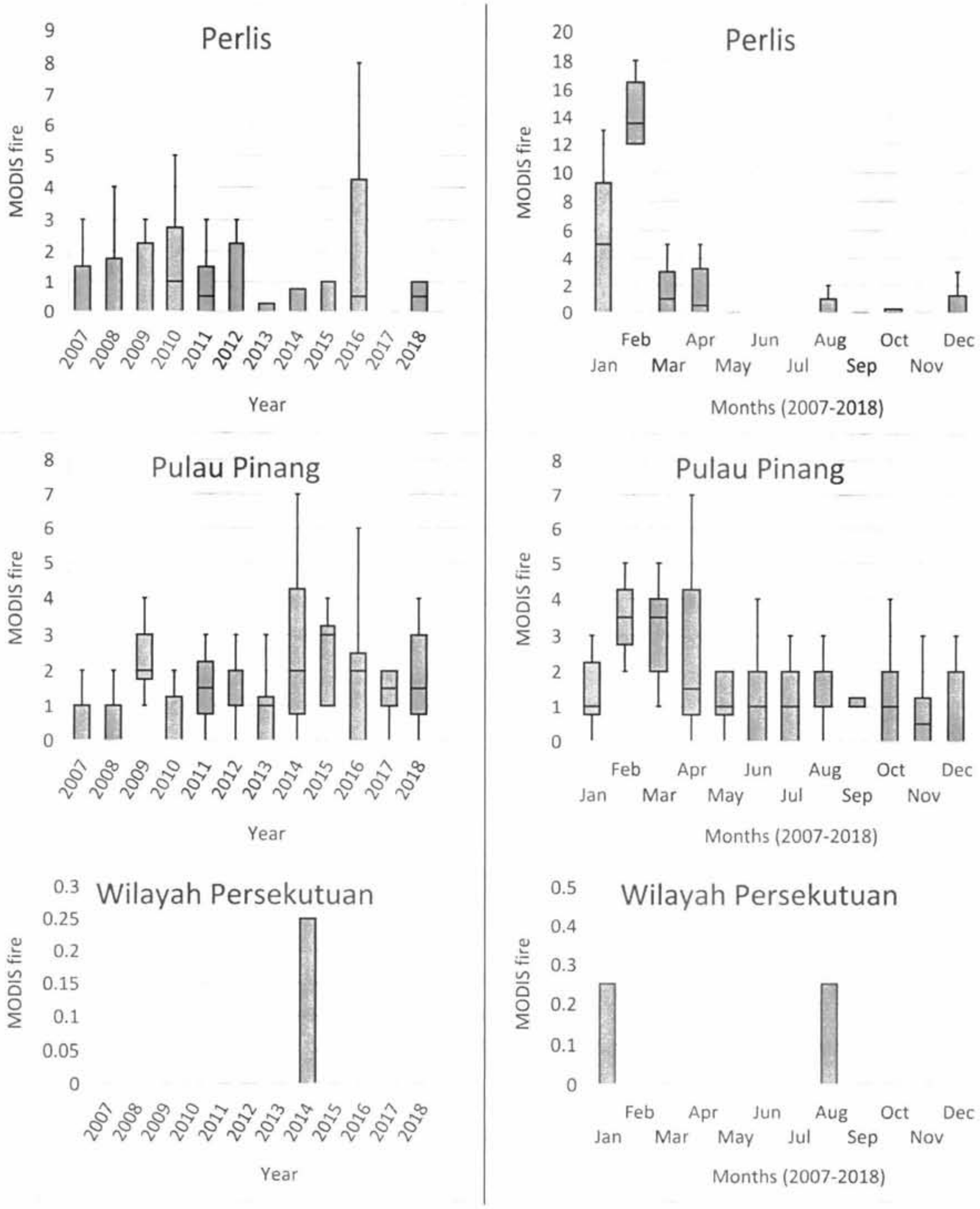

Kelantan
MODIS fire
60
50
40
30
20
10
0
2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


Kelantan
MODIS fire
80
70
60
50
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months (2007-2018)


Kedah
MODIS fire
25
20
15
10
5
0
2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Year


Kedah
MODIS fire
80
70
60
50
40
30
20
10
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months (2007-2018)


Perak
MODIS fire
Year
Perak
MODIS fire
Months (2007-2018)
Negeri Sembilan
MODIS fire
Year
Negeri Sembilan
MODIS fire
Months (2007-2018)
Melaka
MODIS fire
Year
Melaka
MODIS fire
Months (2007-2018)


Perlis
MODIS fire
Year
Perlis
MODIS fire
Months (2007-2018)
Pulau Pinang
MODIS fire
Year
Pulau Pinang
MODIS fire
Months (2007-2018)
Wilayah Persekutuan
MODIS fire
Year
Wilayah Persekutuan
MODIS fire
Months (2007-2018)

NATURAL RESOURCES & ENVIRONMENT ORDINANCE
Natural Resources and Environment
(Fire Danger Rating System) Order, 2004
(Section 18(h))

In exercise of powers conferred by section 18(h) of the Natural Resources and Environment Ordinance (Cap. 84-Laws of Sarawak 1958 Ed.), Majlis Mesyuarat Kerajaan Negeri has made the following Order:

Citation and commencement

1. This Order may be cited as the Natural Resources and Environment (Fire Danger Rating System) Order, 2004 and shall come into force on 19th day of July, 2004.

Application of Order

2. This Order shall apply to burning of timber and vegetative residues on land for development or establishment of commercial plantations.

Pre-established criteria for Burning

3. Burning of timber and vegetative residues in areas to which this Order applies may be undertaken if the criteria and requirements stipulated in the Schedule to this Order are complied with.

Amendment of Schedule

4. The Minister may from time to time, after consultation with the Natural Resources and Environment Board, amend the Schedule.

SCHEDULE

PART I

Pre-Established Criteria for Open Burning Approvals for Plantation at Mineral Soil Areas

Providing the following criteria are diligently and accurately met, open burning may take place without obtaining a written burning permit for the expressed purposes of:

- Clearing, sanitizing and preparing sites for reforestation (panting), oil palm and other plantations;
- Reducing hazardous fuel accumulations to prevent uncontrolled and haze producing wildfires during periods of extended drought;

Providing that:

1. An approved weather station is established and maintained within the area in which open burning is to take place; and,

2. The readings from such station(s) are taken each day as close as possible to 12:00 noon; and,

3. That such readings consist of the following:

    a) *Relative humidity*
    b) *Noon temperature*
    c) *Wind speed*
    d) *24 hr* Rainfall

4. Such readings are transmitted each day to the Natural Resources and Environment Board; and,

5. The Forest Fire Danger Rating is at MODERATE or low level; the drought code as determined by the Forest Fire Danger Rating System is not higher than 75 and the Air Pollution Index (API) does not exceed 100.

6. The forest fire equipment and crew as specified in Table A are immediately available at the burn site prior to light-up and that such equipment and crew are stationed at the site until mop-up is completed.

7. No toxic fire starting materials, such as tyres, plastic or other hazardous combustible starting materials are used, except that prescribed fire forestry drip torches with clean diesel fuel or fuses.

8. A standard fire guard must be established around the area to be burned and such guard must be constructed to mineral soil, free of roots and debris and must not be less than 18 inches in width and in any case must not exceed one bulldozer blade width and all debris created must be cast to the "cold" side of the fire guard.

9. Light-up should take place as early as possible during the day and mop-up must commence as soon as open flame subsides and must continue until no smoke is visible (except for an overnight break if all visible smokes are not eliminated before dark).

10. A burning plan contained in Table B is completed prior to the burning and is complied with during the burning period, including during the mop-up phase.

11. Mop-up operations must commence as soon as it is safe to do so and such operations must continue until no further smoke is showing.

12. All smoke must be eliminated from the burn area within 24 daylight hours after the burn has been completed and mop-up commenced (24 hour rule).

13. Separate burns of up to 50 ha. may be ignited providing each burn is considered to be, and is dealt with as a separate and distinct burn, each with its own burn plan, crew and equipment.

14. At no time, burning should exceed more than 30 percent of an total area prepared or planned for burning.

15. Prior to light up, the Open Burning and Monitoring Unit of the NREB must be notified in writing or by fax or email of the intention to burn.

For peat soils all the foregoing conditions apply except that the following additional conditions shall also apply and a written permit must be obtained from the NREB prior to burning;

1. Test holes must be established at several locations (not less than 3 per hectares) on the burn site prior to light-up and;

2. Standing water is noted to collect at a depth of not more than ½ meter from the soil surface and;

3. At least seven "duff"* probes of not less than two meters each must be added to the standard equipment list as outlined in Appendix A.

Any fire pursuant to these criteria would have to be immediately extinguished if so ordered by any officer of the Natural Resources and Environment Board, Fire and Rescue Department or Forest Department, if or should conditions under such criteria become adverse or altered adversely or the fire is in danger or spreading uncontrollably or dangerously.

Note 1.

When mobile (wheeled) tankers are available, they should not be used as a stationary source of water in lieu of collapsible relay tanks. Instead they should be used as tenders to keep the relay tanks replenished until such time as the fire has been completely mop up.

Note 2.

In the event that a suitable water source (such as a pond or stream) is within operational distance of the burn site, the requirement for a water relay tank may be dispensed with.

Note 3.

The foregoing list of equipment presumes that all the necessary and ancillary hardwares such as valves, back-checks, nozzles and other hardware will be part of the normal equipment.

* a duff probe is a cylindrical pipe with a hose fitting at one end and the other end pointed and closed; the pipe portion of the probe has several holes to allow water to escape into the surrounding biomass when the probe is driven into the ground.

PART II

Forest Fire Equipment and Crew Size Requirements for Open Burning for the Establishment of Plantations

A. When the burn size is four hectares or less the following minimum crew and equipment must be maintained at the site until mop-up is completed;

- Burn crew must not be less than four (4) persons.
- Collapsible or portable water storage of not less than 1000 liters.
- One light weight fire pump capable of producing not less that 75 psi and a flow of 150 litres per minute.
- Not less than 300 meters of 25mm or 38 mm discharge hose with instantaneous couplings.
- Not less than two (2) back pumps of a minimum size of 16 litres.
- A minimum of two (2) shovels.
- A minimum of two (2) pulaskis.
- For peat sites only – three (3) ground probes with 38 mm instantaneous couplings.

B. When the burn size is greater than four hectares but less than 10 hectares the following minimum crew and equipment must be maintained at the site until mop-up is completed;

- Burn crew must not be less than 6 persons.
- Collapsible or portable water storage of not less than 2000 litres in one or more tanks.
- One light or medium weight fire pump capable of producing a minimum of 75 psi and up to 240 litres per minute flow.
- Not less that 450 meters of 25mm or 38mm discharge hose with instantaneous couplings.

- Not less than four (4) back pumps of a minimum size of 16 litres.
- A minimum of four (4) shovels.
- A minimum of three (3) pulaskis.
- For peat sites only – a minimum of four (4) ground probes with 38 mm instantaneous couplings.

C. When the burn size is greater than 10 hectares but less than 20 hectares the following minimum crew and equipment must be maintained at the site until mop-up is completed;

- Burn crew must be not less than 10 persons.
- Collapsible or portable water storage of not less than 3000 litres in one or more tanks.
- One medium weight fire pump capable of producing a minimum of 75psi and not less than 240 litres per minute flow.
- Not less than 750 meters of 38mm discharge hose with instantaneous couplings.
- Not less than five (5) back pumps with a minimum size of 16 litres.
- A minimum of five (5) shovels.
- A minimum of four (4) pulaskis.
- For peat sites only – a minimum of six (6) ground probes with 38 mm instantaneous couplings.

D. When the burn size is greater than 20 hectares but less than 50 hectares the following minimum crew and equipment must be maintained at the site until mop-up is completed;

- Burn crew must not be less than 15 persons.
- Collapsible or portable water storage of not less than 5000 litres in one or more tanks.
- One medium weight fire pump capable of producing a minimum of 75psi and not less than 240 litres per

minute flow and one high performance fire pump capable of producing a minimum of 350psi and not less than 360 litres per minute flow.

- Not less that 900 meters of 38mm discharge hose with instantaneous couplings.
- Not less than seven (7) back pumps with a minimum size of 16 litres.
- A minimum of seven (7) shovels.
- A minimum of six (6) pulaskis.
- For peat sites only – a minimum of eight (8) ground probes with 38 mm instantaneous couplings.

E. When the burn size is greater that 50 hectares but less than 100 hectares the following minimum crew and equipment must be maintained at the site until mop-up is completed;

Note: **All burns of greater than 50 ha. (regardless of soil type) require written permits from the NREB prior to the burns.**

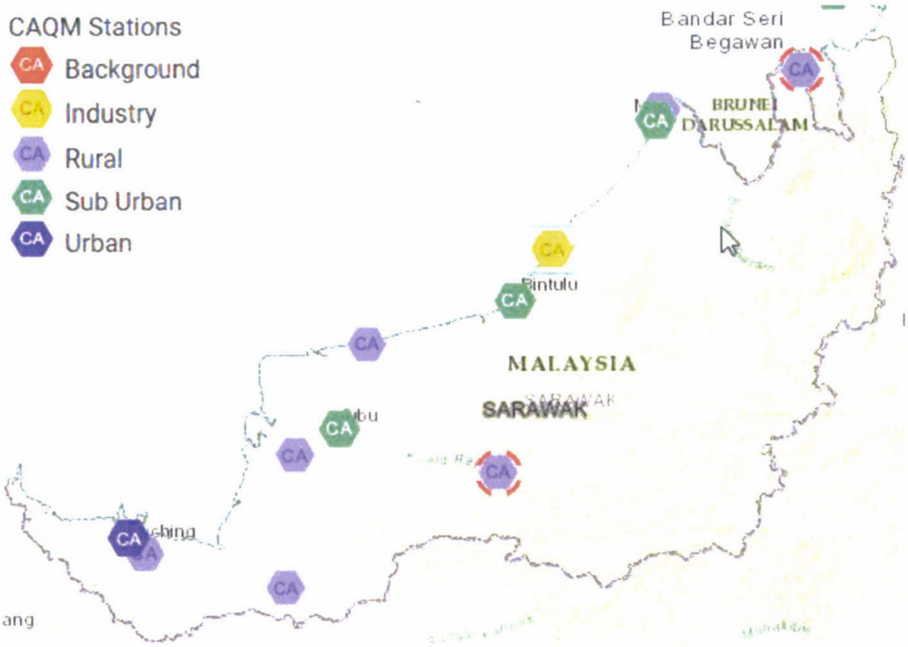
- Burn crew must be not less than 20 persons.
- Collapsible or portable water storage of not less than 7500 litres in one or more tanks.
- Two high performance pumps capable of producing a minimum of 350psi and not less than 360 litres per minute flow.
- Not less than 1200 meters of 38mm discharge hose with instantaneous couplings.
- Not less than nine (9) back tanks with a minimum size of 19 litres
- A minimum of nine (9) shovels.
- A minimum of eight (8) pulaskis.
- For peat sites only – a minimum of ten (10) ground probes with 38mm instantaneous couplings.

Note 1:
When wheeled tanks are used they should be used as tenders to fill portable or collapsible tanks placed at the burn site. Using wheeled or mobile tanks as a fixed water source at the fire site should be avoided as this will lead to leaving the site without water when the tender (mobile tank) goes dry – the tender should dump into the portable holding tank and then immediately return for additional loads until the fire is mopped-up and there s no further need for water.

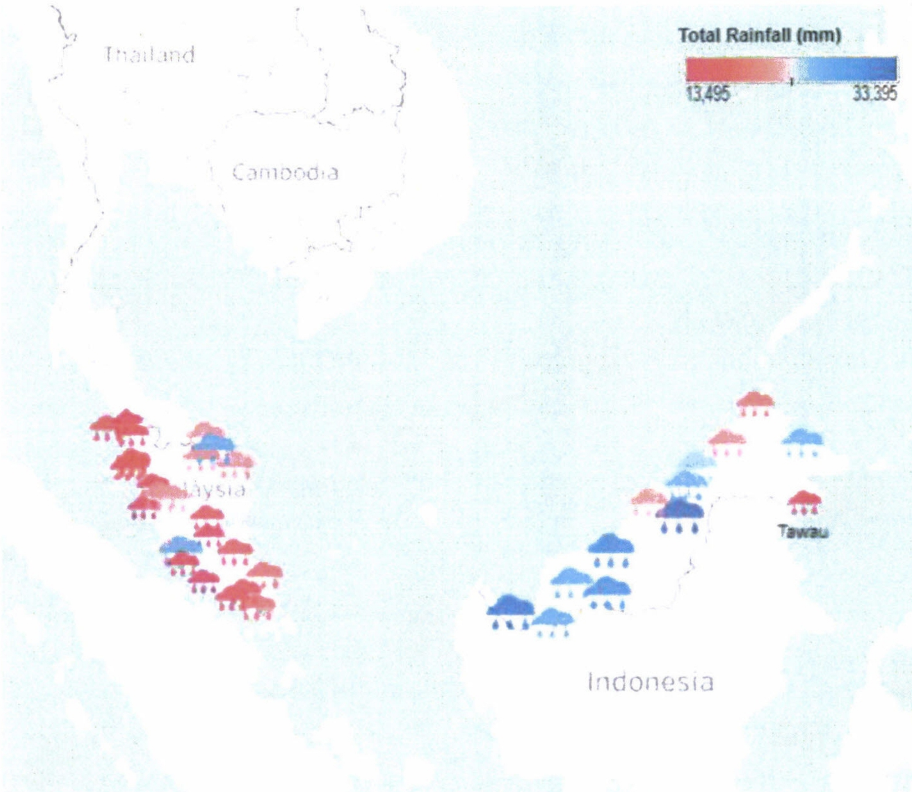
Note 2:
If a suitable water source, from which pumps may be operated, is within operational distance of the burn (and noted on the burning plan) the requirement for water storage at site may be dispensed with.

(ABDUL GHAFUR BIN SHARIFF)
Clerk,
Majlis Mesyuarat Kerajaan Negeri

Appendix 5: API and rainfall stations for data collection



Allocation of API stations around Sarawak (source: NREB).



Allocation of rainfall station in Malaysia from year 2008 to 2014 (OR Technology Malaysia).