EARLY DETECTION OF POTENTIAL FOREST FIRES USING SATELLITE REMOTE SENSING TECHNIQUES

AIDA HAYATI BINTI MOHD HASSAN

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ABSTRACT

In 1997/1998, Malaysia experienced one of the most severe forest fire episodes in history as a consequence of a prolonged dry season following the El- Niňo phenomenon. Since then, uncontrolled fires, atmospheric pollutions and haze remained as a common problem throughout the dry period in this region. The estimated cost of the damage caused by forest fires in Malaysia is about RM816.47 million a year. The loss by forest fire episodes has brought to light the importance of developing better tools for effective forest fire management systems. In this research, three sets of computer programmes were designed for: detecting hot spots; computing the fire risk index and generating spatial analysis for detected fires. Remote sensing and GIS techniques have both been integrated in this work. Eventually, a simple yet robust early warning system for forest fire detection in Malaysia has been devised. Thermal bands of MODIS (Moderate Resolution Imaging Spectroradiometer) were used to extract hot spot information and to generate a fire risk map. Proximity analysis was carried out using an extension in ArcView GIS software. The results from this research were compared with forest fire occurrence information from the Fire and Rescue Department of Malaysia (FRDM) and information of rainfall and temperature from the Malaysian Meteorological Services (MMS). High correlation (R^2 = 0.8) was found between temperature derived from MODIS and the temperature obtained from the MMS. Forest fire map generated from the study also gave a high accuracy (71%). Normalized Difference Vegetation Index (NDVI) values derived from MODIS were found to be highly correlated (R^2 = 0.7 and R^2 = 0.85) with rainfall and temperature data obtained from the MMS, respectively. Hence, the output of the research shows that this system can be used as an early warning system mechanism to mitigate forest fire incidence and can be upgraded into a more complex system to enhance its functioning.

ABSTRAK

Pada tahun 1997/98, Asia Tenggara telah melalui episod kebakaran hutan yang paling ekstrem di dalam sejarah akibat musim kemarau yang panjang kesan fenomena El-Niňo. Berikutan daripada peristiwa itu, pencemaran atmosfera dan jerebu telah menjadi masalah yang lazim pada musim kemarau di sini. Anggaran kerugian daripada kebakaran hutan di Malaysia ialah sebanyak RM816.47 juta setahun. Kerugian yang dialami akibat daripada episod kebakaran hutan tersebut telah menyedarkan banyak pihak tentang kepentingan untuk membina sistem pengurusan kebakaran hutan yang efektif. Di dalam kajian ini, 3 set program komputer telah direka untuk: mengesan titik panas; mengira indeks risiko kebakaran, dan menjana analisa spatial. Teknik remote sensing dan GIS telah digabungkan di dalam kajian ini. Dengan itu, sebuah sistem amaran awal yang ringkas tetapi efektif untuk mengesan kebakaran hutan telah dicipta. Jalur termal dari MODIS (Moderate Resolution Imaging Spectroradiometer) telah digunakan untuk mengekstrak informasi titik panas dan menjana peta risiko kebakaran hutan. Analisa spatial dilakukan dengan menggunakan fungsi dari perisian ArcView. Hasil dari kajian ini dibandingkan dengan data kebakaran hutan dari Jabatan Bomba dan Penyelamat, Malaysia, dan maklumat taburan hujan serta suhu dari Jabatan Kajicuaca, Malaysia. Nilai korelasi yang tinggi (R^2 = 0.8) telah diperolehi diantara suhu yang diekstrak dari MODIS dengan suhu dari Jabatan Kajicuaca. Peta kebakaran hutan yang diperolehi juga mempunyai ketepatan yang tinggi (71%). Nilai *Normalized Difference Vegetation Index* (NDVI) yang diperoleh dari MODIS juga mencatatkan korelasi yang tinggi (R^2 = 0.7 and R^2 = 0.85) dengan data jumlah hujan dan suhu dari Jabatan Kajicuaca. Dengan itu, hasil dari kajian ini menunjukkan bahawa ianya boleh digunakan sebagai satu mekanisma sistem amaran awal untuk mengurangkan kejadian kebakaran hutan dan boleh diperkembangkan lagi menjadi sebuah sistem yang lebih kompleks untuk meningkatkan lagi fungsinya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

EEPSEA	-	Economy and Environment Program for Southeast Asia
NDVI	-	Normalized Difference Vegetation Index (NDVI)
BT	-	Brightness Temperature
VCI	-	Vegetation Condition Index
TCI	-	Temperature Condition Index
VH	-	Vegetation Health Index
FRDM	-	Fire Rescue Department of Malaysia
MMS	-	Malaysian Meteorological Services
KBDI	-	Keetch and Byram Drought Index
FWI	-	Canadian Forest Fire Weather Index
FBP	-	Canadian Forest Fire Behavior Prediction System
CFFDRS	-	Canadian Forest Fire Danger Rating System
FOP	-	Fire Occurrence Prediction System
FFMC	-	Fine Fuel Moisture Code (FFMC)
DMC	-	Duff Moisture Code
DC	-	Drought Code
ISI	-	Initial Spread Index
BUI	-	Buildup Index
FFDM	-	Forest Fire Danger Meter
API	-	Application Programming Interface
GIS	-	Geographical Information System
VAS	-	Visible Infrared Spin Scan Radiometer and Atmospheric Sounder

SWIR	-	Shortwave infrared
LWIR	-	Longwave infrared
µm	-	Micrometer (1 meter = 1 000 000 µm)
km	-	kilometer
mm	-	Milimeter
DMSP	-	Defense Mapping Satellite Program
TM	-	Thematic Mapper
K	-	Kelvin
NOAA	-	National Oceanic and Atmospheric Administration
AVHRR	-	Advanced Very High Resolution Radiometer
MSS	-	Multispectral Satellite
MODIS	-	Moderate Resolution Imaging Spectroradiometer
SNR	-	Signal noise to ratio
NEΔT	-	Noise-equivalent temperature difference
CZCS	-	Nimbus Coastal Zone Color Scanner
HRIS	-	High Resolution Infrared Sounder
GES DAAC	-	Goddard Earth Sciences Distributed Active Archive Centre
GCPs	-	Ground control points
RMS	-	Root Mean Square
VIS	-	Visible
NIR	-	Near infrared
$NDVI_{min}$	-	Multiyear absolute minimum of NDVI
$NDVI_{max}$	-	Multiyear absolute maximum of NDVI
h	-	Planck's constant (Joule per hertz)
c	-	Speed of light in vacuum (m/s)
k	-	Boltzmann gas constant (Joule/Kelvin)
λ	-	Band or detector centre wavelength (m)
T	-	Temperature (Kelvin)
BT_{min}	-	Absolute minimum of smoothed weekly brightness temperature
BT_{max}	-	Absolute maximum of smoothed weekly brightness temperature
T_4	-	Brightness temperature of 4 micrometer channel

T_{11}	-	Brightness temperature of 11 micrometer channel
$\check{T}$	-	Respective mean of the channel for valid neighbouring pixel
N_{aw}	-	Number of water pixel adjacent to the fire pixel
N_{ac}	-	Number of cloud pixel adjacent to the fire pixel
δ	-	Mean absolute deviation of the respective channel for valid neighboring pixel
C	-	Confidence level
TIFF	-	Tagged Image File Format
UTM	-	Universal Transverse Mercator
MOD01	-	Raw MODIS data
MOD02	-	Level 1B MODIS data
MOD03	-	Geolocation MODIS data
MOD035	-	MODIS Cloud Mask product
MOD14	-	MODIS Fire product

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 General Introduction

By the end of 1990, an estimated area of 5.55 million hectares of forest covered 42.2% of Peninsular Malaysia's total land area (Khali, 2001). Of the total, 5.51 million hectares are classified as evergreen rainforest consisting of 4.94 million hectares of Dipterocarp Forests, 0.46 million hectares of peat swamp forest, 0.11 million hectares of mangrove forest while the remaining 0.04 million hectares consists of estate and agricultural areas developed since as far back as 1957 (Mohd Shahwahid, 2004). Generally, the low temperature and moist condition in the natural forests that give rise to a high rate of litter decomposition contribute to the low occurrence of large scale forest fire in Malaysia.

In the last three decades however, large tracts of forestlands have been planted with monoculture crops. Some 1.65 million hectares of rubber and 2.62 million hectares of oil palm have been established, posing a higher fire risk than the natural forests (Hussin, 2000). Also logging activities in the natural forests produce a lot of waste, thereby increasing flammable material, and opening canopies which reduce the water retention capacity of the forests, become more susceptible to fire.

In the past 10 years, there has been an increasing incidence of major fires especially peat forest fires in the Southeast Asia region. In Malaysia, the worst forest fire was reported in Sabah from 1983 to 1985 (Mat Isa, 2001). In these incident, over one million hectares of mostly logged-over forests were burnt. In East Kalimantan, Indonesia, a fire occurrence that started in September 1982 lasted for 10 months and affected more than 35,000 hectares of peatlands (Suhaili and Mohd Yunus, 1999). It has been said that Indonesia needs about 500 years to return the forest back to its primary condition. Anyway, to capture back the ecosystem equalization and variation in the biology seems to be impossible. This problem is further compounded by the fact that some of the affected areas have been burned twice or more. If left unabated, peat areas that will be at risk to burn will be on the increase.

In terms of forest type, the peat forests suffered the most with 63,331 hectares (98%) burned in 1998 (Table 1.1). Land clearing for agriculture by the farmers in the dry season was identified as the most likely cause of the forest fires.

Forest fires could cause a serious environmental problem. During the 1997 big fire event, about 70 million people were forced to breathe polluted air because of the haze from the forest fire. At least six people died from direct health effects and many more were hospitalised (Wan Ahmad, 2001). Poor visibility that was brought about by haze increased the risk of accidents on land. In some regions, schools and shops were forced to close down and business matters were hindered. The tourism industry experienced the worst impact from this event due to the decrease in the number of visitors and a large number of flights cancelled as a precaution.

Table 1.1: Area of forest type burned in 1998 in Malaysia.

Forest Type	Area (Hectares)	Probable cause
Peat Forests	63,331	Land clearing by farmers and indigenous people, hunting and other unknown causes.
Secondary Forest	432	Land clearing by farmers
Degraded Heath Forest	310	Land clearing by farmers
Heath Forest	250	Unidentified
Logged-over Forest	120	Unidentified
Forest Plantation	26	Snapped electrical transmission lines, cigarettes.
Montane Forest	15	Campers
Coastal Swamp Forest	15	Clearing by fishing villagers
Total	**64,499**	

(Source: Ahmad Zainal, 2000)

Consequently, the risk from forest fires to private property and human life has increased making fire fighting more complicated, expensive, and dangerous. Indonesia lost RM16.72 million in the battle to fight the fires (Suhaili and Mohd Yunus, 1999). According to the Economy and Environment Program for Southeast Asia (EEPSEA) study, the estimated incremental cost of the haze damage to Malaysia during the months of August to October in 1997 was RM816 million (Table 1.2).

The transboundary nature that exists in the forest fire problems has suggested a network approach for sharing of information and experience. In October 1997, 1262 firefighters from Malaysia were deployed to Sumatra and Kalimantan to combat the forest fires (Wan Ahmad 2001). Besides supplying help, Malaysia also gained some experience and knowledge which is useful for addressing similar issues.

Table 1.2: Costs of the damage caused by smoke haze in Malaysia.

Type of Damages	RM Million	Percentage
Adjusted cost of illness	36.16	4.43
Productivity loss during the emergency	393.51	48.19
Tourist arrival decline	318.55	39.02
Flight cancellations	0.45	0.06
Fish landing decline	40.72	4.99
Cost of fire fighting	25.00	3.06
Cloud seeding	2.08	0.25
Total	**816.47**	**100.00**

(Source: Mohd Shahwahid and Jamal,1999)

1.2 Problem Statement

Forest fires arise from a sudden encounter between oxygen and fuel material at high temperatures. They would usually damage the forest ecosystems resulting in a decline in biological diversity, environmental degradation, soil erosion, atmospheric and water pollution. The main pollution is the occurrence of haze. Only in the past decade have researchers realized the important contribution of biomass burning to the global budgets of many radiatively and chemically active gases such as carbon dioxide, carbon monoxide, methane, nitric oxide, tropospheric ozone and elemental carbon particulates (Kaufman, 1998; Hashim *et. al*., 2004). These factors result in negative implications on the socio-economic, health and well being of the human. Besides that, the effects of forest fires are not local, they are cumulative and contribute to regional and global problems such as deforestation, global warming, or desertification.

Peat forest fires are a common problem in South East Asia including Malaysia. Controlling peat fires is extremely difficult. Peat will burn from the bottom of the soil layer. The fires burn in a slow and patchy manner, and are widespread. The fires spread slowly through the thick peat layers, making it extremely difficult to detect and extinguish them. In the case of peat, although the surface fires are extinguished, the underground peat will continue to burn unless a large amount of water is used to completely drench the peat layers.

Usually, peat fires are hard to notice. Peat fires are deep underground and can burn uncontrolled and unseen for several months. This fire is potentially a great threat to human health than the Kuwaiti oil fires and hard to extinguish. One cannot notice underground fires (such as peat fires) until occurrence of smouldering smoke, which are then naturally followed by fires. During this time, fires have already burned all the organic material under the ground. Fortunately, much has changed in the field of fire fighting. Today, an early warning indicator is an important component in the total fire management system. Due to the difficulty of detecting underground peat fires and the absence of detailed fire records in many areas, the possibility of using remote sensing satellite observations will be examined.

Human eyes cannot detect subtle differences in thermal infrared energy emanating from the underground peat fires because they are only primarily sensitive to short wavelength visible light from 0.4 to 0.7µm. Human eyes also are not sensitive to the reflective infrared in the range of 0.7 to 3.0µm, or thermal infrared energy in the range of 3.0 to 14µm. Nowadays, thermal detectors which are sensitive to thermal infrared radiation have been designed and manufactured widely. With this advance thermal sensor, thermal remote sensing related studies such as thermal characteristic of the landscape, forest fires and urban heat are possible.

1.3 Objectives

The objectives of the study are divided into three:

i) To determine hot spots from MODIS data;

ii) To derive a fire risk map based on biophysical parameters from MODIS data, and

iii) To develop forest fires interface using remote sensing data derived from objectives (i) and (ii).

1.4 Scope

MODIS datasets were used in this study for several reasons; namely (i) the thermal (10.78-11.28μm) bands of MODIS were specifically developed to detect hot spots along with well developed algorithm for forest fire purpose (Kaufman, 1998). In addition, this band is also used in extracting brightness temperature (BT) as a parameter in generating the vegetation index; and (ii) the visible (620-670nm) and near infrared (841-876nm) bands of MODIS are suitable to extract Normalized Difference Vegetation Index (NDVI), which is a parameter to generate the fire risk map.

Two biophysical parameters are used to generate the vegetation indices, namely Normalized Difference Vegetation Index (NDVI) and brightness temperature (BT). Three indices were developed from the biophysical parameters; namely (i) Vegetation Condition Index (VCI), for estimation of cumulative moisture impacts on vegetation; (ii) Temperature Condition Index (TCI), for estimation of thermal impacts on vegetation; and (iii) Vegetation Health Index (VH), for estimation of moisture and thermal impacts on vegetation. Cumulative of four weeks of VH were used to generate the fire risk map.

Cumulative daily MODIS datasets from 2000 to 2005 were processed in order to generate the fire risk maps. This is however excluding the datasets that covered more than 10% cloud. In order to minimize the cloud effects, the NDVI and BT datasets were composited over a 7-day period. This will reduce the cloud effects.

1.5 Significance of the Study

During the 1997-98 Indonesian forest fires, many national governments and international agencies tried their best to help Indonesia and other affected countries to suppress the fires in order to minimize the impacts. However, there was a lack of information about active forest fires and base line data about water resources, transport networks, land use patterns, topography types and location of settlements. Although emphasis was given to immediate fire suppression, it is realized that there should be long-term strategy measures to mitigate the occurrence of disasters due to forest fires in future. The establishment of an effective early warning mechanism was the focus of discussion by most of the workers involved with forest fire mitigation in the ASEAN region.

This study can provide an alternative to conventional techniques in detecting and monitoring forest fire in an effective way. It is necessary to develop an effective system for forest management in order to control forest fires occurrence. The final result of this study will provide a valuable tool for fire agencies as a fire-prediction strategy. It will provide benefit as one of the technologies used to assist monitoring and evaluation of forest fire risk. Nowadays, with the existence of advanced technology, we can reduce the damage of forest fires.

The development of a detecting and mitigating system in this study can be an advantage to the Department of Environment and the Department of Forestry, and also to other related agencies in order to improve forest management and sustainability. It can also be utilized for various purposes such as teaching and increasing awareness among decision makers in the region about the availability of remote sensing technology to mitigate disasters. Satellite remote sensing monitoring can also provide advance weather information or data that can assist in studying the evolution of fires as they develop.

1.6 Area of Study

The area of study is Peninsular Malaysia, located from 1^{o} 20’ N to 6^{o} 40’ N latitude, and 99^{o} 35’ E to 104^{o} 20’E longitude (Figure 1.1). The total area of Peninsular Malaysia is 131,794 km^2. Topographically, Peninsular Malaysia is characterized by extensive coastal plains in the east and west, hilly and mountainous region with steep slopes in the middle and undulating terrain in other parts of the peninsular.

The climate of Malaysia is typical of the humid tropics and is characterized by year-round high temperature and seasonal heavy rain. Temperature ranges from $26^{o}C$ to $32^{o}C$ and rainfall ranges from 2,000 mm to 4,000 mm per annum.

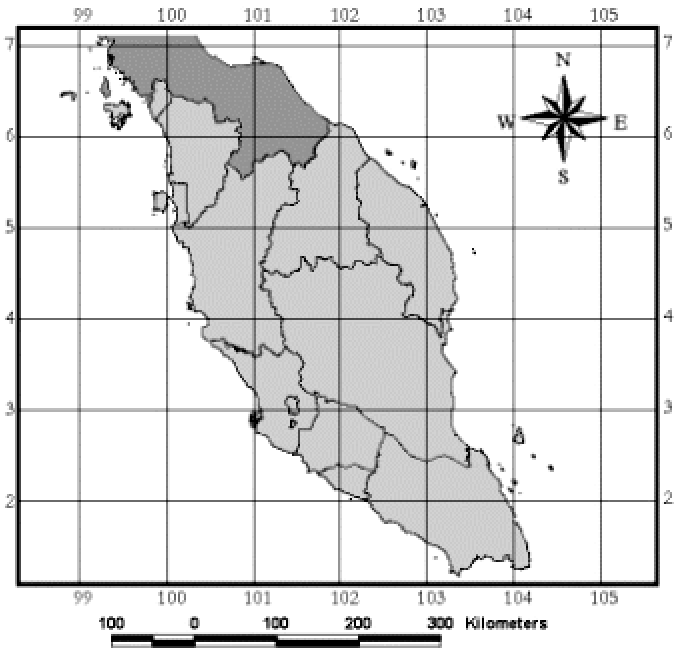

Figure 1.1: Peninsular Malaysia

1.7 Thesis Structure

This thesis will consist of 6 chapters namely; (1) Introduction; (2) Forest Fire Model; (3) Methodology; (4) Forest Fire Interface; (5) Result and Analysis; and (6) Conclusions and Recommendations.

The first chapter of this study discusses introduction to forest fires occurrences. The objectives, scope, problem statement and significance of the study are also included in this chapter.

Chapter 2 explains about forest fires briefly from the terminology of the fire itself, to the method used to detect and monitor it. The methods discussed include conventional techniques, as well as the combination of conventional and remote sensing technology.

The method used in this study is discussed in Chapter 3. This chapter explains in detail the materials used in this study. The methods used to extract hotspots, Normalized Difference Vegetation Index (NDVI), brightness temperature (BT), Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health (VH) are explained together with the analysis.

Chapter 4 explains the forest fire interface from the early phase of its development until the end users requirement.

Chapter 5 consists the results obtained from this study. The analysis is carried out at the end of the chapter. For hot spot analysis, the results from this study are compared to ground truth forest fire occurrences data obtained from the Fire Rescue Department of Malaysia (FRDM). In order to determine the accuracy of the temperature derived from MODIS data, the derived temperature were compared with field temperature obtained from Malaysian Meteorological Services (MMS).

The last chapter, namely Chapter 6, discusses the conclusions derived from this study and also the recommendations to improve this study in future.