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FOREST FIRE HAZARD RATING ASSESSMENT MAPPING IN SABAH, MALAYSIA

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By

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FOREST FIRE HAZARD RATING ASSESSMENT MAPPING IN SABAH, MALAYSIA

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LEEWE BIN YUKILI

February 2015

Chair: Ahmad Ainuddin Nuruddin, PhD
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Forest fires can dramatically affect the ecosystem and has a great impact on the human life as well. In Malaysia, especially Sabah, forest fires has become a serious phenomenon recorded since early 1998. In order to reduce the threat of forest fires incidence and avoid any potential damage, it is very crucial to carry out an assessment of the forest fires hazard rating. This study is based on three objectives; to identify the hotspot patterns, to analyze the Fire Weather Index (FWI) trend for five years period (2006 - 2010) for Sabah and to generate the maps of forest fire hazard zone for the state of Sabah. The hotspot data were obtained from the Agency Remote Sensing Malaysia (ARSM) and Moderate Resolution Imaging Spectroradiometer (MODIS). Weather data was obtained from Malaysian Meteorological Department and Sabah Forestry Department for analysis and deriving of the Canadian Forest Weather Index (CFWI). Hotspot density analysis was carried out for five years period to observe for the annually and monthly hotspot pattern and also by division in the state. In forest fires hazard mapping, data of forest type, road, town, river and hotspot point were developed as layers using Geographical Information System (GIS) software. The Weighted Overlay Analysis were used to composite and generate five categories ranging from the very high fire hazard to the very low fire hazard. Results showed that, during the study, the highest hotspots were obtained in March 2010 with 445 hotspots, and the lowest was in January 2009 where no hotspot was detected. Then, the interior registered the highest number of hotspots with 1159 hotspots followed by 697 in Sandakan, 475 in the West Coast South, 327 in the West Coast North and 226 in Tawau. In the FWI analysis, Kudat station had the highest Extreme, High and Medium fire danger indices with 22 days, 140 days and 440 days respectively during the study period. In forest fire hazard map, about 53 % of the study areas have been classified as low risk, 35 % medium and only 1 % classified as very high risk to forest fire incident. Lastly, forest fire hazard map was validated with past fire incidences data that was collected from Forestry Department of Sabah website. The results of the study showed that out of 15 fire incidences in 2011 and 2012, 7 incidences

had occurred in very high and high risk areas. As a result, the fire hazard map can be used to improve the forest fire management more effectively and systematically.

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

PENILAIAN PEMETAAN TAHAP BAHAYA KEBAKARAN BAGI NEGERI SABAH, MALAYSIA.

Oleh

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Pengerusi: **Ahmad Ainuddin Nuruddin, PhD**
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Kebakaran hutan boleh memberikan kesan yang dramatik terhadap ekosistem dan impak yang besar terhadap kehidupan manusia. Di Malaysia, terutamanya Sabah, kebakaran hutan telah menjadi fenomena yang serius semenjak awal tahun 1998. Dalam usaha untuk mengurangkan ancaman kebakaran hutan dan mengelakkan sebarang potensi kerosakan, adalah sangat mustahak untuk menjalankan penilaian ke atas kebakaran hutan yang berlaku. Kajian ini dijalankan berdasarkan kepada tiga objektif; untuk mengenal pasti corak titik panas, untuk menganalisa trend indeks cuaca kebakaran bagi tempoh lima tahun (2006 - 2010) dan juga untuk menghasilkan peta zon bahaya kebakaran hutan khususnya bagi negeri Sabah. Data titik panas diperolehi dari Agensi Remote Sensing Malaysia (ARSM) dan Moderate Resolution Imaging Spectroradiometer (MODIS). Data cuaca pula diperolehi dari Jabatan Meteorologi Malaysia dan Jabatan Perhutanan Sabah untuk analisis Indeks Cuaca Perhutanan Kanada (CFWI). Analisis ketumpatan titik panas telah dijalankan bagi tempoh lima tahun untuk melihat corak titik panas tahunan dan bulanan mengikut bahagian di negeri ini. Dalam menjana peta tahap bahaya kebakaran hutan, data litupan hutan, jalan, bandar, sungai dan titik panas telah dibentuk sebagai lapisan-lapisan mengunakan perisian Sistem Maklumat Geografi (GIS). Analisis Wajaran Lapisan pula telah digunakan untuk menggabungkan dan menjana lima kategori bahaya kebakaran yang terdiri daripada sangat bahaya kepada sangat rendah bahaya. Hasil kajian sepanjang kajian ini menunjukkan jumlah titik panas tertinggi dicatatkan pada bulan Mac 2010 dengan jumlah 445 titik panas, manakala yang terendah dicatatkan pada bulan Januari dengan nilai sifar titik panas dicatatkan. Kemudian, wilayah Interior menunjukkan jumlah titik panas tertinggi dengan 1159 titik panas diikuti oleh 697 di Sandakan , 475 di Pantai Barat Selatan, 327 di Pantai Barat Utara dan 226 di Tawau. Dalam analisis FWI pula, menunjukan stesen Kudat mencatatkan nisbah tertinggi pada Ekstrim, Tinggi dan Sederhana bahaya api dengan 22 hari, 140 hari dan 440 hari masing-masing dalam tempoh kajian. Bagi peta bahaya kebakaran, kira-kira 53% daripada kawasan kajian telah diklasifikasikan sebagai berisiko rendah, 35% sederhana dan hanya 1% diklasifikasikan berisiko sangat tinggi terhadap ancaman kebakaran hutan. Akhir sekali, peta bahaya kebakaran telah disahkan dengan data kejadian kebakaran yang lalu

yang dikumpul daripada laman web Jabatan Perhutanan Sabah. Keputusan kajian menunjukkan bahawa daripada 15 insiden kebakaran pada tahun 2011 dan 2012, 7 kejadian telah berlaku di kawasan berisiko tinggi dan tinggi. Peta bahaya kebakaran dapat digunakan untuk menambahbaik aktiviti pengurusan kebakaran hutan yang lebih efektif dan sistematik.

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I certify that a Thesis Examination Committee has met on 16 February 2015 to conduct the final examination of Leewe bin Yukili on his thesis entitled "Forest Fire Hazard Rating Assessment Mapping in Sabah, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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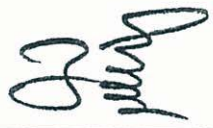

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This is to confirm that:

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LIST OF ABBREVIATIONS

ARSM	Agency Remote Sensing Malaysia
AVHRR	Advanced Very High Resolution Radiometer
BUI	Buildup Index
CFWI	Canadian Fire Weather Index
DC	Drought Code
DMC	Duff Moisture Code
DMSP	Defense Meteorological Satellite Program
ENSO	El Nino–Southern Oscillation
ERDAS	Earth Resources Data Analysis System
ERS	European Radar Satellite
ETM	Enhanced Thematic Mapper
EQR	Environmental Quality Report
FDI	Fire Danger Index
FFRM	Forest Fire Risk Mapping
FFHM	Forest Fire Hazard Mapping
FFMC	Fine Fuel Moisture Code
FHRI	Fire Hazard Rating Index
FIRMS	Fire Information for Recourse Management System
FMU	Forest Management Units
FRIM	Forest Research Institute of Malaysia
FRP	Fire Radiation Power
FWI	Fire Weather Index
FWIC	Fire Weather Index Calculator

GIS	Geographical Information System
GPS	Geographical Positioning System
HRV	High Resolution Visible
HRVI	High Resolution Visible and Infrared
IFFN	International Forest Fire News
IRS	Indian Remote Sensing Satellite
ISI	Initial Spread Index
KBDI	Keetch Byram Drought Index
LiDAR	Light Detection and Laser
MIR	Middle Infrared
MODIS	Medium Resolution Imaging Spectrometer
MRSA	Malaysian Remote Sensing Agency
MSS	Multispectral Scanner
MTC	Malaysian Timber Council
NDVI	Normalized Different Vegetation Index
NOAA	National Oceanographic and Atmospheric Administration
OLS	Ordinary Least Squares
RADAR	Radio Detection and Ranging
RGB	Red Green Blue
SFM	Sustainable Forest Management
SPOT	*Satellite Pour I' Observation de la Terra*
TDI	Topographic Danger Index
TM	Thematic Mapper
WDI	Weather Danger Index
WGEA	Working Group on Environmental Auditing

WWF World Wildlife Fund

CHAPTER 1

INTRODUCTION

1.1 General Background

Forest is a unique ecosystem made up of a many living organisms and dominated by trees (WGEA, 2010). Trees are important components of the environment that buffer the earth, provide shelter and food to other living things as well as being a natural habitat for flora and fauna. Besides, they also serve as carbon storage and conserve soil and water which are essential to human well being (Beedlow *et al*., 2004; Saner *et al*., 2012; Syafinie and Ainuddin, 2013).

Incidences of forest fires have always been one of the major causes leading to forest destruction. Forest fires causes dramatic impact to human lives, properties and livelihoods (Fowler, 2003). Furthermore, they also caused the loss or reduction of biodiversity and infrastructure besides affecting vegetation (Syaufina and Ainuddin, 2011), wildlife (WWF, 2009), soil (Certini, 2005) and water quality (Ainuddin *et al.*, 2006; Smith *et al*., 2011). In addition, it caused the smoke levels to increase at regional, national and global levels (Sastery, 2000; Tacconi *et al.*, 2007; Tangang *et al.*, 2010). Every year, forest fires create a massive ecological damage worldwide and our country has no exception. The occurrence of the worst forest fire in Southeast Asia occurred in Indonesia during the strong El Nino drought from 1986-1987, 1994 and 1997-1998, in which approximately 3.5 million hectares, 4.5 million hectares and 9.5 million hectares of forest land were burned (Karki, 2002) respectively.

Ganz (2002) reported that, in Malaysia, most forest fires are often associated with peat swamp, secondary forest, plantations and forests logged forest fires. Associated with peat swamp forest fire, the fire had been identified as one of the major threats to the destruction of peat swamp forest habitats in particular. For example, the Raja Musa forest reserve experienced the most forest fire occurrences per year and this has become a trend in Malaysia (Ainuddin, 1998).

In Sabah, fire is still being used as a source in agricultural practices, plantations and other development projects. Although the use of fire is not encouraged in agriculture practices and plantations, there are still some unscrupulous people who still use fire where they burn weeds or plants which are not useful in the open. As a result of the negligence, forest fires occur and spread to the forest reserves and resulted in the destruction of natural resources.

However, in this case, no detailed studies on the causes and effects of fire and the occurrence of forest fires had been done, thus making it difficult to assess the real situation. Therefore, a detailed study and further researches on the patterns of forest fires

that occurred in Malaysia should be expanded. One of the technologies available for forest fire and impact assessment is the use of remote sensing and Geographical Information System (GIS). Many studies of forest fire management using remote sensing technique include the estimation of burnt areas (Pereira, 2003), fire detection and mapping (Siegert and Hoffmann, 2000), risk assessment (Sheriza *et al.,* 2010), impact assessment, (Potapov *et al.,* 2007) and monitoring (Pradhan, 2009). According to Peng *et al.* (2007), remote sensing technique is very suitable and the most effective way to assess the risk of fire in almost real time.

The advances of these two technologies, remote sensing and GIS allow some forest management activities to be done more effectively and systematically. One application is using remote sensing and GIS is mapping forest fire hazard areas. Forest fire hazard zoning is very important in forest fires management for identification, mapping and monitoring the forest fires occurrence. Forest fires hazard zone is the location where the fire may have started and thus, would spread to other areas. Many studies have been conducted to develop forest fire hazard map using remote sensing (Patah *et al.,* 2001; Peng *et al.,* 2007; Sheriza *et al.,* 2010; Caceres, 2011). However, in the preparation of the map of forest fire hazard, there is a need to take into account several variables or factors that could influence fire behavior. The study carried out by Jaiswal *et al.* (2002) and Ertena *et al*. (2004) emphasized that, vegetation type, road, settlement and water bodies were needed to develop the forest fire hazard map.

Other than that, in order to reduce the impact of fire, there was a need to predict the potential of fires by using Fire Danger Rating System (FDRS) such Canadian Fire Weather Index (CFWI). The purpose of FWI is to produce the rating of the potential and estimation of the risk of wildfire. Importantly, fire danger rating is quantifying the potential or ability of a fire to start, spread and causes damage (De Groot *et al*., 2007).The FWI is divided into four fire danger classes; Low, Medium, High and Extreme. The extreme fire danger class indicates the high chance of forest fire occurring in that particular area, where the low fire danger class represents the lower the risk of forest fire occurring in that particular area.

1.2 Problem Statement

In Sabah, the destruction of forest area is often associated due to forest fires occurrence. Basically, all parties, which include the government, non-governmental organizations and our community, are responsible in forest conservation because all the major users of the forest. Without the cooperation of all parties, forest fires will continue to be the main cause of forest destruction and therefore, would indirectly affect human lives as well.

Thus, an effort to make early detection and mapping of forest fires on every occurrence is necessary. However, the issues of control of forest fires occurring particularly in the forest reserve in Sabah have been long debated by foresters, but the lack of information due to lack of qualitative and quantitative information about forest fires and their effects have not resulted in any defined approach to control forest fires incidents. Besides that,

the estimation and mapping of forest fire for the state were mostly done by using conventional methods such as aerial photographs interpretation and ground survey which are very expensive and time consuming. In addition, dynamic land use change in Sabah particularly the mountainous terrain is certainly a major problem in forest fire prevention and suppression activities in the state. Therefore, there is a need to find a faster and better alternative method to carry out forest fire assessments.

The purpose of this study is to utilize the remote sensing and GIS techniques in developing forest fire hazard map. Main purpose of forest fire hazard rating is to predict fire occurrence and be prepared for it. Forest fire hazard rating is very important in forest fires management for identification, mapping and monitoring the forest fires occurrence. Forest fires hazard zone is the location where the fire may have started and thus, would spread to other areas. The detection and mapping method by using remote sensing and GIS software are well suited, faster, and more accurate as compared to other conventional methods. The information obtained is not only timely but also reliable and accurate. These sensors are able to provide data in high quality and high resolution to resolve the natural variability such as the characteristics of plants, minerals, and gases in the atmosphere. Hotspot data is one of the examples of coordinated central pixel representing fires detected form high temperature by remote sensing (Wright *et al.*, 2004). By carrying out hotspot analysis, one are able to identify the patterns of hotspots throughout the entire region of the state. This is very crucial as it helps to monitor hotspot patterns and probabilities of forest fire occurrence over a five years period from years 2006 to 2010.

Furthermore, one of the ways to predict fire weather, fire occurrence and fire behavior of forest fires is to use Canadian Fire Weather Index (CFWI).The final result of FWI can be used to predict the potential of fire occurrence and provide early warning of the potential for serious fires. Understanding the period of high and low FWI enables the allocation of resources for forest fire planning and management.

1.3 Objectives

The general objective of this study is to assess and investigate forest fire occurrence for a period of five years (2006- 2010) in Sabah using integrated Geographical Information System (GIS) and remote sensing techniques.

The specific objectives of this study are:

a) To investigate hotspots pattern for a period of five years (2006- 2010) for the state of Sabah.
b) To analyze the temporal trend of fire danger index during the study period (2006- 2010) for the state of Sabah.
c) To generate forest fire hazard zone map for Sabah.

REFERENCES

Abdullah, M.J., Ibrahim, M.R. and Rahim, A.R.A. (2002). The Incidence of Forest Fire in Peninsular Malaysia: History, Root Causes, Prevention and Control. In *Proceedings of Prevention and Control of Fire in Peatlands*, pp. 20-27.

Ainuddin, A.N. and Ampun, J. (2008). Temporal Analysis of the Keetch- Byram Drought Index in Malaysia: Implications for Forest Fire Management. *Journal of Applied Sciences.* 8(21): 3991-3994.

Ainuddin, A.N., (1998). Forest Fire Management in Malaysia: An Overview. *IFFN*. 18: 51-52.

Ainuddin, A.N., Mei Leng, H. and Farida, B. (2006). Peat Moisture and Water Level Relationship in a Tropical Peat Swamp Forest. *Journal of Applied Sciences*. 6(11): 2517-2519.

Ainuddin, N.A. and Goh, K. (2010). Effect of Forest Fire on Stand Structure in Raja Musa Peat Swamp Forest Reserve, Selangor, Malaysia. *Journal of Environmental Science and Technology.* 3(1): 56-62.

Alaghmand, S., Abdullah, R., Abustan, I., and Vosoogh, B. (2010). GIS-based river flood hazard mapping in urban area (a case study in Kayu Ara River Basin, Malaysia). *International Journal of Engineering and Technology*. *2*(6); 488-500.

Alexander, M.E. (2008). *Proposed Revision of Fire Danger Class Criteria for Forest and Rural Areas in New Zealand. 2nd Edition.* National Rural Fire Authority, Wellington, in association with the Scion Rural Fire Research Group, Christchurch. P. 62.

Arianoutsou, M., Corona, P., and De las Heras, J. (2012). *Post Fire Management and Restoration of Southern European Forests*. Dordrecht: Springer. (pp. 121-150)

Arroyo, L.A., Pascual, C. and Manzanera, J.A. (2008). Fire Models and Methods to Map Fuel Types: The Role of Remote Sensing. *Forest Ecology and Management*. 256: 1239-1252.

Barrett, K. and Kasischke, E.S. (2013). Controls on Variations in MODIS Fire Radiative Power in Alaskan Boreal Forests: Implications for Fire Severity Conditions. *Remote Sensing of Environment.* 130: 171–181.

Beedlow, P.A., Tingey, D.T., Phillips, D.L., Hogsett, W.E. and Olszyk, D.M. (2004). Rising Atmospheric CO^2 and Carbon Sequestration in Forests. *Frontiers in Ecology and the Environment*. *2*(6): 315-322.

Bethel, G.R. (2013). USDA Remote Sensing Overview 2013. Retrieved 18 September 2013 from https://calval.cr.usgs.gov/wordpress/wp-content/uploads/BethelJACIE2013USDA.pdf

Brown, A.A. and Davis, K.P. (1973). *Forest Fire Control and Use. Second Edition*. New York: McGraw- Hill, Inc.

Byram, G.M. (2004). Some Principles of Combustion and Their Significance in Forest Fire Behavior. *Fire Management Today*. 64(1): 37-44.

Caceres, C.F. (2011). Using GIS in Hotspots Analysis and for Forest Fire Fisk Zones Mapping in the Yeguare Region, Southeastern Honduras. Volume 13, *Papers in Resource Analysis* (pp.14). Winona, MN. Saint Mary's University of Minnesota University Central Services Press.

Cane, D., Ciccarelli, N., Gottero, F., Francesetti, A., Pelfini, F. and Pelosini, R. (2008). Fire Weather Index Application in North-Western Italy. *Advances in Science and Research.* 2: 77–80.

Certini, G. (2005) Effects of Fire on Properties of Forest Soils: A Review. *Oecologia*. 143(1): 1-10.

Countryman, C.M. (2004). The Concept of Fire Environment. *Fire Management Today*. 64(1).

Cramer, O.P., (2004). Recognizing Weather Conditions that Affect Forest Fire Behavior. *Fire Management Today*. 64(1): 29-33.

De Groot, W.J. (1998). Interpreting the Canadian Forest Fire Weather Index (FWI) System. *Proc. of the Fourth Central Region Fire Weather Committee Scientific and Technical Seminar.* Edmonton, Canada. 1998.

De Groot, W.J., Field, R.D., Brady, M.A., Roswintiarti, O. and Mohamad, M. (2007). Development of the Indonesian and Malaysian Fire Danger Rating System. *Mitigation and Adaptation Strategies for Global Change.* 12(1): 165-180.

Dennis, R., Hoffmann, A., Applegate, G., Gemmingen, G.V. and Kartawinata, K. (2001). Large Scale Fire: Creator and Destroyer of Secondary Forest in Western Indonesia. *Journal of Tropical Forest Science.* 13(4): 786-799.

Department of Statistics, Malaysia, (2013). *Environmental Statistic Time series. Malaysia 2013*. Department of Statistics: Malaysia. ISSN 2289-2060.

Dolling, K., Pao, S.C. and Fujioka, F. (2005). A Climatological Study of the Keetch/Byram Drought Index and Fire Activity in the Hawaiian Islands. *Agricultural and Forest Meteorology*. 133: 17–27.

Dowdy, A.J., Mills, G.A., Finkele, K. and Groot, W.D. (2009). *Australian Fire Weather as Represented by the McArthur Forest Fire Danger Index and the Canadian*

Forest Fire Weather Index. Australian. Centre for Australian Weather and Climate Research. Report No. 10.

Dymond, C.C., Field, R.D., Roswintiari, O. and Guswanto. (2005). Using Satellite Fire Detection to Calibrate Components of the Fire Weather Index System in Malaysia and Indonesia. *Environmental Management*. 35(4): 426–440.

Ertena, E., Kurgunb, V. and Musaoglu, N. (2004). Forest fire risk zone mapping from satellite imagery and GIS a case study. *Geo-imagery bridging continents, Istanbul, Turkey*. Available online: http://www.isprs.org/proceedings/XXXV/congress/yf/papers/927.pdf (accessed on 4 November 2013).

Fire and Rescue Department of Malaysia (2012). *Annual Report 2012: Fire Station Management Manual.* Fire and Rescue Department: Malaysia. (pp. 30-65)

Forestry Department of Sabah, (2006). *Annual Report 2006: Forest Protection*. Sabah Forestry Department: Sabah, Malaysia. (pp. 113-116). Retrieved 20 August 2013 from http://www.forest.sabah.gov.my/download/2006/ar2006.htm.

Forestry Department of Sabah, (2007). *Annual Report 2007: Forest Protection*. Sabah Forestry Department: Sabah, Malaysia. (pp. 113-116). Retrieved 20 August 2013 from http://www.forest.sabah.gov.my/download/2007/19.%20Forest%20Protection.pdf

Forestry Department of Sabah, (2008). *Annual Report 2008: Forest Protection*. Sabah Forestry Department: Sabah, Malaysia. (pp. 157-163). Retrieved 20 August 2013 from http://www.forest.sabah.gov.my/download/2008/19_Protection.pdf.

Forestry Department of Sabah, (2009*). Annual Report 2009: Forest Protection*. Sabah Forestry Department: Sabah, Malaysia. (pp. 185-191). Retrieved 20 August 2013 from http://www.forest.sabah.gov.my/ar2009/chap%2019.pdf.

Forestry Department of Sabah, (2010). *Annual Report 2010: Forest Protection*. Sabah Forestry Department: Sabah, Malaysia. (pp. 191-200). Retrieved 26 August 2013 from http://www.forest.sabah.gov.my/pdf/ar2010/Chap19.pdf.

Fowler, C.T. (2003). Human Health Impacts of Forest Fires in the Southern United States: A Literature Review. *Journal of Ecological Anthropology*. 7(1): 39-63.

Fox, D.M., Maselli, F. and Carrega, P. (2008). Using SPOT Image and Field Sampling to Map Burn Severity and Vegetation Factor Affecting Post Forest Fire Erosion Risk. *Catena.* 75: 326- 335.

Fredriksson, G.M., Danielsen, L.S. and Swenson, J.E. (2006). Impacts of El Nino related Drought and Forest Fires on Sun Bear Fruit Resources in Lowland

Dipterocarp Forest of East Borneo. *Biodiversity and Conservation*. 15(4): 1271-1301.

Fuller, M. (1991). *Forest Fire; An Introduction to Wildland Fire Behavior, Management, Firefighting And Prevention*. United States: John Wiley & Sons, Inc.

Ganz, D. (2002). *Framing Fires: A Country by Country Analysis of Forest and Land Fires in the ASEAN Nations*. Indonesia: Project Fire Fight South East Asia.

Gisborne, H.T. (2004). Fundamentals of Fire Behavior. *Fire Management Today*. 64(1): 15-23.

Hamdan, O. (2013). Aboveground Biomass and Carbon Stock Mapping and Changes Monitoring in the Forest of Peninsular Malaysia Using L-Band ALOS Palsar and JERS. Retrieved 26 February 2014 from http://www.eorc.jaxa.jp/ALOS/en/kyoto/apr2013_kc19/pdf/2-2_KC19_HamdanOmar_FRIM.pdf

Harrison, M.E., Susan, E.P. and Suwido, H.L. (2009). The Global Impact of Indonesian Forest Fires. *Biologist*. 56(3): 156-163.

Hasmadi, M.I., Zaki, M.H., Ismail, A.M., Pakhriazad H.Z. and Fadlli, M.A.Y., (2010). Determining and Mapping of Vegetation using GIS and Phytosociological Approach in Mount Tahan, Malaysia. *Journal of Agricultural Science*. *2*(2): 80-89.

Hassan, A.J., Ghani, A.A., and Abdullah, R. (2006). Development of flood risk map using GIS for Sg. Selangor Basin. In *Proceeding of the 6th International Conference on ASIA GIS, 9-10 Mar 2006, Johor, Malaysia*.

Heil, A. and Goldawer, J.G. (2001). Smoke haze pollution: A review of the 1997 episode in Southeast Asia. *Regional Environment Change*. 2: 24-34.

Husain, Y.A., Mutumwa, M. and Narangeral, Z. (2008). The Applications of Remote Sensing and GIS in Modeling Forest Fire Hazard in Mongolia. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* 37: 289-294.

IFFN, (2001). Forest Fire Situation in Malaysia. *International Forest Fire New*, No. 26 (January 2001), p. 66-74. http://www.fire.uni-freiburg.de/iffn/country/my/my_2.htm. Accessed on 16 December 2013.

IFFN, (2002). Forest Fire Management in Canada. *International Forest Fire New*, No. 27 (July 2002), p. 2-5. http://www.fire.uni-freiburg.de/iffn/country/ca/ca_7.htm. Accessed on 16 December 2013.

Imas, S.S., Razaly, Y., Norwati, M. and Ainuddin, A.N. (2012). Classification of application algorithms in data mining for hotspot occurrence predection in Riau Province Indonesia. *Journal of Theoretical and Applied Information Technology*. 43(2): 214-221.

Jaiswal, R.K., Mukherjee, S., Raju, D.K. and Saxena, R. (2002). Forest Fire Risk Zone Mapping from Satellite Imagery and GIS. *International Journal of Applied Earth Observation and Geoinformation*. 4: 1-10.

Jaya, N.S., Purnama, E.S., Arianti, I. and Boonyanuphap, J. (2007). *Forest Fire Risk Assessment Model and Post-Fire Evaluation using Remote Sensing and GIS: A Case Study in Riau, West Kalimantan and East Kalimantan Provinces, Indonesia*. MSc. Dissertation, Bogor Agricultural University, Bogor, Indonesia

Jia, H.Z., Feng, M.Y., Cheng, L., Li, M.Y. and Vijendra, K.B. (2011). Detection, Emission Estimation and Risk Prediction of Forest Fires in China Using Satellite Sensors and Simulation Models in the Past Three Decades; An Overview. *International Journal Environmental Research and Public Health*. *8*: 3156-3178.

Johnson, E.D. and Miyanish, K. (2001). *Forest Fires: Behavior and Ecological Effects* (Vol. 593). San Diego, CA: Academic press.

Karki, S. (2002). *Community Involvement in and Management of Forest Fires in South East Asia.* Indonesia: Project Fire Fight South East Asia.

Keetch, J.J. and G.M. Byram, (1968). A Drought Index for Forest Fire Control. *USDA Research Paper SE*-38, pp: 1-32, http://www.srs.fs.usda.gov/pubs/rp/rp_se038.pdf. Accessed on 18 December 2013.

Liew, S.C. (2001). Satellite Detection of Forest Fire and Burn Scars. *Proceedings on the Workshop on Minimizing the Impact of Forest Fire on Biodiversity in ASEAN*, pp. 34-46.

Malik, T., Rabbani, G., and Farooq, M. (2013). Forest Fire Risk Zonation Using Remote Sensing and GIS Technology in Kansrao Forest Range of Rajaji National Park, Uttarakhand, India. *International Journal of Advanced Remote Sensing and GIS.* 2(1): 86-95.

Mastura, M., (2005). Active Fire and Hotspot Emissions in Peninsular Malaysia During the 2002 Burning Season. *Geografia Online [TM] Malaysian Journal of Society and Space. 1: 32–45.*

Mathias, M. and Rymdteknik, A. (2013). *Study on Forest Fire Detection with Satellite Data* (p. 28). Sweden: Lulea Tekniska Universitet.

McArthur, A.G. and Luke, R.H. (1963). Fire behaviour studies in Australia. *Fire Control Notes*, *24*(4), 87-92.

Mcmorrow, J. and Talip, M.A. (2001). Decline of Forest Area in Sabah, Malaysia: Relationship to State Policies, Land Code and Land Capability. *Journal of Global Environmental Change*. 11: 217-230.

Naidoo, R., Trent, M., and Adam, T., (2009). Economic Benefits of Standing Forests in Highland Areas of Borneo:Quantification and Policy Impacts. *Conservation Letters.* 2(1): 36-45.

Natasa, S.M. (2013). Detecting Forest Fires in Croatia; Testing the MPEF Active Fire Monitoring (FIR) product. *European Association of Remote Sensing Laboratories*. 33(94): 16-20.

Patah, N.A., Mansor, S. and Mispan, M.R. (2001). An Application of Remote Sensing and Geographic Information System for Forest Fire Risk Mapping. Retrieved 20 January 2014 from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.97.1605&rep=rep1&type=pdf

Peng, G.X., Jing, L. and Norizan, A.P. (2007). A Forest Fire Risk Assessment Using ASTER Images in Peninsular Malaysia. *Journal of China University of Mining & Technology*. 17(2): 0232-0237.

Pereira, J.M. (2003). Remote Sensing of Burned Areas in Tropical Savannas. *International Journal of Wildland Fire*. 12(4): 259-270.

Potapov, P., Yaroshenko, A., Turubanova, S., Dubinin, M., Laestadius, L., Thies, C. and Dmitry Aksenov, D. *et al.* (2008). Mapping the World's Intact Forest Landscapes by Remote Sensing. *Ecology and Society.* 13(2): 51.

Pradhan, B. (2009). Hotspot detection and monitoring using MODIS and NOAA AVHRR images for wild fire emergency preparedness. *Applied Geoinformatics for Society and Environment (AGSE)*. 1: 53-61.

Pradhan, B., Dini Hairi, M.S. and Arshad, M.A. (2007). Forest Fire Susceptibility and Risk Mapping using Remote Sensing and Geographical Information Systems (GIS). *Disaster Prevention and Management*. 16(3): 344-352

Randall, C.K. (2003). Fire in the Wildland-Urban Interface: Understanding Fire Behavior. Retrieved 26 February 2014 from http://www.srs.fs.usda.gov/factsheet/pdf/fire-understanding.pdf

Rowell, A. and Moore, P.F. (2000). *Global Review of Forest Fires*. IUCN/WWF, 64 pp.

Saner, P., Loh, Y.Y., Ong, R.C. and Hector, A. (2012). Carbon Stocks and Fluxes in Tropical Lowland Dipterocarp Rainforests in Sabah, Malaysian Borneo. *PloS One*. *7*, e29642.

Sastary, N. (2000). Forest Fires, Air Pollution and Mortality in Southeast Asia. *Demography*. *39*: 1-23.

Schrier-Uijl, A.P., Silvius, M., Parish, F., Lim, K.H., Rosediana, S. and Anshari, G. (2013). Environmental and social impacts of oil palm cultivation on tropical peat–a scientific review. *Roundtable on Sustainable Palm Oil.* 2: 131-168.

Schweithelm, J. and Glover, D. (1999). Causes and Impact of the Fire. *Indonesia's fires and haze: The cost of a catastrophe*. 1: 1-13.

Shahwahid, H.O., and Jamal, O., (1999). Malaysia. Indonesia's fires and haze: The cost of a catastrophe (Glover, D. & T. Jessup, eds.). *Institute of South East Asian Studies.* Singapore. 3: 22-50.

Sheriza, M.R. and Ainuddin, A.N. (2012). A Method of Mapping Forest Fuel Types in Peat Swamp Forest. *African Journal of Agricultural Research.* 7(12): 1901-1909.

Sheriza, M.R., (2006). *Forest Fire Hazard Rating Assessment in Peat Swamp Forest using Integrated Remote Sensing and Geographical Information System (GIS) Technique*. MSc. dissertation, Universiti Putra Malaysia: Selangor, Malaysia.

Sheriza, M.R., Ismail, A.M., Norizan, A.P. and Ainuddin, a.n. (2010). Forest Fire Hazard Rating Assessment in Peat Swamp Forest using Landsat Thematic Mapper Image. *Journal Application Remote Sensing*. 4(1): 043531.

Siegert, F. and Hoffmann, A.A. (2000). The 1998 Forest Fire in East Kalimantan (Indonesia): A Quantitative Evaluation using High Resolution, Multitemporal ERS-2 SAR Images and NOAA- AVHRR Hot Spot data. *Remote Sensing Environment*. 72(1): 64-77.

Smith, H., Cawson, J., Sheridan, G. and Lane, P. (2011). *Desktop review; Impact of Bushfires on Water Quality.* Retrieved 10 January 2013 from http://155.187.2.69/water/publications/quality/pubs/impact-of-bushfires.pdf

Sowmya, S.V. and Somashekar, R.K. (2010). Application of Remote Sensing and Geographical Information System in Mapping Forest Fire Risk Zone at Bhadra Wildlife Sanctuary, India. *Journal of Environmental Biology.* 31(6): 969-974.

Steenis, M.Z. and Fogarty, L.G. (2001). *Determining spatial factors associated with fire ignition zones.* Jakarta: Berau Forest Management Project (pp. 33).

Stephens, S.L., and Ruth, L.W., (2005). Federal Forest Fire Policy in the United States. *Ecological Applications*. 15(2): 532-542.

Syafinie, A.M. and Ainuddin, A.N. (2013). Biomass and Carbon Estimation of *Eugeissona tristis*. *Sains Malaysiana.* 42(10): 1461–1466.

Syaufina, L. and Ainuddin, A.N. (2011). Impact of Fire on South East Asia Tropical Forest Biodiversity: A Review. *Asian Journal of Plant Sciences*. 10(4): 238-244.

Tacconi, L., Jotzo, F. and Grafton, R.Q. (2007). Local Causes, Regional Co-operation and Global Financing for Environmental Problems: The Case of Southeast

Asian Haze pollution. *International Environmental Agreements: Politics, Law and Economics*. *8*(1): 1-16.

Tangang, F.T., Latif, M.T. and Juneng, L. (2010). The Roles of Climate Variability and Climate Change on Smoke Haze Occurrences in Southeast Asia region. *Climate change: Is Southeast Asia up to the challenge*. 1: 36-49.

Tran, A.T., Dinh, N.D., Nguyen, D.T.H. and Phonekeo, V. (2008). Forest Fire Risk Mapping by using Satellite Imagery and GIS for Quang Ninh Province, Vietnam. Retrieved 27 February 2014 from http://www.researchgate.net/publication/260871777_FOREST_FIRE_RISK_MAPPING_BY_USING_SATELLITE_IMAGERY_AND_GIS_FOR_QUANG_NINH_PROVINCE_VIETNAM

Van Wagner, C.E., (1987). *Development and Structure of the Canadian Forest Fire Weather Index System* (Vol. 35). Canadian Forestry Service, Ottawa, Ontario.

Voelkert, J.C., (2009). A Brief Guide to Fire Chemistry and Extinguishment Theory for Fire Equipment Service Technicians. *Fire and Fire Extinguishment*. http://amerexfire.com/wpcontent/uploads/2011/12/fire_and_fire_extinguishment.pdf. Accessed on 17 December 2013.

Walsh, R.P.D. (1996). Drought Frequency Changes in Sabah and Adjacent Parts of Northern Borneo since the late Nineteenth Century and Possible Implications for Tropical Rain Forest Dynamics. *Journal of Tropical Ecology.* 12(3): 385-407.

WGEA (2010). Auditing Forests: Guidance for Supreme Audit Institutions. Chapter 1: Forests. *International Organization of Supreme Audit Institutions (INTOSAI)* pp. 11- 18.

Woods, P. (1989). Effects of Logging, Drought, and Fire on Structure and Composition of Tropical Forests in Sabah, Malaysia. *Biotropica*. 21(4): 290-298.

Wright, D.B., Yotsumata, T., El-Sheimy, N. and Liu, C.H. (2004). Real Time Identification and Location of Forest Fire Hotspots from Geo-referenced Thermal Images. *International society for Photogrammetry and Remote Sensing.* 1: 1-6.

WWF (2009). *High Conservation Value Forest (HCVF) Toolkit for Malaysia: A National Guide for Identifying, Managing and Monitoring High Conservation Value Forests, First Edition October 2009*. WWF Malaysia: Kuala Lumpur, Malaysia.

Zainal, A.M.I. (2001). Forest Fire in Malaysia: Its Management and Impact on Biodiversity. *Asean Biodiversity*. 1: 31-35.

Zarekar, A., Vahidi, H., zamani, K., Ghorbani, S. and Jafari, H. (2012). Forest Fire Hazard Mapping using Fuzzy AHP and GIS Study Area: Gilan Province of Iran. *International Journal on Technical and Physical Problems of Engineering.* 4(3): 47-55.