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DYNAMIC BEHAVIORS OF FOREST FIRE IN UPPER NAN WATERSHED DURING 1999-2007

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences

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ชนิตา ดวงยิหวา: ลักษณะการเกิดไฟป่าเชิงพลวัตบริเวณลุ่มน้ำน่านตอนบนระหว่างปี พ.ศ. 2542-2550. (DYNAMIC BEHAVIORS OF FOREST FIRE IN UPPER NAN WATERSHED DURING 1999-2007) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ดร. สมบัติ อยู่เมือง, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม : รศ.ดร. นันทนา คชเสนี, 139 หน้า.

การประยุกต์ใช้เทคโนโลยีรีโมทเซ็นซิ่งร่วมกับระบบสารสนเทศภูมิศาสตร์ช่วยรวบรวมและวิเคราะห์รูปแบบเชิงพื้นที่ของไฟป่าได้อย่างรวดเร็วและมีประสิทธิภาพมากขึ้น งานวิจัยครั้งนี้ได้ใช้ข้อมูลภาพถ่ายจากดาวเทียม LANDSAT-5 ระบบ TM ที่บันทึกระหว่างช่วงเดือนธันวาคมถึงเดือนเมษายน ช่วงระหว่างปี พ.ศ. 2542-2550 ในบริเวณลุ่มน้ำน่านตอนบน ประเทศไทย ศึกษาการเปลี่ยนแปลงของพื้นที่ป่าที่ถูกไฟไหม้ในบริเวณดังกล่าว

ในการศึกษาได้ใช้ข้อมูลภาพถ่ายจากดาวเทียม LANDSAT-5 ระบบ TM และเลือกช่วงคลื่นที่จะมาวิเคราะห์จำนวน 3 ช่วงคลื่น คือ 7, 4 และ 2 เพื่อทำภาพผสมสีเท็จ แปลตีความพื้นที่ป่าที่ถูกไฟไหม้ด้วยสายตาบนจอภาพ ร่วมกับการใช้วิธีการหาค่าดัชนีความแตกต่างของการเผาไหม้ จากนั้นจึงนำข้อมูลพื้นที่ป่าที่ถูกไฟไหม้ที่ได้มาจัดสร้างเป็นฐานข้อมูลสารสนเทศภูมิศาสตร์ และทำการตรวจสอบความถูกต้องของการแปลความหมายของพื้นที่ป่าที่ถูกไฟไหม้ด้วยการสุ่มสำรวจในภาคสนาม จากนั้นจึงนำผลที่ได้มาจัดทำเป็นแผนที่แสดงพื้นที่และสังเคราะห์แนวโน้มการกระจายตัวการเกิดไฟป่าดังกล่าวในแต่ละช่วงเวลาตามลำดับ

ผลการศึกษาพื้นที่เกิดไฟป่าบริเวณลุ่มน้ำน่านตอนบนปี พ.ศ. 2542, 2544, 2547 และ 2550 พบว่ามีไฟป่าเกิดขึ้นในแต่ละปี คิดเป็นพื้นที่รวมประมาณ 37, 107, 81, และ 80 ตารางกิโลเมตร ตามลำดับ ซึ่งผลการวิเคราะห์ทั้ง 4 ช่วงเวลาพบว่าพื้นที่เกิดไฟป่าส่วนมากจะอยู่ในเขตพื้นที่ภูเขาสูงและพื้นที่ลาดชัน ที่อยู่ในบริเวณตอนเหนือของพื้นที่ลุ่มน้ำน่านตอนบน

การวิเคราะห์เพื่อประเมินความสัมพันธ์ของปัจจัยที่มีอิทธิพลต่อการเกิดไฟป่า ได้ใช้ข้อมูลจากพื้นที่เกิดไฟป่าและข้อมูลที่เกี่ยวข้อง ได้แก่ความลาดชัน ทิศของความลาดชัน ระยะห่างจากถนน ระยะห่างจากที่ตั้งชุมชน พืชพรรณ และสิ่งปกคลุมดิน มาทำการวิเคราะห์ด้วยวิธีของความน่าจะเป็นแบบตัวแปรเดี่ยว และการคำนวณค่าความสัมพันธ์ของปัจจัยที่มีอิทธิพลต่อการเกิดไฟป่า ผลการวิเคราะห์ได้จัดทำเป็นแผนที่แสดงความสัมพันธ์ของปัจจัยที่มีอิทธิพลต่อการเกิดไฟป่าขึ้นในบริเวณพื้นที่ศึกษา และยังได้นำผลที่ได้ไปประยุกต์ใช้เพื่อจัดทำเป็นแผนที่แสดงพื้นที่เสี่ยงต่อการเกิดไฟป่าในบริเวณลุ่มน้ำน่านตอนบนเอาไว้ด้วย

ข้อมูลและผลวิเคราะห์ที่ได้จากการศึกษาในครั้งนี้ สามารถนำไปใช้เป็นข้อมูลเชิงพื้นที่สำหรับสนับสนุนการตัดสินใจในการกำกับ ติดตามและควบคุมการเกิดไฟป่าในพื้นที่ดังกล่าว ให้การจัดการไฟป่ามีประสิทธิภาพอย่างเป็นรูปธรรมที่มีเป้าหมายในเชิงพื้นที่ที่ชัดเจนในการดำเนินการที่ดีขึ้นในอนาคต

ภาควิชา ธรณีวิทยา	ลายมือชื่อนิสิต ชนิตา ดวงยิหวา
สาขาวิชา โลกศาสตร์	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก
ปีการศึกษา 2552	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม

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KEYWORDS : GIS AND REMOTE SENSING / FOREST FIRE / UPPER NAN WATERSHED / THAILAND

CHANITA DUANGYIWA : DYNAMIC BEHAVIORS OF FOREST FIRE IN UPPER NAN WATERSHED DURING 1999-2007. THESIS ADVISOR : ASST. PROF. SOMBAT YUMUANG, Ph.D., THESIS CO-ADVISOR : ASSOC.PROF. NANTANA GAJASENI, Ph.D.,139 pp.

The applications of Geographic Information System (GIS) and Remote Sensing help gathering and analysis the spatial patterns of the forest fire more quickly and more efficiently. This research used the temporal Landsat-5 TM imageries covered the upper Nan watershed, Thailand, acquired between December to April during 1999-2007, to study the changes of the forest fire affected areas.

In this study, Landsat-5 TM bands 7-4-2 were chosen to create the false color composite. The visual interpretation combined with Difference Normalized Burn Ratio (dNBR) method was conducted to analyze the forest fire affected areas that were created in GIS database. Field investigations were also used to test for accuracy of the forest fire interpretation. The results were used to produce the burned scar maps and synthesize for the trend of forest fire distribution during those periods.

The analysis found that most forest fire patches distributed on high mountainous and steep slope area that are mainly in the northern part of the watershed. The forest fire areas in 1999, 2001, 2004 and 2007 were summarized approximately as 37 km^2, 107 km^2, 81 km^2, and 80 km^2, respectively.

The relationships of burned areas and relevant parameters, namely slope, aspect, distance from road, distance from settlement, vegetation and land cover were analyzed for forest fire susceptibility assessment. Various maps were constructed from the forest fire relevant parameters derived from the database. The parameters, univariant probability method, and calculation of forest fire susceptibility were applied to modify the forest fire rating risk classes and be presented as the forest fire risk map in the upper Nan watershed.

The final results from this research can be used as a spatial data for supporting decision making in handling, monitoring, and controlling the forest fires in Thailand for much better efficient management.

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Field of Study : Earth Sciences	Advisor's Signature S. Yumuang
Academic Year : 2009	Co-advisor's Signature Nantana Gajaseni

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CHAPTER I

INTRODUCTION

Forest fire has been acknowledged as a part of factor effecting ecological changes in all types of forest all over the world. Forest fire can be a real ecological disaster, regardless of whether it is caused by natural forces or human activities. Forest fires can cause environmental damages and diminish the biodiversity. Annual forest fires may decrease the growth of the grasses, herbs and shrubs, which may result in increased soil erosion. Understanding the occurrence, spatial patterns and dynamic behavior of fires are significant for forest fire management (Kandya et al., 1998).

1.1 Rationale

In Thailand, especially in the northern part, forest fires are annual occurrences. Almost all are caused by people, either intentionally or accidentally. They occur annually during the dry season from December to May, with the most forest fires occurring in the hottest period of February and March. Most forest fires in Thailand are categorized as surface fires (Kanchanasak Phonboon, 1997).

The significant factors that have an influence on the availability of forest and plant community in Thailand are water, climate, rock and soil type, elevation, and biotic that including forest fires which occur during the dry season. The forest fire which occurs regularly especially in deciduous forest are the cause of the occurrence in mixed deciduous forest and deciduous dipterocarp forest. Forest fires are the main factor that can change forest types and plant community (Tawatchai Santisuk, 2006).

Since 1985, Forest Fire Control Division of the Royal Forest Department reported that causes of forest fires in Thailand are gathering of forest non-timber products, shifting cultivation, incendiary fire, hunting animals, cattle raising, illegal logging, lacking of awareness and carefulness, and unidentified causes (Forest Fire Control Division, 2003).

There are forest fires in the upper Nan watershed during the dry season every year especially in the national parks, wildlife sanctuary and national forest areas. Effective forest fire management requires the use of new techniques using Geographical Information Systems (GIS) and remote sensing that produce results in a timely and cost-effective manner. Landsat-5 TM and other data, including GIS vector data, were applied to mapping forest fires.

This thesis addresses the spatial patterns, repeated occurrence, and dynamic behavior of forest fires in upper Nan watershed during 1999-2007.

1.2 Objectives

The purposes of this present study are

- To study the spatial patterns and dynamic behaviors of forest fire in the upper area of Nan watershed during 1999 – 2007, and
- To determine the forest fire risk areas in upper Nan watershed.

1.3 Scope and limitation

The scope of this thesis is limited to study spatial patterns and repeated occurrence of forest fire during 1999 – 2007 and analyze the dynamic behavior of forest fire in those periods to detect the forest fire risk locations in upper Nan watershed. Meteorological factor is not addressed in this research.

1.4 Location of the study area

The study area was conducted in the upper Nan watershed, situated in Changwat Nan that is in the east of Northern Thailand. It locates between 18° 1' and 19° 34' N latitude and between 100° 24' and 101° 15' E longitude (Figure 1-1). The total study area is about 11,898 square kilometers, covering path 129-130 of LANDSAT-5 TM. Its elevation ranges from 50 to 2000 meters above average mean sea level. The geographical features of the study area consist of high mountainous and narrow flood plain areas (Figure 1-2).

1.5 Expected outputs

The expected outputs of this thesis consist of:

- Burned scar map in the upper Nan watershed.
- Relationship between burned area and forest fire affected factor, such as land cover, slope and aspect in the study area.
- Forest fire risk map.

These results should supply planners and decision-makers with adequate and understandable information for a more effective planning with appropriate strategies for reducing and mitigating forest fire hazards and related phenomena in a long term risk that may be repeatedly occurred in the study area as well as in other areas of similar geographical conditions.

Figure 1-1 Location of the study area.

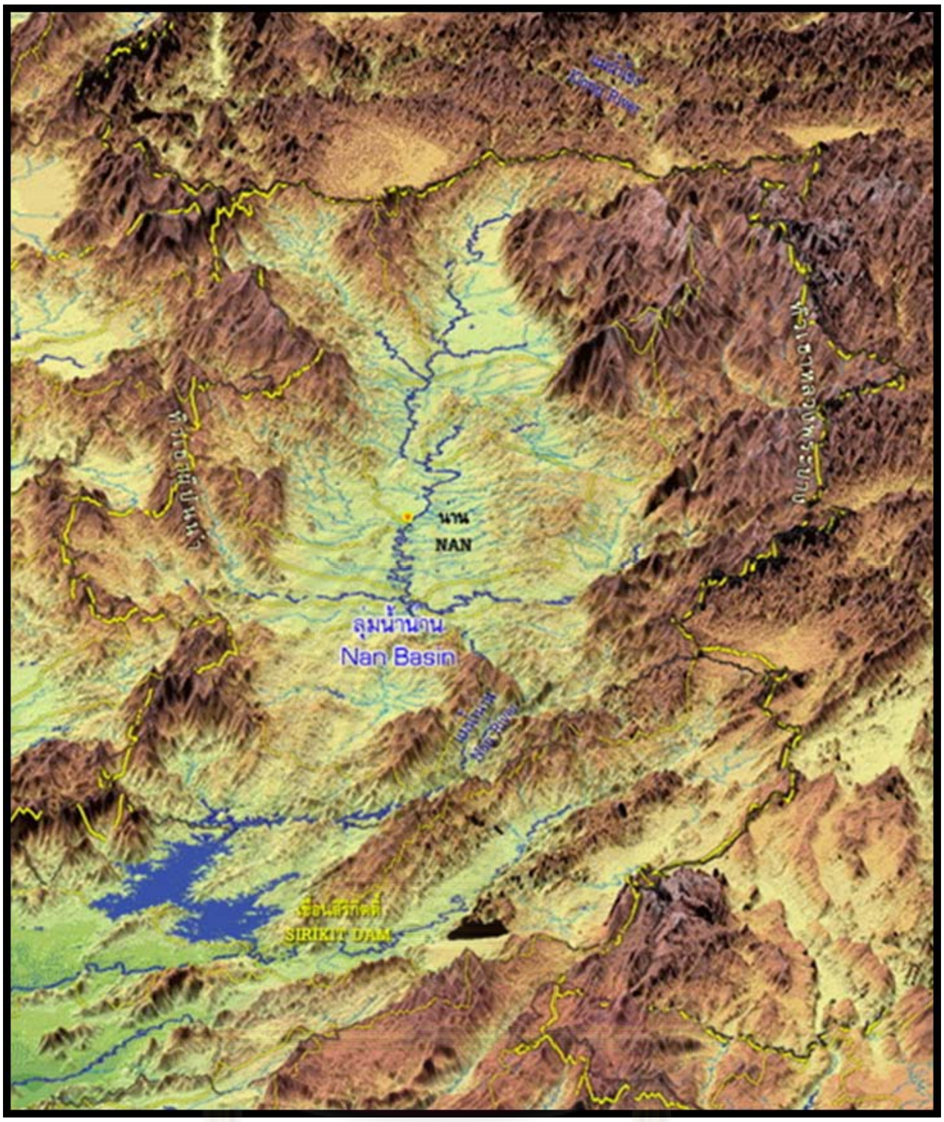

Figure 1-2 3D Digital Terrain Model of Northern Thailand (GISTHAI, 2009).

1.6 Research methodology

To accomplish the aims of this thesis, the research involves four sequential steps are designed. Each of which is described as follows:

1.6.1 Preparation

This step includes:

- Literature review of the related researches in the study area, northern Thailand, and other countries.
- Acquisition and study of the previous basic data acquisition, i.e. satellite images of medium resolution (Landsat), topographic map, and land use map to understand the topography and land use pattern of the study area as general background information.
- Intensive comprehension on the conceptual framework of forest fire and especially the criteria to evaluate forest fire occurrence.

1.6.2 Field investigation

The field investigation and direct observation were carried out as follows:

- Reconnaissance to understand and recognize the limitation in the study area for preparing the data and related plan that would be used in further steps of the field investigation.
- Intermediate field investigation to conduct ground-truth to inspect the correctness of the analyzed results from the remote sensing image analysis and interpretation.

1.6.3 Laboratorial studies

The laboratorial analysis is conducted as follows:

- Thematic (GIS and remote sensing) data preparation. These inventory data consist of topography (slope, aspect), land use and land cover. Software of geographic information system (GIS) and remote sensing (ArcGIS 9.2 and ERDAS IMAGINE 8.5) are applied in developing, manipulating, and analyzing the digital data.
- Interpretation of medium resolution satellite images (Landsat TM) that were acquired during 1999-2007. This sub-step was conducted to develop the new data (e.g. burned scars). These inventory data were also checked from ground-truth information from brief field traverses to inspect the accuracy in the intermediate field investigation.
- Forest fire analysis in upper Nan watershed is conducted. This is preliminary forest fire analysis by univariant probability method to present the spatial relationship between the burned areas and each of available forest fire influencing parameters (as theoretically mentioned) in upper Nan watershed, namely, slope, aspect, land cover, distance from road, and distance from settlement, respectively. The GIS was used to compile a vast amount of data efficiently.

1.6.4 Synthesis, discussion and conclusions

This step includes:

- Synthesizing, discussing and concluding forest fire occurrence in upper Nan watershed.

In order to accomplish the objectives of this research, the schematic diagram illustrating the present methodology system was designed as shown in Figure 1-3.

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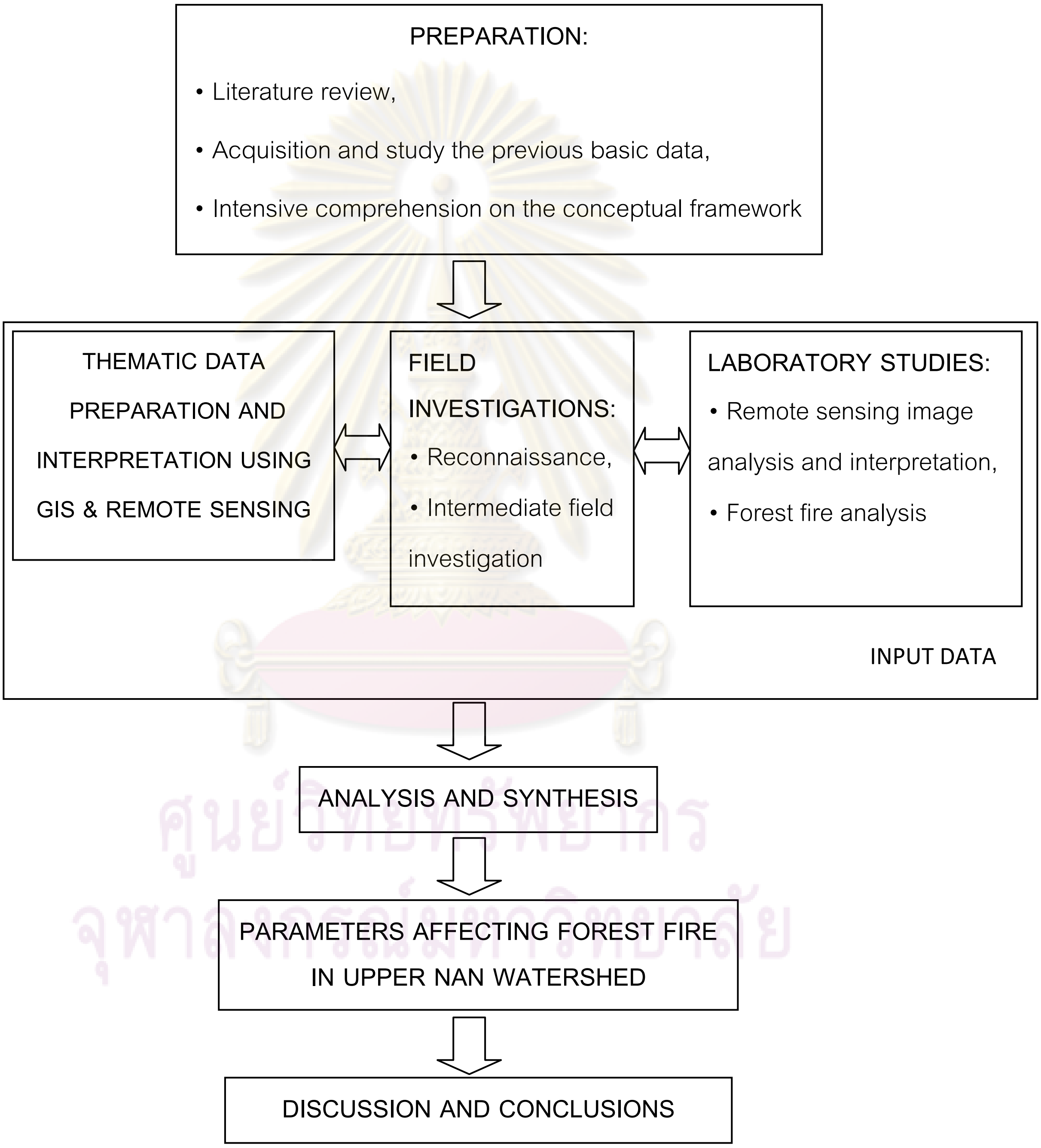

Figure 1-3 Schematic diagrams illustrating the research methodology system.

1.7 Components of the thesis

This thesis comprises five chapters including this introductory Chapter 1. Chapter 2 is initiated with the definition and terminology of forest fire as well as the components of fire research. The applications of the remote sensing and geographic information system (GIS) in forest fire assessment are briefly reviewed. The previous investigations from the related technical literatures are also presented.

Since the possibilities and limitations of the proposed methodology can only be evaluated critically when field data are available. Data preparation and interpretation in terms of types of input data and data production stage is given in Chapter 3. In this chapter, data input from thematic data pre-processed with the application of geographic information system (GIS) and remote sensing techniques are produced and interpreted.

Following the data preparation and interpretation stages, forest fire analysis of upper Nan watershed by the statistic approach is proposed in Chapter 4. Forest fire susceptibility is preliminary analyzed using the influencing parameters by univariant probability method to present the spatial relationship between the detected burned areas and each of the influencing parameters in the watershed. Besides, forest fire risk analysis in the study area is also proposed in this chapter.

In Chapter 5 the attention is focused on discussion of the forest fire susceptibility results. Finally, the assessment of forest fire in upper Nan watershed are summarized and concluded with further recommendation in this chapter.

CHAPTER II

LITERATURE REVIEW

2.1 Definition and terminology

There are many definitions about forest fire. For example, Brown and Davis (1973) defined as "an uncontrolled fire that spreads though vegetative fuels, exposing and possibly consuming structures". While the United States Geological Survey-USGS (2008) defines as "combustion, marked by flames or intense heat, in natural settings, often ignited by lightning or human activities". The Royal Thai Forest Department, however; defines the meaning of the forest fire as "a fire that occurs on forestland for any reason and in the absence of any control" (Atchara Rakyutidharm, 2002).

The term "fire risk" which used in classic, is derived from the first national, institutionalized decision-support system implemented in the U.S. fire community-the National Fire Danger Rating System-NFDRS (Deeming et al., 1972). The NFDRS defined the term "fire risk" as the occurrence of a spreading fire, or fire incidence. In addition, the NFDRS classified fire risk from the sources into two groups as follows: lightning risk and man-caused risk. Man-caused forest fire is derived through inference from the relative level of human activity, the principal sources of human-caused ignitions and other factors. Then, a more generalized definition of "fire risk" has been commonly adopted by the fire community as the chance that a fire might start, as affected by the nature and incidence of causative agents.

Bachmann and Allgower (2000) remarked that the term "hazard" can be used not only represent the precondition for a specific process, but also refer to the process itself. They defined the term of "fire hazard" as the potential fire behavior for fuel type, regardless of the fuel types' weather-influenced fuel moisture content. Assessment was based on the physical fuel characteristics, such as fuel management, fuel load, herbaceous vegetation, and presence of elevated fuels.

Hardy (2005) defined the term of "fire hazard" as a fuel complex, defined by volume, type, condition, arrangement, and location that determines the degree of ease of ignition and the resistance to control. Fire hazard expresses the potential fire behavior for a fuel type, regardless of the fuel type's weather-influenced fuel moisture.

Fire severity has been used to describe an environment of fire-related characteristics, effects, and phenomenon. These have included flame length, fire size, resistance to control, rate of spread, fuel consumption, and others too numerous to list. According to paper on fire severity, Simard (1991) defined "fire severity" as the magnitude of significant negative fire impacts on wildland systems.

To conclude, in forest fire management, the term "Fire Risk" refers only to the probability of ignition of a spreading fire and does not address values or damages. "Fire Hazard" is a fire-centric term, and is independent of weather. The term "hazard" must only be used to express the state of the fuel complex. "Fire Severity" is a characterization of the effects of fires on wildland systems, rather than of the fire itself.

2.2 Use of Remote Sensing and GIS in forest fire assessment

Forest fires are most accurately documented by crews equipped with GPS receivers and great knowledge of the affected areas. However, this in situ monitoring is not always the most feasible approach (Ichoku et al., 2003). Advancements in remote sensing satellite sensors and the associated analysis are clear the way for a new era of burned scar mapping and fire monitoring techniques. The development of spectral indices designed specifically for studies on vegetation and the further advancement of

GIS technologies is leading the field of forest fire research in to a knowledge which is not restricted by the limitations of field work. Size, intensity, and frequency of forest fire can now be monitored by land management officials on a regular and timely basis. Furthermore, the regeneration of vegetation and environmental impact can be studied with continuity and precision which may not be possible when rely on human observations.

The field of remote sensing has improved dramatically in sensor technology and data processing techniques over the course of the last twenty years (Kushla and Ripple, 1998). Several transformation techniques such as Principal Component Analysis (PCA), Normalized Difference Vegetation Index (NDVI), and Tasseled Cap Transformation (TCAP) have been applied to burned scar studied with various degree of success. The Normalized Burn Ratio (NBR), developed in 1996 by Key and Benson (2004), is one of the most widely accepted methods of burned scar mapping. The NBR index has been approved by numerous land management agencies and forest fire researchers as the effective tool for recording burned scars and mapping their recovery. The more detailed explanation of this index will be given in the following pages.

The condition of spectral transformation and indices are based on reflection in certain wavelengths and therefore, can be applied to multiple satellite sensors. This study will be concerned with a single family of platforms and two sensors. The Landsat family of remote sensing satellites was launched in the early 1970's out of an increasing require for data on the Earth's terrestrial resources. Until now, seven Landsat satellites have been launched with six reaching orbit. The Thematic Mapper (TM) sensor onboard Landsat 4 and 5 has given the scientific world a much more detailed look at the Earth's surface. The eighty meter resolution of the Multi-Spectral Scanner (MSS) has been increased to a spatial resolution of thirty meters and spectral resolution was redefined into more discrete wavelengths (Campbell, 2002).

Practically every Earth monitoring satellite up to now has been used for burned scar mapping studies in some aspects. The daily satellite imageries such as the Geostationary Operational Environmental Satellites (GOES) family and the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, provide the public with important daily data on the state of fires on a global scale. However, the coarse spatial resolution make highly detailed studies difficult or impossible (Li et al., 2000). The Landsat based sensors have reached a compromise between spatial and temporal resolution. The 30 meter pixel size of Landsat is detailed enough to provide information on the local scale, whereas the temporal resolution provides frequent imaging. Image scenes are acquired approximately every two weeks, which provides an opportunity for coverage throughout the year and across seasonal transitions. The footprint of Landsat TM and ETM+ images is approximately 170 km north-south by 183 km east-west (Campbell, 2002). This scene size in large enough to provide researchers with a view of an entire region while still maintaining the necessary detail needed to specific fire events.

Various combinations of Landsat bands provide the analyst with different information sets relevant to different studies. As stated previously, combining the visible and infrared channels has been extremely used for vegetation studies. In the assessment of burned scar, several band combinations have been especially valuable. The study of forest fire in Greece by Koutsias and Karteris (2000) assigned a combination of bands 7,4,1 or 7,4,2 to the visible colors red, green, blue (RGB) respectively, to create an image in which burned scars appear as clearly visible or bright red patches, distinct from the surrounding vegetation. However, the study of forest fires in Amazon by Pereira and Setzer (1993) was used bands 3,4,5 while in Spain bands 4,5,7 combination were used (Chuvieco and Congalton, 1988). The selection of band combination may depend on the characteristics of the studied scene. In addition, the display of Landsat image of coastal Louisiana in the U.S.A. with the 7,4,2 RGB bands combination shows the burned areas as bright red or deep red areas distinctly different from the unburned areas surrounding, which appear in green or pink.

Burned areas can show a higher return in Landsat band 7 due to a reduction in plant canopy moisture and therefore decreasing in the absorption of the wavelength. They are also low in band 4 reflectance because of loss of vegetation (Key and Benson, 2004). If these bands are set to red and green respectively, burned areas will appear as bright red due to the high band 7 reflectance and show little or no green due to the low band 4 reflectance. This combination of bands makes the burned scars distinguish from unburned areas. This visually based procedure provides a practical display image, which is instrumental in the qualitative study of the burned scars. However, it does not provide the researcher with enough data to fully quantify with speed and efficiency, including the impact and extent of the fire event being monitored. With the aim to fully understand the forest fires, the preceding mentioned transformations and indices can be applied to Landsat imageries. The researchers can truly gather a full understanding of the forest fire events and the associated environmental impacts by capitalizing on the full capabilities of the data (Key and Benson, 2004).

2.3 Components of forest fire assessment

2.3.1 The nature of forest fire

In the ecological viewpoint, fire is considered as a non-biotic factor which, in most cases, works within the ecosystem to decay, recycle and select. As a decomposition agent, fire releases the chemical energy stored in the available fuel. Fire liberates in slightly altered forms, many of the constituent biochemical residing in the litter. An ecosystem subjected to fire must cope with this discharge of energy and chemical, with the eradication of some organisms and introduction of others, and with the simultaneous processes of selective destruction and selective enhancement. It became apparent that fire is a major factor (Fuller, 1991).

Fire has always been a part of terrestrial environments. Biotic communities adapt and compensate for it, just as they do for the temperature or water. As with most environmental factors, human has greatly modified its effects, increasing its influence in many cases and decreasing it in others. Because of careless behaviors, human has increased the effect of fire then the productive environment is destroyed or injured (Fox and Stuart, 1994).

2.3.2 Forest fire spread

A fire spreads horizontally by igniting a series of particles of fuel at or near its edge. At first the flames burned at one point, the source of ignition, and then move outward, accumulation enough heat to keep burning on their own. As the flames move out from the point of ignition, either wind or slope lengthens the perimeter of the flames into an ellipse with an origin (Figure 2-1). Noted that this ellipse is a model, not all forest fires burn in this way. The head of the fire is the end of the ellipse that the wind blows ahead into new fuels. The head of the fire advances faster than do its sides or flanks because the leading flames are the first to reach the unburned fuel preheating the fuel and drying it. On the other hand, the rear of the fire is slanted toward the already-burned center, and so the flames move outward more slowly. As the speed of the wind increases, the ellipse becomes more elongated (Fuller, 1991).

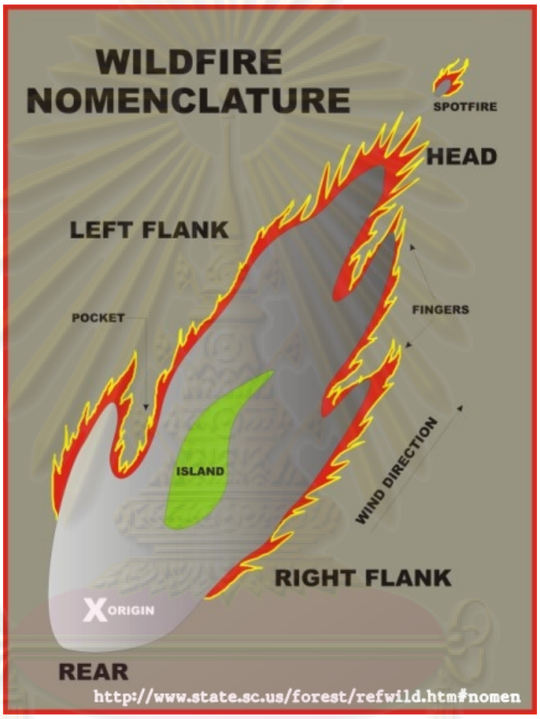

Figure 2-1 Wind and slope elongate a wildland fire into an ellipse
(South Carolina Forestry Commission, 1994).

Slope affects a fire in a way similar to that of wind but, instead stretches it uphill. Fire can also spread downhill or against the wind, but such a fire will be the flanks or rear of the ellipse formed by the main fire. As a result, a flanking fire advances crosswind or across a slope, and a backing fire advances against the wind or downslope. In any case, the shape of a fire seldom remains elliptical, because barriers slope, changes in fuel, and spotting cause it to develop fingers and even multiple heads. A fire with an expanding perimeter is a line fire.

In timber, crown fires can spread 5 or more miles per hour, but in grass, fire spread at a rate of only 2 to 4 miles an hour. But the fuels such as plants, shrubs, and trees, left behind may still burn after the flaming front had passed (Fuller, 1991).

2.3.3 Topography and forest fire

Topography is the physical shape and features of a region, and it affects fires by varying the weather within just a small area. Because warm air rises, preheating uphill fuels, fires advance uphill faster than they travel downhill (Figure 2-2). A slope raises the fuels in front of the fire, thus bringing them closer to the flames and also acts like a chimney carrying heat and flames uphill (Andrews and Chase, 1989). Therefore, depending on slope angle and wind speed, slope can be more important than wind in determining the rate of a fire's spread.

Topography also affects fires by means of elevation, the shape of the land, and the direction in which slope face. High elevations have a colder and wetter climate, and so there the fire season is shorter. The direction of a slope determines how much sunlight it receives. South and west slopes receive the most sunlight, and so they are much warmer and drier than north slopes are, which get the least amount of sunlight. South and west slopes therefore have a longer fire season, a longer daily burning, and a greater number of fires than north slopes do, and more of the fires that start there become large.

This variation in sunlight means that all slopes have different microclimates. Different species and amounts of vegetation grow in the different microclimates. Because north slopes and deep canyons receive less sun, they hold more moisture and so stay green longer and support more vegetation than south slope do.

Other topographical features, such as canyons, ridges, and bare areas, also influence fires. For example, a fire starting at the bottom of a slope is more likely to become large because more fuels are situated above it, and fire burns more easily uphill. Fires in narrow canyons preheat fuels across the canyon from them and also send embers across. A steep, narrow canyons pull ups heat and flames as in a chimney.

Where two canyons join, fire spreads unpredictably because the wind in both canyons form eddies where they meet. At the top of ridges, the fire may meet upslope winds from the other side, which slow it down. For these reasons, firefighters often build control lines along or near ridge tops.

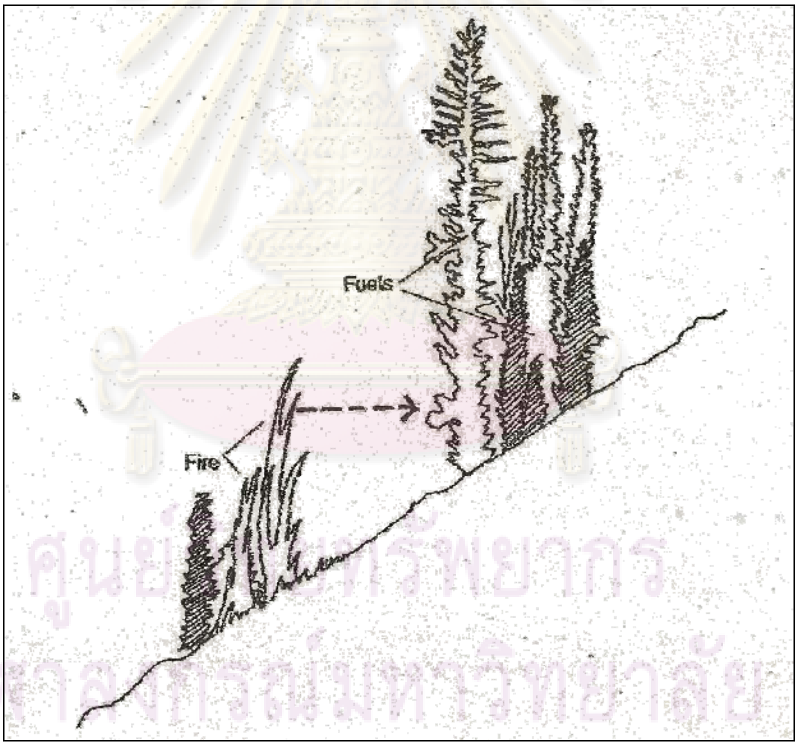

Figure 2-2 A slope raises fuels and thereby puts them closer to the fire below (Fuller, 1991).

2.3.4 Forest fire Intensity

Another characteristic of a fire is its intensity, or the rate which a fire release heat. Intensity is determined by the amount of heat energy produced. Heat intensity is measured in Btus or British thermal units. One Btu is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit. Fire intensity is expressed in different ways, according to how the figures will be used. Fire-line intensity is the number of Btus per foot per second, or per unit length. High rates of spread in light fuels like grass produce a high-intensity fire. In heavy fuels, however, even a low spread rate can produce a high-intensity fire.

The intensity of a fire is also related to the length of its flames, which limits the possible methods of suppressing it. When the flames are no more than 4 feet in length, firefighters can usually attack the fire with hand tools. But when the flames are over 8 feet long, no control of any kind is likely to be effective. And when the flames are longer than 11 feet, fires often crown, spot, and make a rapid spread through surface or crown fuels.

A crown fire is one that attacks the crown, or head of foliage, of a tree or shrub (Figure 2-3). It also needs thick fuels and tree crown in close proximity. Low moisture in fine fuels and low moisture and flammable chemicals inn foliage also make crowning more likely. For a crown fire to stay in the three crowns and keep moving, strong winds, steep slope, or high fire intensity must be present.

Because crown fires usually travel rapidly, they do not stay in one place long and so may be less destructive than the length of their flames would indicate. But when crown fires become very large and intense and spread quickly, they was renamed conflagrations, which are large destructive fires with moving fronts and rapid rates of spread. This type of fire occurred in Yellowstone, The United States, in 1988.

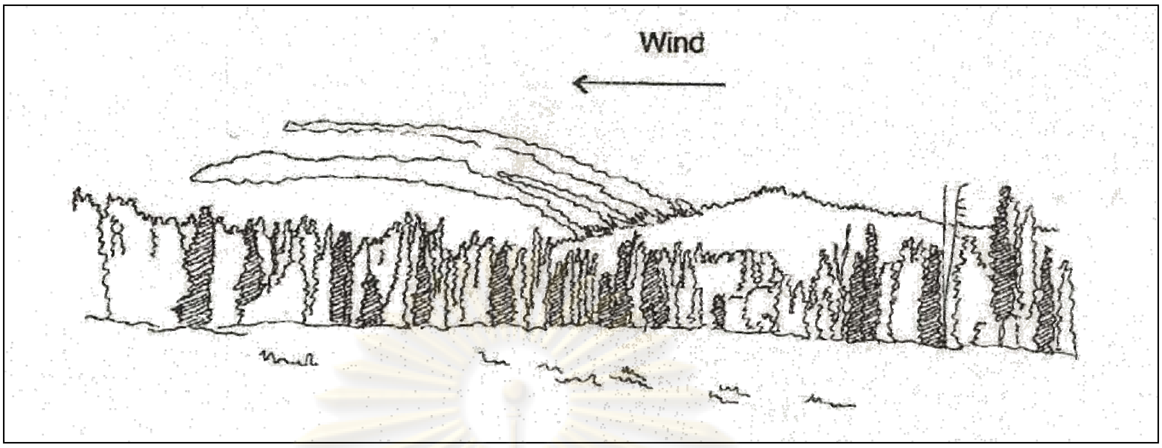

Figure 2-3 Crown fires are usually found only in the presence of strong winds (Fuller, 1991).

Spotting occurs when the hot air rising from the fire carries embers or firebrands (pieces of burning wood) upward and over to stands of trees ahead of the fire, where they start new fires. Long-range spotting requires firebrands large enough to travel long distances and to stay burning until they hit the ground. When the temperature is high and the humidity and fuel moisture are low, almost all the firebrands can starts fires.

2.3.5 Predicting forest fire behavior

Fire behavior analysts still watch the weather and the characteristics of the fire itself, but today they also use mathematical and computer systems. In 1972, Richard Rothermel, a researcher from the Intermountain Research Station' Fire Sciences Laboratory in Missoula constructed a mathematical model called the Rothermel model, which combines data regarding the fuels, weather, and site of the fire to predict the spread of surface fires. Fire managers using the Rothermel model or the BEHAVE program feed in data on the wind speed, slope, and properties of the fuels. They compare the vegetation of the fire site with descriptions of different fuel models, estimate the moisture of live fuels from how much of the grasses have cured or dried out, and gauge the moisture of dead fuels from the time of day, relative humidity, temperature, degree and aspect of slope, and amount of shade.

From the fuel type, time since ignition, topography, fuel moisture, and weather measurement, BEHAVE can describe many aspects of fire behavior, including its rate of spread, future perimeter, area, length-to-width ration, and flame lengths. It is helpful for fire managers to have a trained fire behavior analyst interpret the results. It can accurately predict surface fires in continuous fuels but cannot predict fire behavior when fires begin spotting or crowning (Rothermel, 1972).

2.3.6 The weather and forest fire behavior

Certain weather factors such as temperature, humidity, air stability, wind speed, and wind direction, directly affect the way that fires burn. Other factors, such as the weather's long-term climatic influence on the fuels and their dryness, indirectly affect fires. Both short-term and long-term effects are part of the fire environment.

Since the weather largely determines how fires behave and when and where they occur, fire managers have named fire weather the weather characteristics that influence fires. For example, hot dry weather with gusty winds and intense lightning storms means fire. During the fire season, to help them, the National Weather Service provides daily fire weather forecasts during the times of high fire danger or when fire managers request them.

The climate of each geographical region determines the fuel (vegetation) types and the length of the fire or the time of year when most fire occur.

The difference in the sun's heating of the earth's surface lead to the major weather and climate variations that contribute to fire danger. As the sun warms the earth's surface, it also heats the air above it. Then the heated air creates air pressure differences that cause the basic wind patterns, that is, air flowing from higher-pressure to lower-pressure zones.

Moisture and pollutants in the air, the angle and duration of the sunlight, and the properties of the earth's surface combine to determine how much the air heats. One such property affecting the heating is the color of the earth's surface. Colors like black absorb heat better than others do. Texture also affects the surface heating; for example, a rough surface absorbs heat better than a smooth one does. Moreover a transparent material like water, distributes heat more evenly rather keeping it on the surface. Furthermore, some substances, like rock, conduct heat better than others do. Materials also vary in the heat they can absorb, that is, their specific heat, the ratio of the heat absorbed or given off by a material to its rise or fall in temperature. Water has a high specific heat, and so wet surfaces heat more slowly than dry ones do. Therefore, differences in air moisture can greatly affect fire weather (Fuller,1991).

- Air moisture

At low humidity, fuels or vegetation dry out, therefore catching fire more easily and burning faster. The moisture in the air comes from evaporation from the ground, water bodies and the transpiration of plants. When the air holds as much water vapors as it can at its prevailing temperature, it is saturated. Air usually holds less than it can and so is unsaturated. Meteorologists describe air moisture with the term relative humidity, or the ratio of the amount of water vapor in a given volume of air to what it could hold if it were saturated at the same temperature. This ratio is expressed as a percentage and saturated air has 100 percent relative humidity.

Because more water vapor is needed to saturate warm air than cool air, when the air temperature rises, the relative humidity drops. On the other hand, when the temperature drops, the relative humidity rises because air cools as it rises, at higher elevations air with the same amount of water vapor as air lower down has a higher relative humidity and is closer to saturation.

- Air stability

The air's stability is the ability to resist vertical motion. This ability, which influences the development of winds, depends on how fast the air cools with elevation. Scientist measure air stability by examining how much an invisible balloon of air cools as it rises, as compared with the air around it, if they do not mix, even though in the real world they do mix. This cooling with altitude without any mixing is called the adiabatic lapse rate.

The adiabatic lapse rate for unsaturated air is 5.5° F per 1000 Feet. Unsaturated air seldom cools at this rate, however, because of mixing and other factors. Saturated air cools at an even lower rate, 3° F per 1000 feet, called the moist adiabatic rate. The reason that it is lower than the dry rate is that as air cools, some of its water vapor condenses, and the condensation warms the air, thereby slowing the cooling rate.

When the air cools at less than the dry adiabatic rate, it is considered stable. If something pushes this air up or down, it will return to its original level. Stable air seldom moves vertically. Stable air will hold in smoke but reduce fire activity. As the earth's surface cools the air next to it at night, it makes the air more stable, enabling fires to "lie down" at night, especially in valleys. Stable air can be identified by noticing haze, layered clouds, steady winds, or fogs; any smoke columns tend to drift apart after only a short rise.

If the air stays at the same location when lifted or forced downward, it is neutral. Neutral air usually remains calm because its temperature lapse rate equals the dry adiabatic rate.

On the other hand, if the air continues to move in the same direction, it is unstable. The temperature lapse rate of unstable air exceeds the dry adiabatic rate. Unstable air usually rises and keep going up until it reaches air it own temperature. On a hot day the air is so hot near the ground that it cools much faster than air cooling at the dry adiabatic rate, therefore heating is one caused of unstable air. When air becomes unstable, fire activity increases, and the tall smoke columns carry firebrands high up in the air. Finally, the sun's warmth causes air to be more unstable during the day than it is at night.

Air stability simply means that the air tends to move up or down until it reaches air its own temperature. Above the earth's surface, the various layers of air may have different degrees of stability or instability. When an air layer is lifted, the lifting stretches the top of the layer farther from the bottom. This stretching then increases the difference in temperature throughout the layer, which makes the air less stable. Surface heating, cold fronts, and mountains all can lift air layers.

Although unstable air causes fire problems, stable air can also lead to dangerous fire behavior when a high-pressure system enters an area. In high-pressure system, the air sinks to the earth's surface and diminishes fire activity because it reduces vertical motion. While the air sinks, it warms and the relative humidity drops, which increases fire activity. In a high-pressure area, the air high above the ground can be warmer than that on the surface; that is, it is a temperature inversion. Inversions often occur at night when the ground cools off and cools the air just above it. This cool air runs downhill and collects in the valleys. Because night inversions usually do not extend to the ridge tops, they can slow a fire in a valley that still is burning actively on the ridge tops.

Because of this tendency for the inversions to form, the areas halfway up the slopes are the warmest and driest. It is called thermal belts, which are warm because they are above the nighttime inversions but below the ridge tops' cool winds and temperatures. Fire, then, are more active in these belts than in the areas above and below them.

Furthermore, inversions trap smoke in the valleys, and so planes spraying fire retardants or helicopters with water buckets must wait for the inversion to end before they can fly. However, when an inversion does end, the air often becomes unstable which can cause a sudden increase in fire activity (Fuller,1991).

- Convective or local winds

The local winds caused by heating differences are called convective winds, because the heating causing the air to move. These winds blow harder in the mountains and near the ocean. In the mountains they blow upslope during the day and downslope at night. As the sun warms the slopes in the morning, the air above them warms and rises, and the cool air from the base of the slopes move uphill to replace it. At night the air over the slopes cools faster than does that in the valleys, becomes heavier than the air below it, and slowly moves back down the slopes as a downslope wind. When it flows into the valley, it pushes the air down the valley (Figure 2-4). Upslope winds may reach 15 miles an hour and contain turbulence, but downslope winds blow smoothly at only 2 or 3 miles an hour.

The times when upslope change to downslope winds and the strength of those winds are depend on the number of hours of sunlight that the slope receives.

Because south and west slopes receive sunlight for more hours of the day, the air above them is hotter and so produces stronger slope winds. Upslope winds here also begin earlier in the day and change to downslope winds later than do winds on north slopes, which get less sun.

On hot days, when the air heats above the slopes and spirals up in columns, it draws in the surrounding surface air. These whirlwinds are caused by very unstable air and obstacles like big rocks or isolated trees that start the air spinning. The can span 100 feet, rise to 4000 feet, and spin at 50 miles an hour. Within a fire, they are called fire whirls. Another convective local wind occur in thunderstorm, when rain or hail cools the air and causes severe downdrafts, and the three kinds of foehn wind are most responsible for fire problems (Fuller,1991).

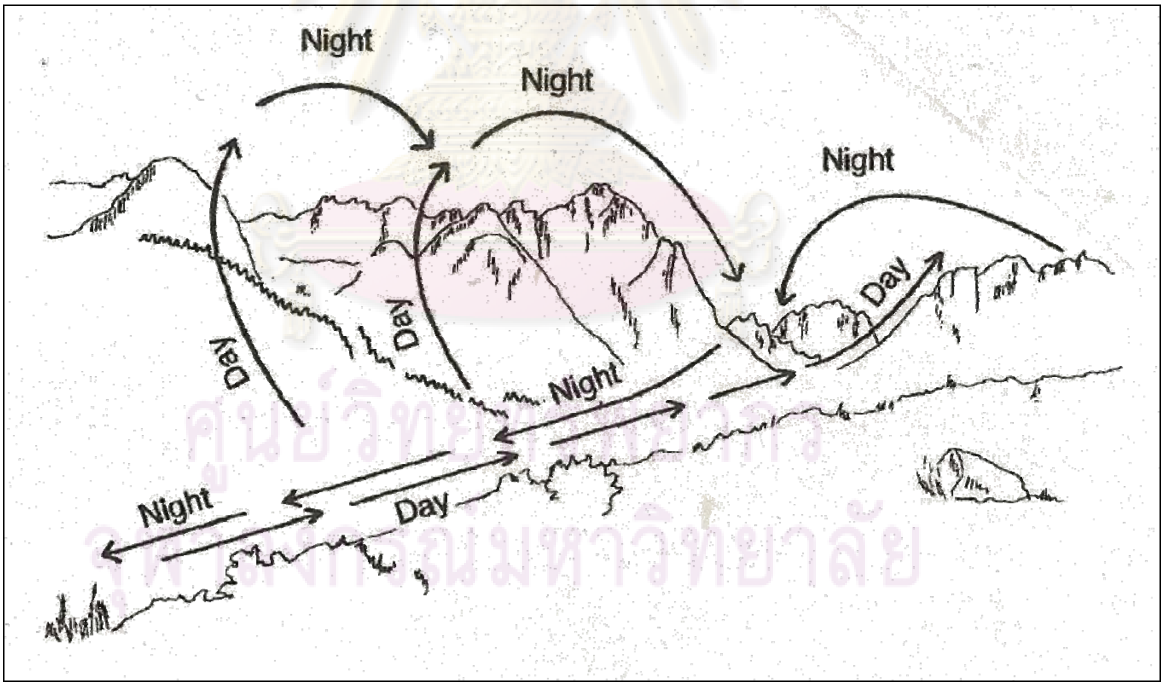

Figure 2-4 The occurrence of Convective or Local winds (Fuller,1991).

- Foehn Winds

A foehn wind is produced when the air descends a mountain range; warming as it falls and speeding up in response to gravity (Figure 2-5). When the air is lifted over a mountain range, it loses moisture and so will be much warmer when it descends on the outer side by means of gravity, in a wind called a foehn, Chinook, or other local name. Foehn winds are usually much warmer than normal for the season. They may develop in several ways. In the first, prevailing winds force a layer of moist air from a low pressure-area over a range into a high-pressure area. The air loses its moisture through precipitation as it climbs and cools at the moist adiabatic rate because it is saturated. As the air goes down the lee side of the range, it is no longer saturated, and so the increasing air pressure warms it at the much faster dry adiabatic rate. Therefore, the air becomes much warmer and drier than it was on the windward side.

The second type of foehn wind is caused by a low-pressure area on one side of a mountain range and a cold high-pressure area on the other, but with only gentle prevailing winds. In this case the wind blows naturally from the high pressure toward the low pressure. The air warms in the same way as it descends and under the force of gravity, pushes out the surface air as fast as 90 miles per hour.

In the third kind of foehn wind, a high-pressure area extends across an entire mountain range. As the air of the high-pressure area rises and cools, it loses moisture, then warms, and speeds up as it descends. All foehn winds cause fires to spread rapidly, just as winds associated with warm and cold fronts do (Fuller,1991).

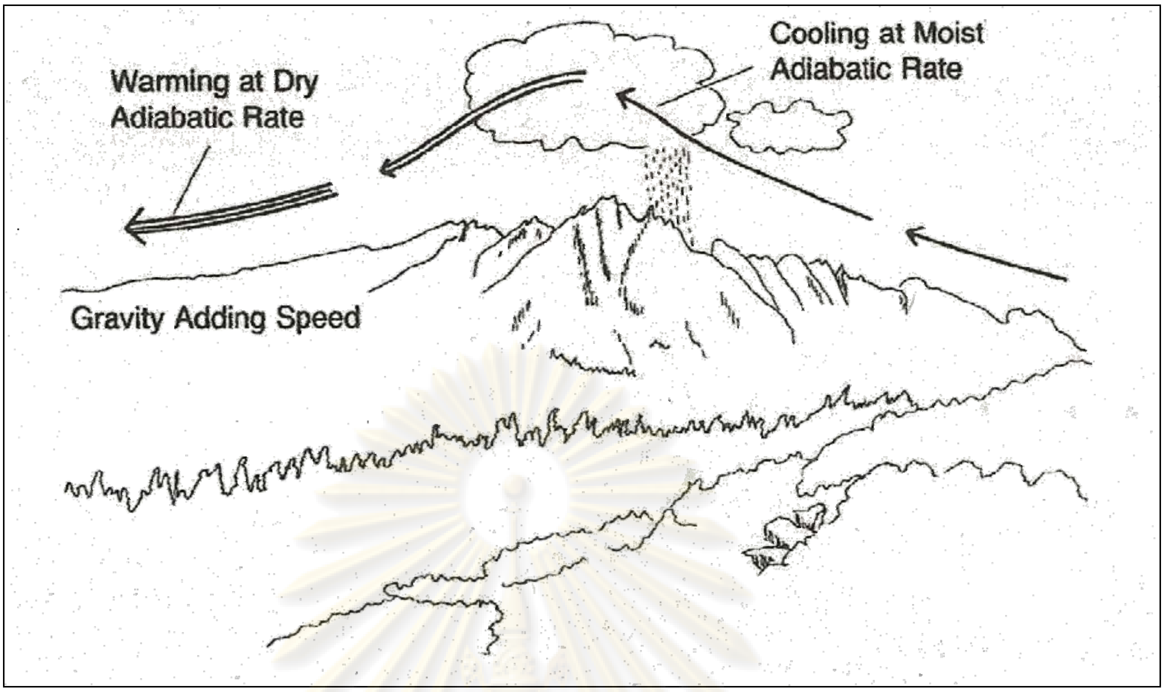

Figure 2-5 The occurrence of Foehn Wind (Fuller, 1991).

- **Fire weather terminology**

Many weather terms are familiar because they often appear in the daily weather reports; other are used only to describe weather as it affects forest fires. Fire managers have named the time when fires are most active, usually from 10 A.M. to 5 P.M., the burning period. The months each year when wildland fires are common are called the fire season. The typical fire season in an area is its fire climate. The fire climate plus the fuel and ignition patterns make up the fire regime.

These terms have resulted from research on fire weather. Researchers at the Forest Fire Laboratory of the Pacific Southwest Forest and Range Experiment Station in Riverside, California, USA, have found that the short-range variations in weather make it difficult to forecast it for longer periods. Because small variations do not slow up in the large-scale processes that influence the variations, errors can multiply rapidly. Because the measurements sometimes contain errors and data are lacking for some parts of the country, the longer the computer models run, the greater such errors become. Therefore, weather forecasts usually are accurate for only one to three days. At the Riverside Lab researchers are also trying to find out how weather creates large areas of high fire danger, by correlating past weather records with fire records and by gathering statistics on the relationship of conditions in the upper atmosphere to those of the surface weather (Fuller,1991).

2.3.7 Mosaic pattern of forest fire

Forest fires create varied and broken patterns, called mosaics that are typical of forest ecosystems. Because of this variation, only a third of this vegetation within the perimeter of a large fire actually burns (Fuller, 1991). Fires cause mosaic patterns by burning at different intensities in different places and by burning different areas in different years. Each area or "piece" of the mosaic is called a patch; the study of these is called patch dynamics. There are several reasons for the varying intensity.

1) Since the night temperature inversions reduce the wind, fires burn less vigorously at night than during the day. As a result, crown fires may drop to the surface at night, where they usually kill only the understory of the trees.

2) Fuel moisture varies with the location. As the sun shines on south slopes for more hours each day, they dry out more than do north slopes and also burn better. Moreover, a forest of older trees has a large percentage of dead material, so that fire will kill more of its trees.

3) Fires do not normally pass through areas that have been burned recently; that is, old burns tend to stop fires.

4) Fire burning in strong winds sometimes damage trees less because the wind blows the flames and hot gases to the lee side of the tree, where the trunk of the tree acts like a chimney to channel them upward.

5) Mosaics also result from differences among tree species in how easily their foliage burns. For instance, foliage that contains oils, resins, or other flammable liquids burns quickly and intensely (Fuller,1991).

2.4 Previous investigation on forest fire assessment

The previous investigations on forest fire assessment have been studied in many parts of the world. Some important literatures have been briefly reviewed below in chronological order to be the background information.

Flannigan and Vonderhaar (1986) conducted a study using the advanced very high resolution radiometer to monitor forest fires during a severe fire outbreak in north central Alberta between June 12 and June 21, 1982. A multispectral technique was used to indentify forest fires and estimate forest fire size. The study was concluded that satellite observations of forest fires are not sufficiently accurate but they are of value in providing a rapid, inexpensive supplement, especially in remote forested areas.

Belda and Melia (2002) examined the variability of normalized difference vegetation index (NDVI) on forest vegetation in Alicante, Spain between 1984 and 1994 and to analyze the influence of climatic parameters in the regeneration of forest areas burned by fires. Landsat TM images from 1984 to 1994 were used to calculate the NDVI. Geographical Information System was used to monitor forest vegetation and its relationship with climatic parameters, that is, rainfall and soil moisture.

Jaiswal et al. (2002) concluded that the evolved GIS-based forest fire risk model was found to be in strong agreement with actual fire-affected sites. The study proposed that the fire proneness of any area depends on many factors such as vegetation type/density, humidity of the area, proximity to settlements and distances from road. A geographic information system (GIS) was used effectively to combine different forest-fire-causing factors for demarcating the forest fire risk zone map. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability.

Loboda and Csiszar (2007) used the Fire Spread Reconstruction (FSR) to provide a method for characterization of fire occurrence over large territories from remotely sensed data. FSR determines the number of fire events, their approximate size, duration, and fire spread rate and allows for the analysis of fire occurrence and spread as a function of vegetation, fire season, fire weather and other parameters. FSR is also used to identify the points of ignition for individual fire events in spatio-temporal domain for fire danger and fire threat modeling.

Vafeidis (2007) proposed the method for modelling the hydrologic response of catchments to burning with the use of remote sensing and GIS. The model incorporates the effects of forest fire on the parameters that control erosion using remotely sensed estimates of the characteristics of the fire, such as the temperature and the extent. The method was implemented in four regions in Greece where severe wildfires took place during the summer of 1998. Pre-fire and post-fire model runs showed significant changes in runoff and erosion patterns as a result of the passage of the fire and a notable increase in the spatial variability of post-fire erosion rates.

Albuquerque et al. (2007) used map algebra in the geographic information system environment to integrate climate model data with remote sensing data intending to obtain a wildfire hazard map. The model has provided relative humidity, components of the horizontal wind and temperature. From the land cover phytophysionomic type characterization, a forest wildfire fuel map has been created. The integration of the different maps has been made using geographic information system and a new map with its associated GIS database was generated showing the most vulnerable zones to wildfire hazard.

Strino et al. (2007) focused the study on forest fires originated by accidental human events. Digital Elevation Model - DEM was used to detect the topographic risks looking for slope and orientation parameters as well as the classification of vegetation areas which play an important rule to understand the green areas humidity. The areas that may be susceptible to originate fire accidentally and quickly spread were classified in different risk levels. The final result was illustrated with a fire risk level map covering the Metropolitan Area of Barcelona.

Fuller (1991) indicated that trees can lose 20-30% of their crown to fire before the loss will affect their growth rate. The cambium, just inside the bark, is a formative layer that produces new plants tissue. It is damaged more by the duration of a fire than by its intensity. The difference of tree species grow helps determine a fire's intensity as well. Thick bark protects against fire because fire can penetrate it deeply without injuring the cambium. Deciduous trees resist fires better than evergreen trees do, because their foliage contains more moisture and fewer organic compounds than the foliage of most evergreens does. Furthermore, deciduous trees can grow new leaves each year. The effects of fire on trees also depend on their stage of growth. As a consequence, inactive plants resist heat better because their tissue moisture is low, but they also burn better when they have little moisture. Conifers are most flammable in the spring, when the old needles reach their lowest annual moisture level and the new needles have not yet grown, and in the fall when all the foliage has dried out and the older needles have died.

Fuller (1991) further concluded that the effects of forest fire on animals change over time, but the biggest impact is the modification of their habitat. Few studies have examined the adaptation of animals to fire, but biologists believe that animals with flexible habits and diets thrive after fires and that those animals that eat foods found only in mature forests seldom survive. In long term, fire creates more forest "edge", which provides habitat for a wider variety of animals than the forest did before the fire. The effect of fire on animals depends on the type of fire and type of vegetation. Fire in areas of heavy fuel loading tends to be more intense and kills more animals, especially invertebrates and micro–organisms. Generally, vertebrates are rarely killed in fires and where death does occur, it usually has a negligible effect on the species population.

Fuller (1991) studied the effects of forest fire on soil and concluded that in severe fires, only ashes remain on the surface, and the upper mineral soil is cooked and discolored by a chemical change. The studies of fires in California chaparral show that if the soil surface reaches 1000° F and 1 inch underground reaches 400° F, the chemical change will occur. As fire blackens the soil surface and removes the shade of the trees, it raises surface temperatures in the post-fire environment as much as 25° F. Nitrogen, phosphorus, potassium, and calcium can vaporize in a severe fire. There is some studies show that after a fire the level of these minerals in shrubs increases, but others show no increase because the fertilizer effect varies with how much nitrogen vaporizes, compared with how much ash and charcoal is deposited plus the effect of the fire on soil microorganisms. Forest fire can also kill the symbiotic fungi called mycorrhizae that grow on the roots of many shrubs and trees. Mycorrhizae get their food from their host shrubs or trees and acts as auxiliary root hairs for the host plant. This fungus can recover rapidly after a fire. They need moisture more than the shrubs and trees do, and most trees and shrubs depend on the mycorrhizae to help them absorb nutrients. Therefore, drought will hinder their regrowth by preventing the mycorrhizae, and the trees and shrubs from growing.

Fuller (1991) concluded that fire can damage the soil by burning the roots and the humus that hold back the runoff and by burning the trees and shrubs that formerly took up water. This damage makes erosion more likely. Fire can also cloud streams with sediment, which may harm spawning fish. For these reasons, intense fires usually damage the watershed. The additional runoff and resulting erosion vary with the type of the forest, the steepness of the slope, and the amount of precipitation soon after the fires. The amount of erosion after a fire also depends on how rapidly plants cover the ground, in some cases, it takes years. Erosion is worst where fire has deposited water-repellant layers in the soil. Since it increases soil and water temperance, fire changes streams and the life in and along them. The lack of tree and shrub cover also causes more fluctuation in water temperatures daily and seasonally. The ash and the charcoal raise the pH of the stream, making the water more alkaline. Fire retardant chemicals can also pollute the streams, but the effects are minor, and researchers are continuing to improve the retardants to reduce their effects on water.

In Thailand, the literatures on forest fire assessment and similar phenomena are also reviewed in chronological order as below.

According to the Forest Fire Control Division (2003), the occurrences of forest fire in Thailand have been recorded since 1971, with the assistance of Canadian International Development Agency. In the 1970s, the forest officers were trained for modern forest fire control in Canada and the United States. Afterward, the Forest Fire

Control Section was established under the Forest Management Division of Royal Forest Department in 1976.

Royal Forest Department of Thailand (1992) reported that the forest fires statistics indicate that almost all fires are caused by human especially by those who live close to the forest. The various causes of forest fires and their relative importance are as follows:

- To facilitate collection of non-timber forest products (25%)
- Burning of agricultural debris (20%)
- Forest conversion to farmland (19%)
- To drive animals or attract them to burned areas during hunting (12%)
- Carelessness (12%)
- Other causes (12%)

Nipon Tangtham (1997) summarized that in Thailand, forest fires occur annually during the dry season from December to May, with the most fires occurring in February and March. Most are surface fires with take place mainly in dry diptetocarp forest, mixed deciduous and forest plantations, including some extent in dry evergreen forest, hill evergreen forest or in some parts of the tropical rainforest. In remarkably dry areas, double or multiple recurrences of forest fires in one season is common. These surface fires consume litter and small vegetation. In the past decade, a notable number of crown fires have occurred in the pine forest. Moreover, ground fires have also occurred even in swamp forests in Southern Thailand, where they are pointed out as the heavy disturbance to ecosystem.

Nipon Tangtham (1997) also reported that the forest fires affected areas each year may be as much as 117 million rai, including multiple occurrences in the same area. From the aerial surveys of fire affected areas showed that in 1984-1986 fire occurred on about 19.5 million rai of forest. There was the repeated study in 1992, 1993, and 1994. It was showed that in the respective years, fire occurred on about 12.7, 9.2 and 4.77 million rai of forest.

San Kaitpraneet et al. (1997) presented that the effects of forest fires in Thailand are as follows:

- Effect on vegetation and wildlife.

Fire can kill plants and animals and slow down their growth and development. It has been estimated that in a fire, 40% of young trees are killed and the growth of the remaining ones is reduced by 20-25%. Moreover, approximately 80% of roots at or near the surface are damaged in a fire. About 20% of one to five-year old trees have been estimated to die in plantation fire.

- Effect on soil and water.

Surface runoff has been estimated to increase three-fold and soil erosion from 3% to 30% after forest fires occurred, as a result, the rate of flow suspended sediment and turgidity increase along the rivers.

Soil and water losses in from teak plantation are the heaviest, in the mixed deciduous forest with teak are moderate and in the deciduous dipterocarps forest are the lowest. The causes are attributed to the degree of slope and organic matter and clay content of the soil. (Chunkao et al. cited in Nipon Tangtham, 1992)

- Effect on air quality and scenic beauty.

Smoke remains in the atmosphere for weeks or even months after forest fires. The various greenhouse gases were accumulatively released to the atmosphere. In addition, smoke leads to reduction in light intensity, visibility, and scenic beauty.

- Economic losses.

In terms of the value of trees alone, it has been estimated that annual losses from forest fires may reach about 50 billion baht. Based on the calculation of Pannaphitak et al. (1991) the values of fire damage for dry dipterocarp forests, mixed deciduous forests, pine forests and reforested plantation are about 5,717, 2,460, 3,792, and 1,400 baht per rai per year respectively.

Giri and Shrestha (2000) found that the Landsat Thematic Mapper ™ data is extremely useful for accurate delineation and demarcation of burned area that occurred during the peak fire season of 1998 in the Kha Khaeng Wildlife Sanctuary of Thailand. Their study is recommended to acquire and analyze multilayer and multiseasonal satellite data in order to create a fire history of the area and to capture all forest fire events of the season. It is also recommended to create a GIS database consisting of biophysical and socio-economic variables needed for fire hazard mapping and forest fire simulation.

Tanpipat and Honda (2002) carried out the forest fire experiment using the ThermoViewer to observe the temperature change before, during and after the fire. The experiment had been conducted not only the day of the forest fire experiment but also continued for four months after the forest fire had been gone. The results showed that the temperature difference is significant in the afternoon; therefore, afternoon satellite passing is better and suitable time for active forest fires and burned scars detections.

Hoarse (2004) studied the process for community and government cooperation to reduce the forest fire and smoke problem in Thailand. The study area is located in Amphoe Song Khwae, Amphoe Chiang Klang and Amphoe Tha Wang Pha which are the part of Nan watershed. The study showed that major causes of the smoke problem are burning of grassland by hunters and uncontrolled burning of upland fields for agriculture. Moderate causes of smoke were burning of grassland, urban and roadside fires, and burning of paddy rice straw. Hoarse also proposed that improved satellite technology at lower cost is needed before it can be useful at the provincial or district level for monitoring fires.

Anusorn Rungsiapnich and Kampanat Deeudomchan (2007) studied on forest fire in Changwat Chiang Mai, Thailand by applied on the Remote Sensing data and Geographic Information System as input for risk area modeling. The result showed that forest fire pattern occurs wave-like.

CHAPTER III

METHODOLOGY AND DATA PREPARATION

The sources of input data and the steps in image processing used remote sensing are comprehensively explained hereafter indicate that as the data entry and production are the most cumbersome and time consuming steps of any kinds of GIS and remote sensing techniques. The thematic data used in this thesis are prepared and processed below. Meanwhile, phases of burned scar mapping analysis in GIS-based forest fire risk zoning techniques are reviewed. However, the detailed statistic analysis of the forest fire database and the parameter maps will be explained in the following chapter.

3.1 Phases of burned scar mapping analysis in GIS-based forest fire risk zoning techniques

The following phases can be distinguished in the process of a risk analysis using GIS (Van Westen, 1993 and 1994 cited in Yumuang, 2005). They are listed in logical order or sequence though sometimes they may be overlapping as follow:

- Preliminary phase:

  Phase 1: Defining of objective of study and the methods of analysis which will be applied.

- Data collection phases:

  Phase 2: Collection of existing data (collection of existing maps and reports with relevant data)

  Phase 3: Image interpretation (interpretation of images and creation of new input maps)

Phase 4: Data base design (design of the database and definition of the way in which the data will be collected and stored)

Phase 5: Fieldwork (to verify the image interpretation)

Phase 6: Laboratory analysis

- GIS work:

  Phase 7: Data entry (digitizing of maps and attribute data)

  Phase 8: Data validation (validation of the entered data)

  Phase 9: Data manipulation (manipulation and transformation of the raw data in a form which can be used in the analysis)

  Phase 10: Data analysis and modelling (analysis of data for preparation of risk maps)

  Phase 11: Presentation of output maps (final production of risk maps and adjoining report)

An ideal GIS for risk analysis combines conventional GIS procedures with image processing capabilities and a relational data base. Map overlaying, modeling, and integration with satellite images are required, thus a raster system is preferred. The program should be able to perform spatial analysis on multiple-input maps and connected attribute data tables for map overlay, reclassification, and various other spatial functions.

3.2 Thematic data preparation from GIS and remote sensing techniques

Remote sensed data can be merged with other sources of geo-coded information as a GIS. This allows the overlapping of several layers of information with the remotely sensed data, and the application of a virtually unlimited number of forms of data analysis.

The input data used for forest fire detection in this thesis consists of several spatial data categories from the available resources (as shown in Table 3-2), being digitized from available maps and prepared from image interpretation, and from field investigation data. These input data will be further used to analyze the dynamic behavior of fire and fire risk locations by the statistic analysis in the Chapter 4.

The brief techniques and thematic maps of the input data produced in this thesis, namely, elevation (slope and aspect), transportation, human settlement, vegetation and land cover are consequently presented as below.

Table 3-1 Overview of the important input data themes that were pre-processed and invented in this thesis.

Main themes	Sub-themes	Data preparation methodology
Elevation	Slope	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
	Aspect	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
Transportation	Roads	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
Human settlement	Villages	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
Vegetation	Vegetation	Derived from interpretation of remote sensing imageries and field investigation
Land cover	Land cover	Derived from interpretation of remote sensing imageries and field investigation
Burned scar inventory	Burned scars	Derived from interpretation of multi-temporal remote sensing imageries and field investigation

3.2.1 Slope

The slope is a measurement of surface steepness and is calculated in degrees of inclination. The color-coded slope map is conducted in Figure 3-1. The slope has a range between 0 degree and 90 degrees, 0 degree representing the flat lying areas and 90 degrees as the vertical ones. Any other value indicates the inclined areas**.** In the center of the study area consists of gentle slope that range between 0 to 10% while the edge of the area consists of steep slope that range between 15 to greater than 35%.

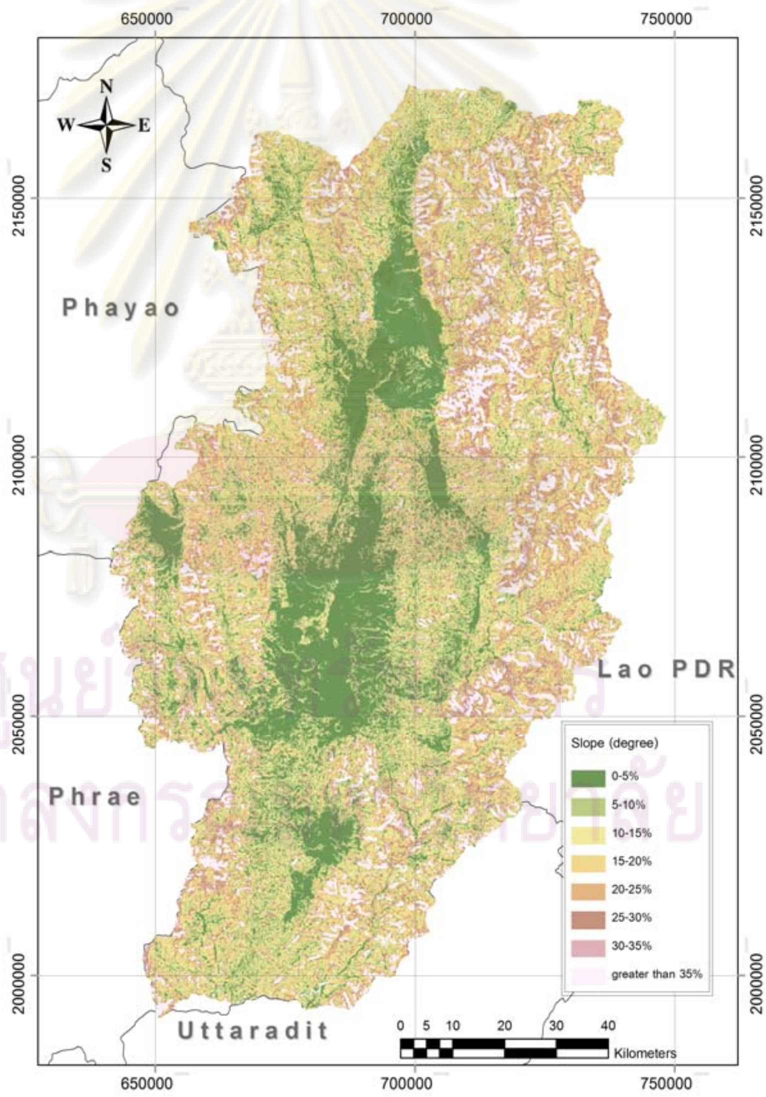

Figure 3-1 Slope map of the study area.

3.2.2 Aspect

The aspect is a measure of slope orientation and is calculated in geographic directions as the azimuthal degree from the North. The color-coded aspect map is presented in Figure 3-2. The aspect map reveals a range between -1 and 359, -1 representing the flat lying areas (no direction) and 0 as the North, and other values are the azimuth measurement from North.

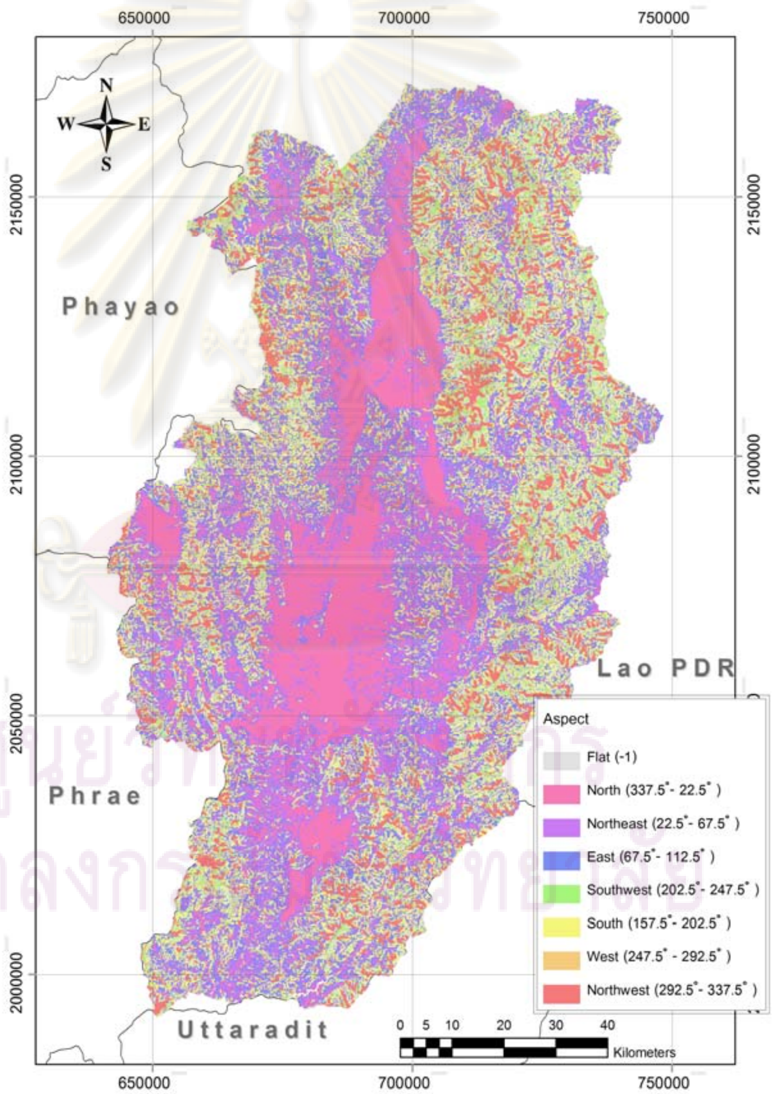

Figure 3-2 Aspect map of the study area.

3.2.3 Transportation

The presence of transportation such as road network might contribute to the evolution of forest fire in the area. For the construction of transportation map, the necessary features were derived from 1:50,000 scale digital maps of Land Development Department (Figure 3-3).

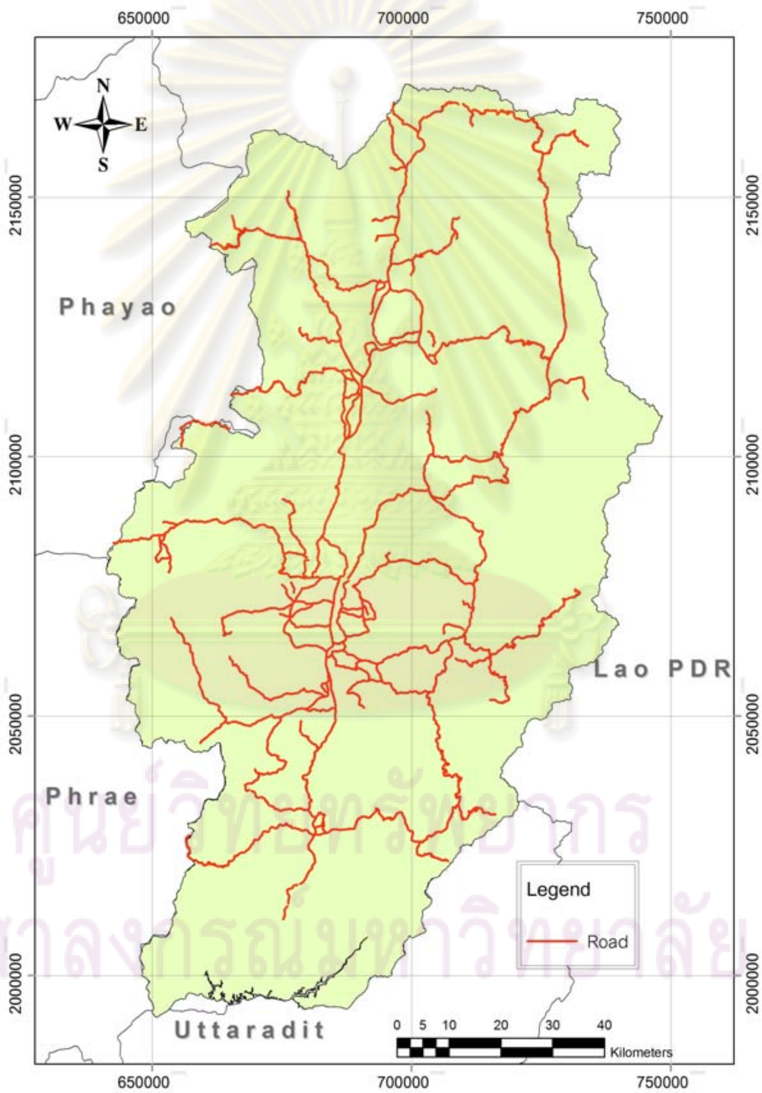

Figure 3-3 Transportation map of the study area.

3.2.4 Human settlement

The presence of human settlement might contribute to the evolution of forest fire in the area. For the construction of human settlement map, the necessary features were derived from 1:50,000 scale digital maps of Land Development Department (Figure 3-4).

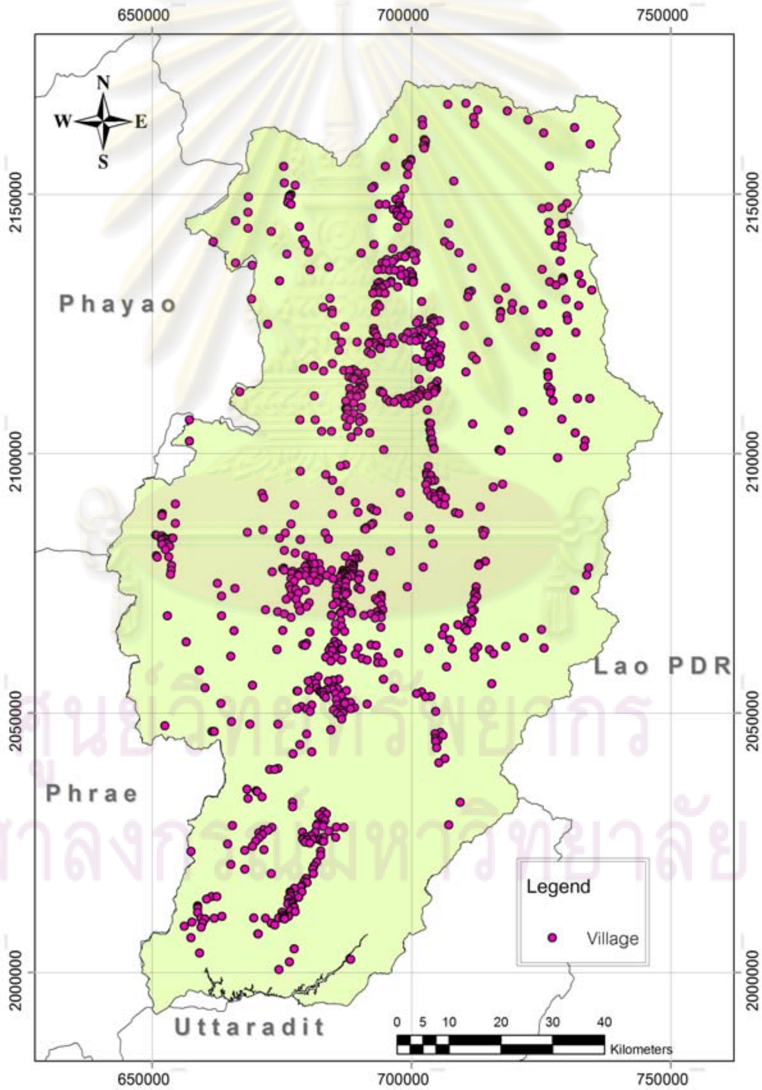

Figure 3-4 Human settlement map of the study area.

3.2.5 Vegetation

The vegetation types were classified according to the moisture context that has an influence on breaking out forest fire (Strino et al., 2007). Basically a vegetation map is obtained by classifying remotely sensed images. Typically this is performed by the spectral analysis of individual pixels and their association with other neighboring pixels. The results of classification depend largely on the type of area, land-cover type, and image acquisition date. The classification of vegetation index (NDVI) was carried out using image analysis techniques, and image classification techniques with ERDAS IMAGINE 8.5.

- Data sources

Classification of vegetation in the study area was carried out using many sources of remotely sensed data. Sources of data using for this research are summarized in Table 3-2. Landsat 5-TM acquired on 20th and 29th December 2006 were selected as primary remotely sensed data used for classifying the vegetation in the study area in the following data processing steps.

- Data processing

Individual image band files obtained from the Geo-Informatics and Space Technology Development Agency (GISTDA) were stacked using the layer stack function in ERDAS IMAGINE 8.5 software to create a multi-band image file. Scenes acquired from other data sources were presented in this way from the source. All files were subset to an area which encompasses the upper Nan watershed area. In order to determine the study area, the shapefile for the upper Nan watershed was converted to an Imagine Area of Interest (AOI), which was utilized to extract the study area from the full scene.

Table 3-2 Satellite images that are used as a primary data source of this thesis.

Image Type	Acquisition date	Original		
		Format	Scale and Resolution	Source
Landsat-5 TM	December 23, 1998	LGSOW	30 m.	GISTDA
Landsat-5 TM	December 30, 1998	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 21, 1999	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 30, 1999	LGSOW	30 m.	GISTDA
Landsat-5 TM	December 28, 2000	LGSOW	30 m.	GISTDA
Landsat-5 TM	January 4, 2001	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 19, 2001	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 26, 2001	LGSOW	30 m.	GISTDA
Landsat-5 TM	December 12, 2003	LGSOW	30 m.	GISTDA
Landsat-5 TM	January 6, 2004	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 18, 2004	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 27, 2004	LGSOW	30 m.	GISTDA
Landsat-5 TM	December 20, 2006	LGSOW	30 m.	GISTDA
Landsat-5 TM	December 29, 2006	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 20, 2007	LGSOW	30 m.	GISTDA
Landsat-5 TM	April 27, 2007	LGSOW	30 m.	GISTDA

Remarks: GISTDA Geo-Informatics and Space Technology Development Agency (Public Organization)

To compare images from different acquisition times, it is necessary to correct for natural fluctuations in the earth's orbit and the images relational aspect to the sun. Before any image enhancement techniques are performed, adjustments must be made to the raw digital numbers (DNs). These values, as they appear in raw Landsat imagery, do not reflect the effects of the elliptical orbit of the Earth around the sun. In addition to orbital fluctuations, adjustments must be made to account for the changing solar illumination. Digital numbers must be scaled to an "at sensor" reflectance value to account for variations in atmospheric conditions and solar illumination fluctuations. In processing the raw image through a reflectance model, much of this atmospheric noise can be normalized to simplify valid multi-temporal image comparison (Campbell, 2002; NASA, 2006).

The Landsat Imagery obtained from GISTDA on 23 December 1998, 30 December 1998, 21 April 1999, 30 April 1999, 28 December 2000, 4 January 2001, 19 April 2001, 26 April 2001, 12 December 2003, 6 January 2004, 18 April 2004, 27 April 2004, 20 December 2006, 29 December 2006, 20 April 2007 and 27 April 2007, respectively, were geometrically and radiometrically corrected, and therefore were only run through the reflectance portion of the model. Images corrected to "at sensor" reflectance were used exclusively for all image derived products.

The Geometric Correction of the Satellite Data was used to avoid geometric distortions in the above satellite images. It consists of the selection of suitable Ground Control Points (GCPs), determination of parameters, and resampling. The GCPs were obtained from the 1:50,000 Royal Thai Survey Department topographic maps.

Second order polynomials transformation was found to be the best for rectifying the image. The pixel size was resampled to 25 meters using nearest neighbor method for all image data.

Normalized Difference Vegetation Index (NDVI) was used to classify the vegetation in this research. A vegetation index is a value that is calculated from sets of remotely sensed data that is used to quantify the vegetative cover on the Earth's surface. Though many vegetation indices exist, the most widely used index is the NDVI. Like most other vegetation indices, NDVI is calculated as a ratio between measured reflectivity in the red- and near infrared portions of the electromagnetic spectrum. These two spectral bands are chosen because they are most affected by the absorption of chlorophyll in leafy green vegetation and by the density of green vegetation on the surface. Also, in the red- and near-infrared bands, the contrast between vegetation and soil is at a maximum (Rouse et al., 1974). NDVI transformation is computed as the ratio of the measured intensities in the red (R) and near infrared (NIR) spectral bands using the following formula.

NDVI = (NIR - red) / (NIR + red)...................... (Equation 3-1)

The resulting index value is sensitive to the presence of vegetation on the land surface and can be used to address issues of vegetation type, amount, and condition. Many satellites have sensors that measure the red- and near-infrared spectral bands, and many variations on NDVI exist. The index is written for Landsat TM and ETM+ as

NDVI = (TM4-TM3)/(TM4+TM3) .... (Equation 3-2)

Where TM4 and TM3 are Landsat Thematic Mapper (or ETM+) band four and band three. The Red and NIR images are used to calculate an NDVI value for each pixel. The NDVI equation produces values in the range of -1.0 to 1.0, where vegetated areas typically have values greater than zero, while the negative values indicate the non-vegetated surface features such as water, barren, ice, snow, or clouds Difference NDVI images can provide a quick and efficient measure of vegetation change due to the fire.

The false color composite of Landsat 5-TM imageries (R=5, G=4, B=3) acquired on 20th and 29th December 2006 were used in the classification of vegetation and land cover. The vegetation can be classified (After Córdova, 2009) in fresh, fresh-like, moist, dry and very dry as show in Figure 3-5.

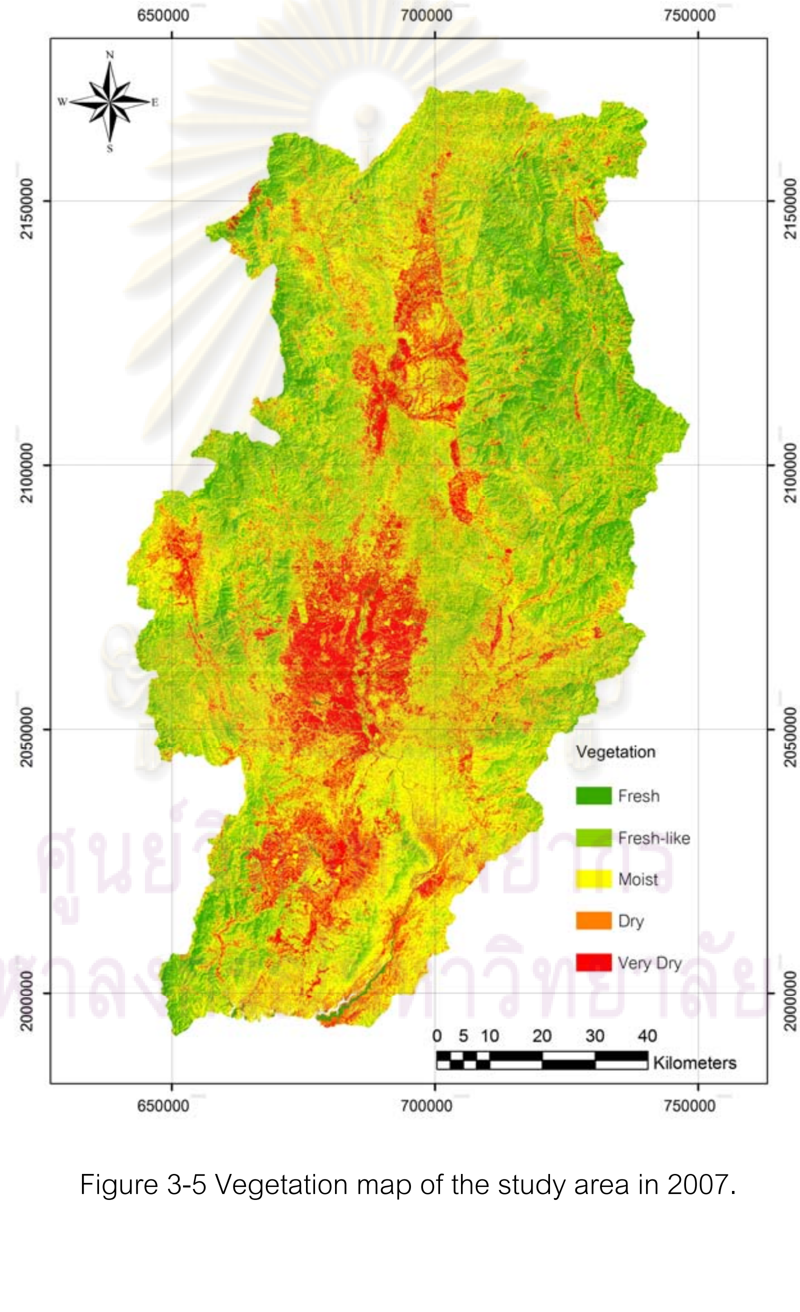

Figure 3-5 Vegetation map of the study area in 2007.

3.2.6 Land cover

The land cover in upper Nan watershed in 2007 derived from interpretation of remote sensing imageries and field investigation (Figure 3-6). The classification of land cover was carried out using image analysis techniques, and image classification techniques with ERDAS IMAGINE 8.5 and ArcGIS 9.2.

- Data sources

Classification of land cover in the study area was carried out using many sources of remotely sensed data. Sources of data using for this research are summarized in Table 3-2. Landsat 5-TM acquired on 20th and 29th December 2006 were selected as primary remotely sensed data used for classifying the vegetation in the study area in the following data processing steps.

- Data processing

After the Landsat imageries were prepared in the data possessing that were mention in the classification of vegetation. The land cover was classified using supervised classification method. The intention of land cover classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This categorized data set will then be used to produce thematic maps of land cover presented in an image. Thematic maps provide an easily interpretable summary with which the eventual end user can make the well- informed decisions.

In conventional classification of multi spectral data, the maximum likelihood classifier is considered to provide the best results since it takes into account the shape, size and orientation of a cluster. Based on the class mean and the variance-covariance matrix, an unknown pixel is assigned to the most likely class.

Maximum likelihood classification (MLC) technique was employed to perform the classification of an unknown pixel. This technique had been found to be the most accurate procedure in quantitatively evaluate both the variance and correlation of the category spectral reflectance patterns. The land cover/land use was classified into four categories, based on vegetation characteristics and field investigations.

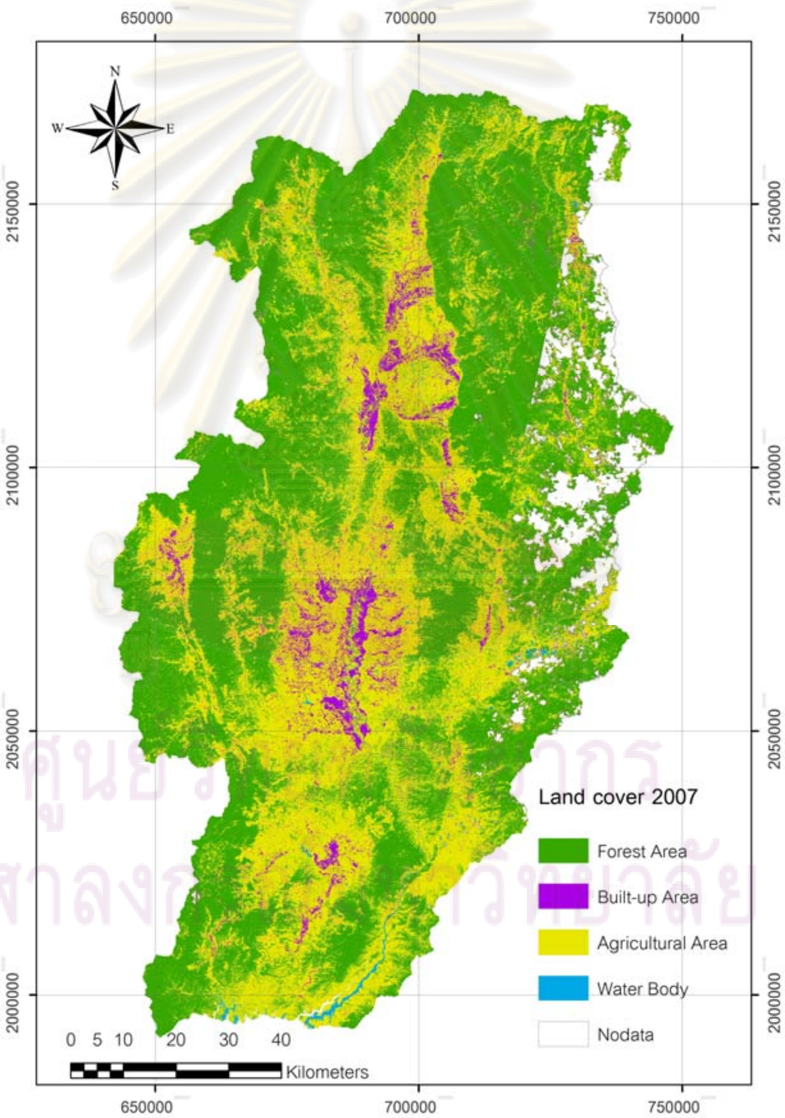

Figure 3-6 Land cover map of the study area in 2007.

3.2.7 Burned scar inventory

Numerous methods have been used to identify burned versus unburned pixels in a scene. In this research, several of the proposed methods were tested against one another to determine the most useful method for burned area extraction in the upper Nan watershed. Both single image and multi-date methods were used and compared. This semi-automated method was compared to a manually created burned scar map for verification. Although handmade fire scar outlines were created for this research, their construction is unrealistic for day to day management practices. The need for the development of a generalized burned scar extraction method is readily apparent when the difficult task of manually defining burned areas is undertaken.

- Data sources

Classification of vegetation in the study area was carried out using many sources of remotely sensed data. Sources of data using for this research are summarized in Table 3-1. Landsat 5-TM acquired on 23^{th} December 1998, 30^{th} December 1998, 21^{th} April 1999, 30^{th} April 1999, 28^{th} December 2000, 4^{th} January 2001, 19^{th} April 2001, 26^{th} April 2001, 12^{th} December 2003, 6^{th} January 2004, 18^{th} April 2004, 27^{th} April 2004, 20^{th} December 2006, 29^{th} December 2006, 20^{th} April 2007 and 27^{th} April 2007, respectively, were selected as primary remotely sensed data used for classifying the vegetation in the study area in the following data processing steps.

- Data processing

In the study of burned scar mapping in Spain, the researcher found it difficult to distinguish unburned areas from lightly burned area using Landsat TM imagery because of an increase in post-fire soil reflectance (Chuvieco and Congalton, 1988). They maintained that band ratio could be used to improve results. Numerous band combinations and transformations have been used in the field of forest fire study. The spectral reflectance characteristics of burned areas allow researchers to exploit the wavelength sensitivities of the sensor. The radiometric capabilities of Earth monitoring satellites can be capitalized on through the use of spectral indices. By utilizing a ratio or linear combination of spectral bands, a great deal of information can be gathered about the effects and extent of a fire. The process of band ratio of indices can also provide a semi-automated process which can speed the burned scar mapping process as well as reduce problems associated with interpreter subjectivity. Numerous methods use these theories in the study of forest fires, but significant differences between methodologies have been reported (Coppin and Bauer, 1996).

Differenced Normalized Burn Ratio (dNBR) is the index that was used to map and monitor the forest fire affected areas. The Normalized Burn Ratio (NBR) was presented by Key and Benson (2004) to achieve a greater accuracy than the Normalized Difference Vegetation Index (NDVI) in their study. Under the joint NPS-USGS National Burn Severity Mapping Project, Key and Benson put a method that capitalizes on the post-fire reaction of vegetation in the near and mid infrared wavelengths.

The NBR index is based on the idea that in forested areas, the post-fire reflectance is decreased in the near-infrared (NIR) owing to the removal of green vegetation. The middle-infrared (MIR) simultaneously increases because the burned area is dry. The NBR includes Band 4 reflectance (TM4), which naturally responds positively to leaf area and plant productivity, and Band 7 reflectance (TM7), which positively reacts to drying and some non-vegetated surface. The NBR has a theoretical range from -1.0 to +1.0. It is positive when TM4 is greater than TM7. This occurs over most vegetated areas that are productive. The NBR is negative when TM7 is greater than TM4.This show severe water stress in plants and the non-vegetated characteristic within burned areas. The NBR index can be written as:

$$NBR = (TM4 - TM\ 7) / (TM4 + TM\ 7) \ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 3-3)}$$

NBR = Normalized Burn Ratio

TM4 = Reflectance of band 4 satellite image data

TM7 = Reflectance of band 7 satellite image data

To generate dNBR values for each pixel, the NBR image for each post-fire acquired date was deducted from the NBR of the image acquired most recently before the fire. The dNBR provides the theoretical range from -2.0 to +2.0.The calculation of dNBR is:

$$dNBR = (\text{Pre-FireNBR}) - (\text{Post-FireNBR}) \ldots\ldots\ldots\ldots \text{(Equation 3-4)}$$

The differenced Normalized Burn Ratio (dNBR) provides the analyst a floating point image with theoretical values ranging from -2 to 2. These values are hypothesized to give a rating of burn severity on the burned area's response to the fire. In forested areas, a strong positive value in the NBR is expected with the removal of vegetation, but a negative reaction may be possible in a grassy community due to the quick response of actively repopulating grasses.

A high value in the dNBR image is indicative of a fire affected area, while stable areas fall out at a value near zero. Pixel values with a strong negative value theoretically represent an area of renewed energy due to the positive effects of fire (Key and Benson, 2004). The NBR and dNBR have been successful in several burned scar mapping studies. They have been implemented as reliable measures of fire extent and severity, and are now the primary method utilized when mapping large remote fires which occur on public lands (Cocke et al., 2005).

The explanations of “burned area” are the important subject of the research in remote sensing. Several studies that related to "burned area mapping" have analyzed the spectral properties of burned areas and compared them to the spectral properties of other land-cover types. In summary, burned areas are characterized by an increase in the visible and middle-infrared and a decrease in the near-infrared part of the spectrum when compared with healthy vegetation. However, it has been shown that burned area are characterized by specific spectral properties that vary depend on the type of ecosystem, the length of time between fire occurrence, spectral data acquisition and the severity of fires. Consequently, this enables us to distinguish them from other land features (Chuvieco, 1999 cited in Palandjian et al., 2008).

Therefore, if the burned area perimeter mapping is the goal, images should be acquired within one growing season after fire. The dNBR also shows problems when dealing with drought situations. Key and Benson (2004) remarked that because the index uses two bands that are sensitive to vegetation and soil moisture, burned areas of low severity can be difficult to distinguish from unburned areas during an extremely dry period.

In this research, Landsat-5 TM imageries acquired during 1999-2006 (Table 3-2) were used to get the burned scar maps. The imageries were first resampled to achieve 25 m pixel size. The Landsat imagery consists of seven spectral bands, Band 1, 0.45-0.52μm (blue), Band 2, 0.52-0.60μm (green), Band 3, 0.63-0.69μm (red), Band 4, 0.77-0.90μm (Near Infrared), Band 5, 1.55-1.75μm (Short-wave Infrared), Band 6, 10.40-12.50μm (Thermal Infrared), and Band 7, 2.09-2.35μm (Short-wave Infrared).

The difference Normalized Burn Ratio (dNBR) was applied to the Landsat imagery in order to utilize pixels that showed a low return in band four and a relatively high return in band seven. The dNBR model was run using the image subset and dNBR values generated for each pixel. In a grey scale display of the image, the level slice function was used to operate the image while comparing the identified pixels to the 7, 4, 2 band combination to identify burned areas. A minimum was established such that pixels with a value of zero or less were identified as burned. This range of values did not account for all pixels within the plainly visible burned scars, but including pixels with a value of greater than zero led to an abundance of pixels outside the burned scars being identified as burned. The image was recoded to a thematic representation reflecting the identification as burned or unburned. The resulting image was then run through an overlay function to combine the burned area class with the image (Howard et al., 2002).

In order to classify burned areas from a single Landsat image (without a pre-fire reference point), the visual interpretation and the difference Normalized Burn Ratio (dNBR) were used together. A combination of LANDSAT-5 TM Bands 7-4-2 (Figure 3-7) was used in the visual interpretation where some characteristics such as shape, pattern, color, site, and activity in a burned region are also used. Forest areas appear in pale green and light green color while file scar is shown as dark brown color. Then the polygon of burned scars was manually digitized (Figure 3-8, 3-9, 3-10, 3-11and 3-12).

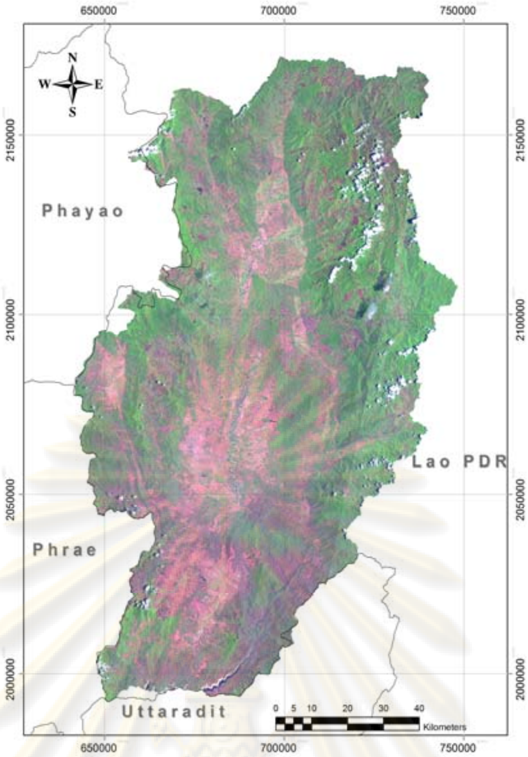

Figure 3-7 False color composite of Landsat 5-TM (R=7, G=4, B=2) acquired on 28th December 2000 and 4th January 2001 in the study area.

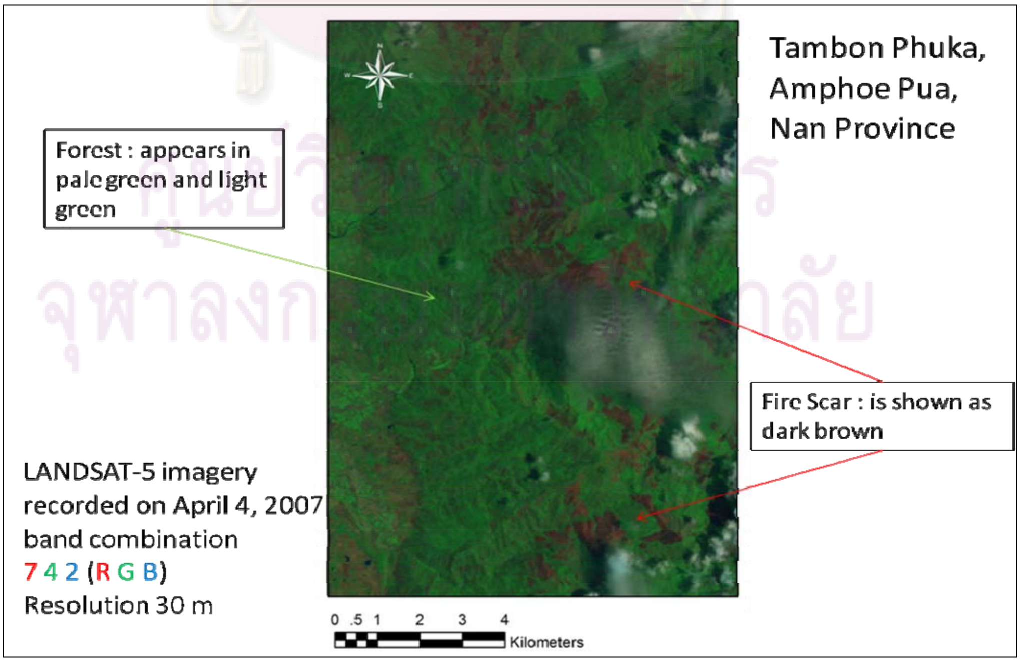

Figure 3-8 Burned scars mapping.

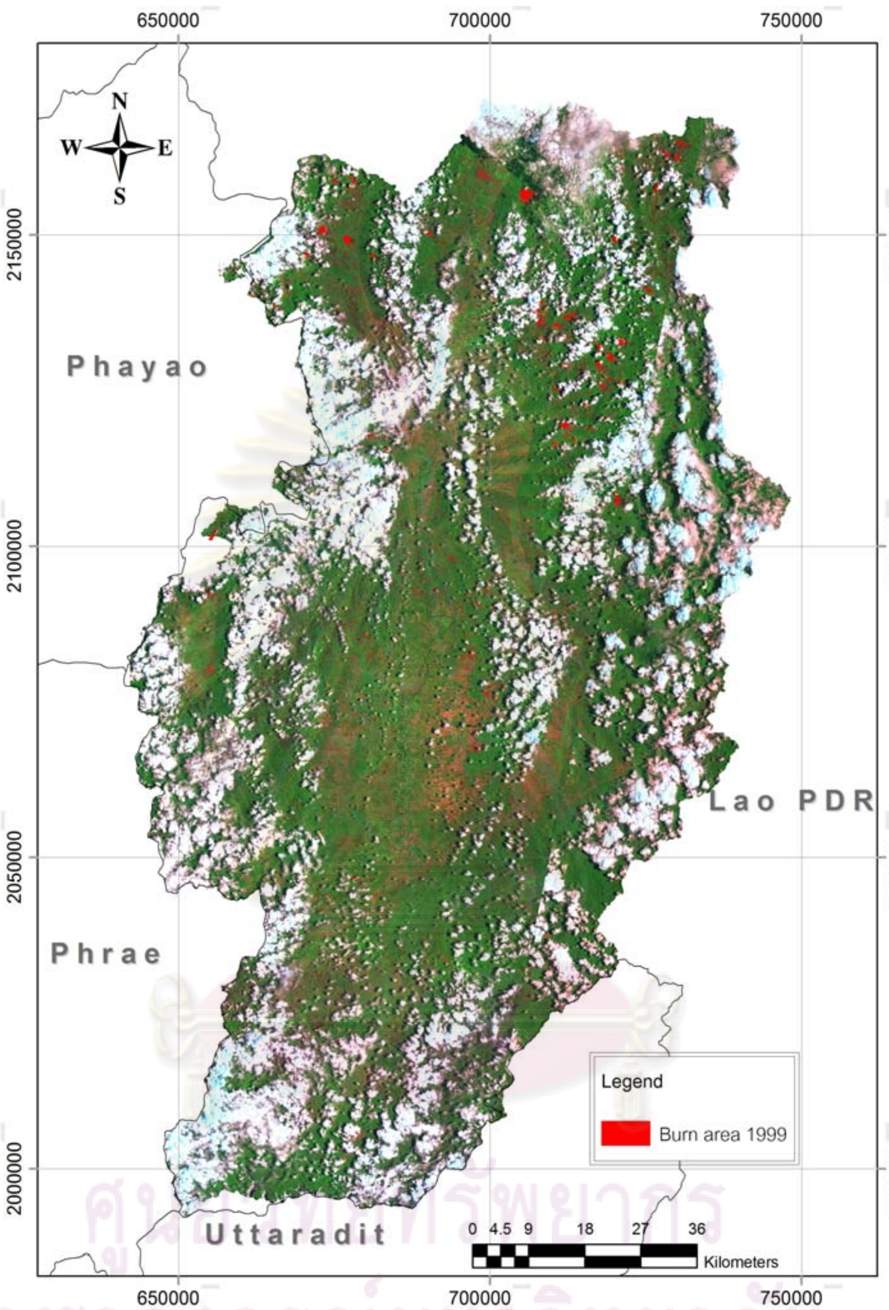

Figure 3-9 Burned scars overlain on the false color composite of Landsat 5-TM (R=7, G=4, B=2) acquired on 21th and 30th April 1999 in the study area.

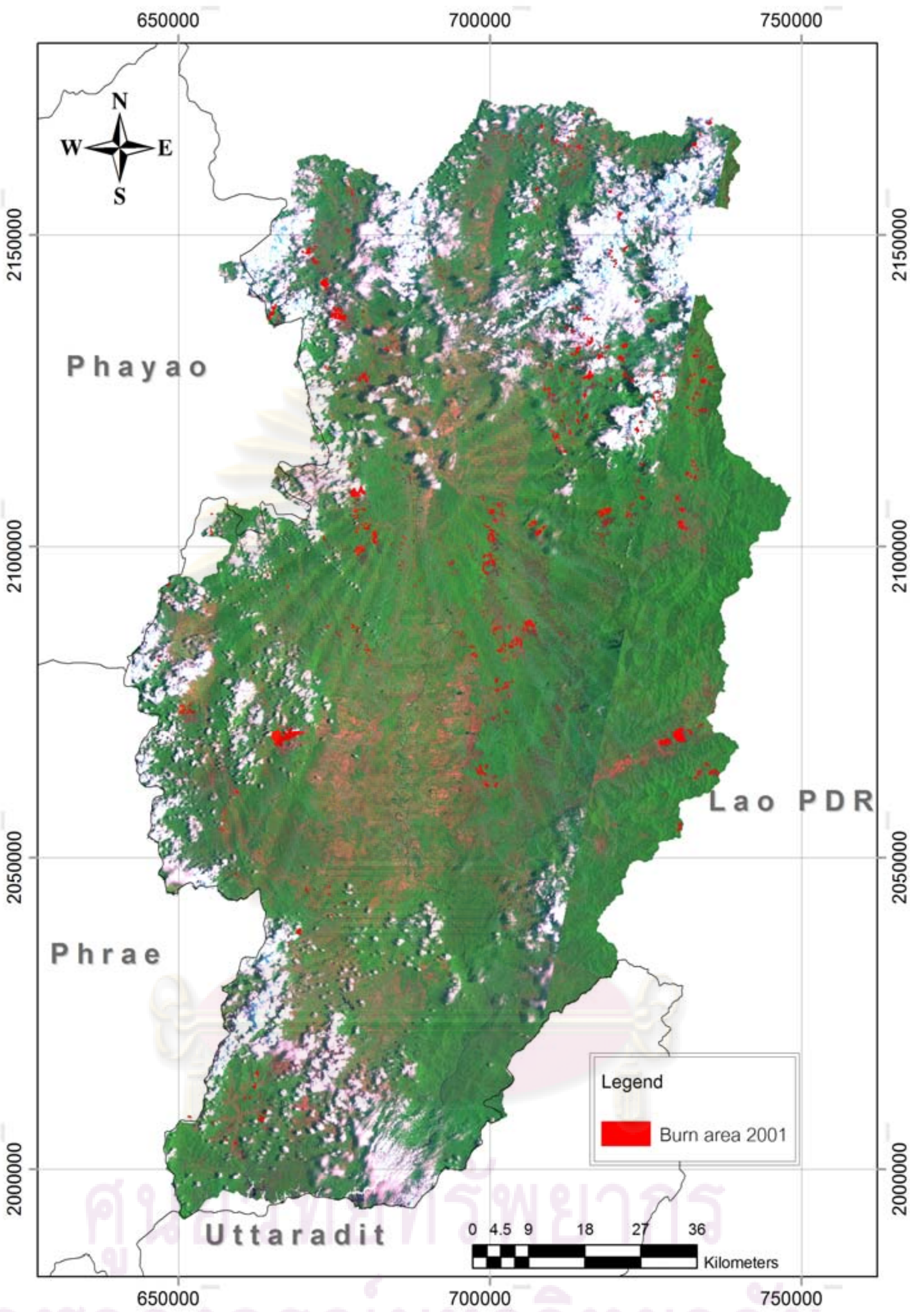

Figure 3-10 Burned scars overlain on the false color composite of Landsat 5-TM (R=7, G=4, B=2) acquired on 19th and 26th April 2001 in the study area.

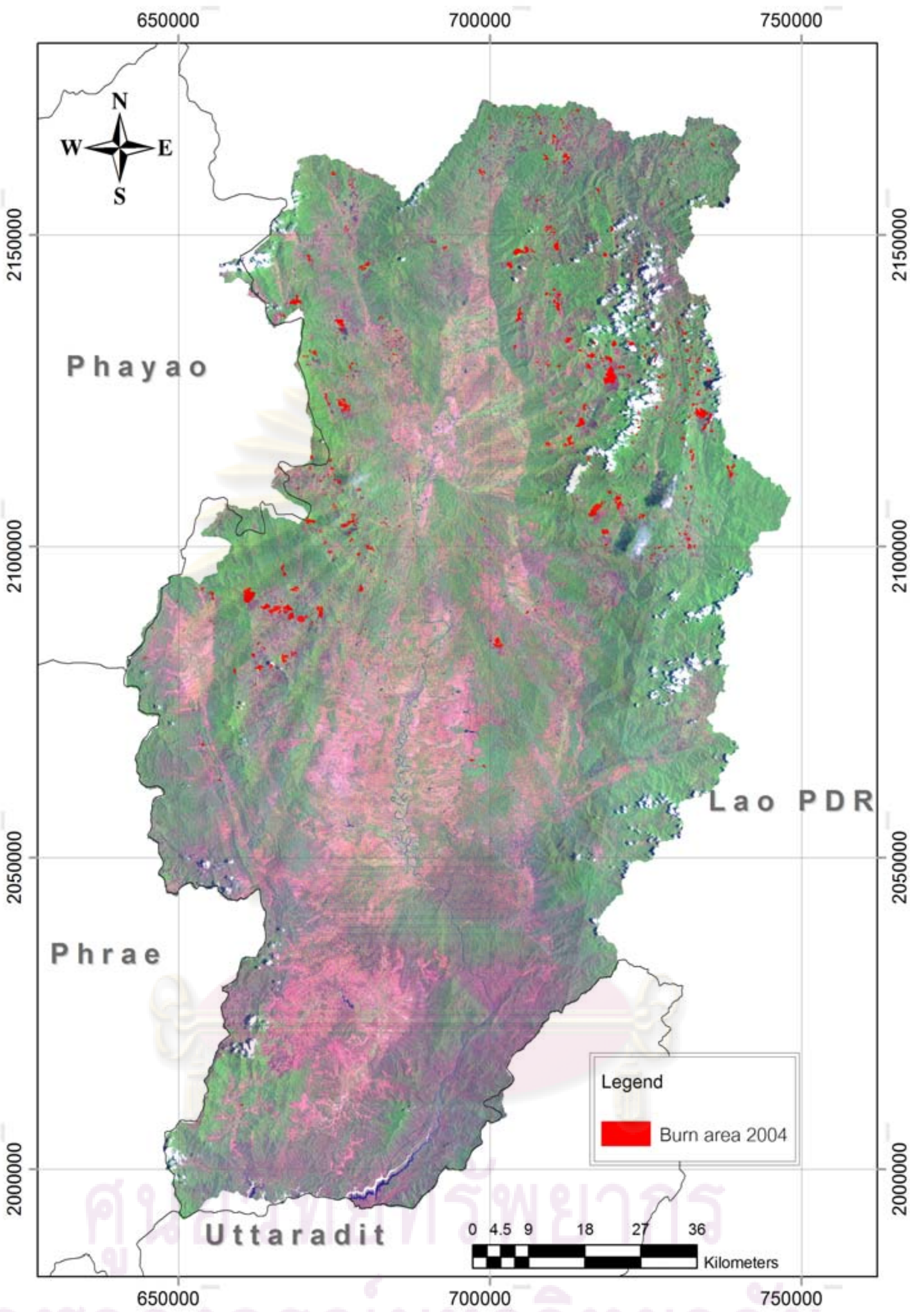

Figure 3-11 Burned scars overlain on the false color composite of Landsat 5-TM (R=7, G=4, B=2) acquired on 18th and 27th April 2004 in the study area.

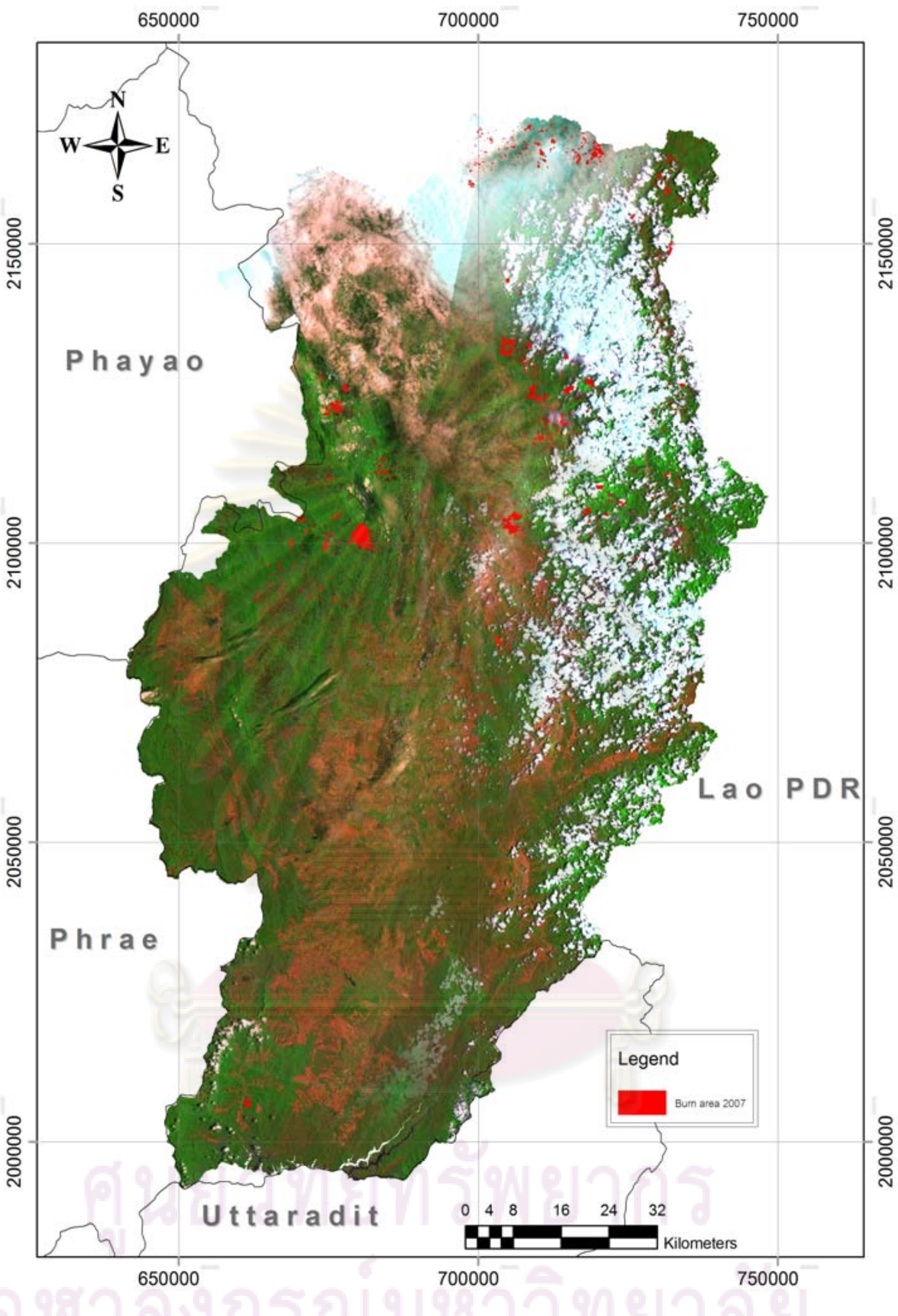

Figure 3-12 Burned scars overlain on the false color composite of Landsat 5-TM (R=7, G=4, B=2) acquired on 20th and 27th April 2007 in the study area.

- Accuracy assessment of burned scar mapping

A complete accuracy test of a burned scar map would be a verification of every pixel. Obviously this is impossible and indeed defeats the purpose of the image classification. Therefore, representative test areas must be used instead to estimate the map accuracy with as little error as possible. Then user's accuracy (or map accuracy) which a map user is interested in the reliability of the map in how well the map represents what be really on the ground. Figure 3-13 illustrated the survey tracks for field data investigation. The location photographs were illustrated in Appendix.

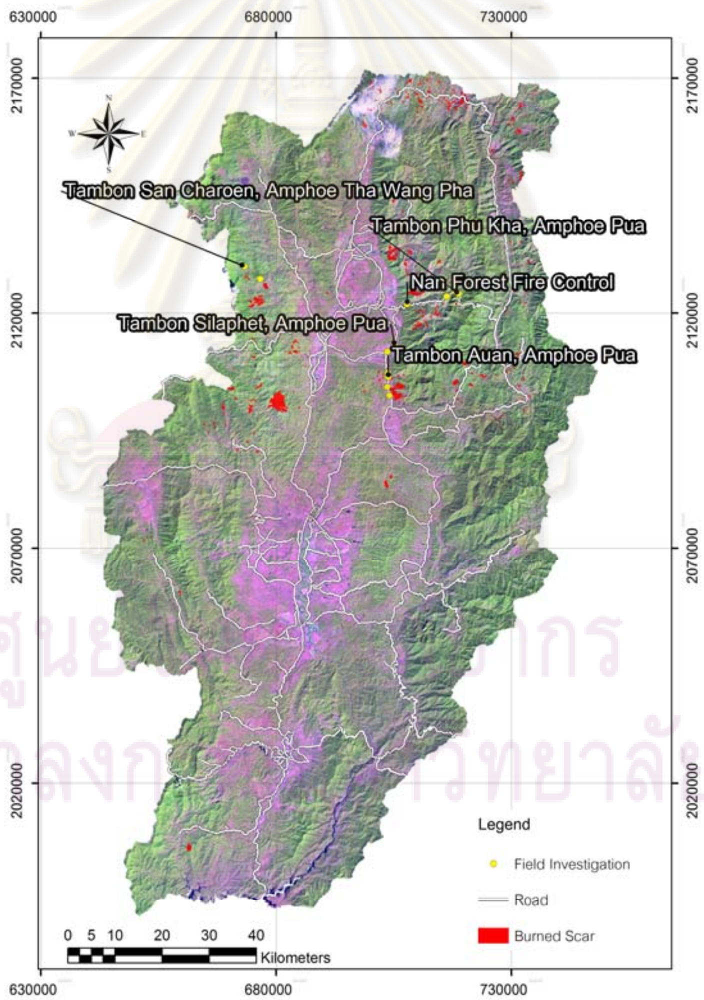

Figure 3-13 Field investigation located in Landsat 5-TM(R=5, G=4, B=3) acquired on 28th December 2000 and 4th January 2001.

The field investigation was mainly done in Ban San Charoen, Tambon Pha Thong, Amphoe Tha Wang Pha; Tambon Phu Kha, Amphoe Pua; Tambon Silaphet, Amphoe Pua; and Tambon Auan , Amphoe Pua, Changwat Nan. Moreover, there were an information interviews at Ban San Charoen, Tambon Pha Thong, Amphoe Tha Wang Pha, and Nan Forest Fire Control Station, Tambon Wora Nakorn, Amphoe Pua, Changwat Nan. (Figure 3-14, 3-15, 3-16)

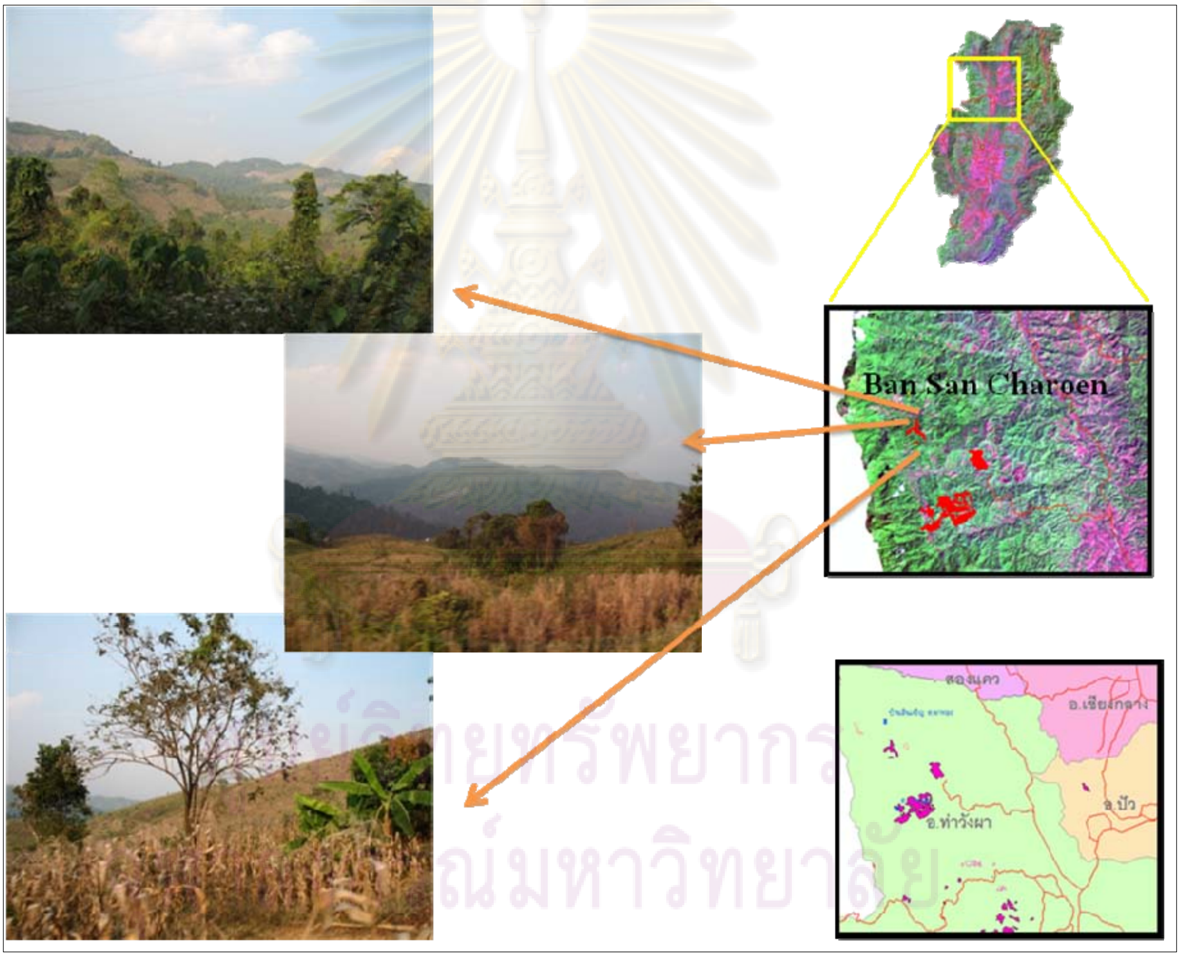

Figure 3-14 Field investigation located in Ban San Charoen, Tambon Pha Thong, Amphoe Tha Wang Pha, Changwat Nan.

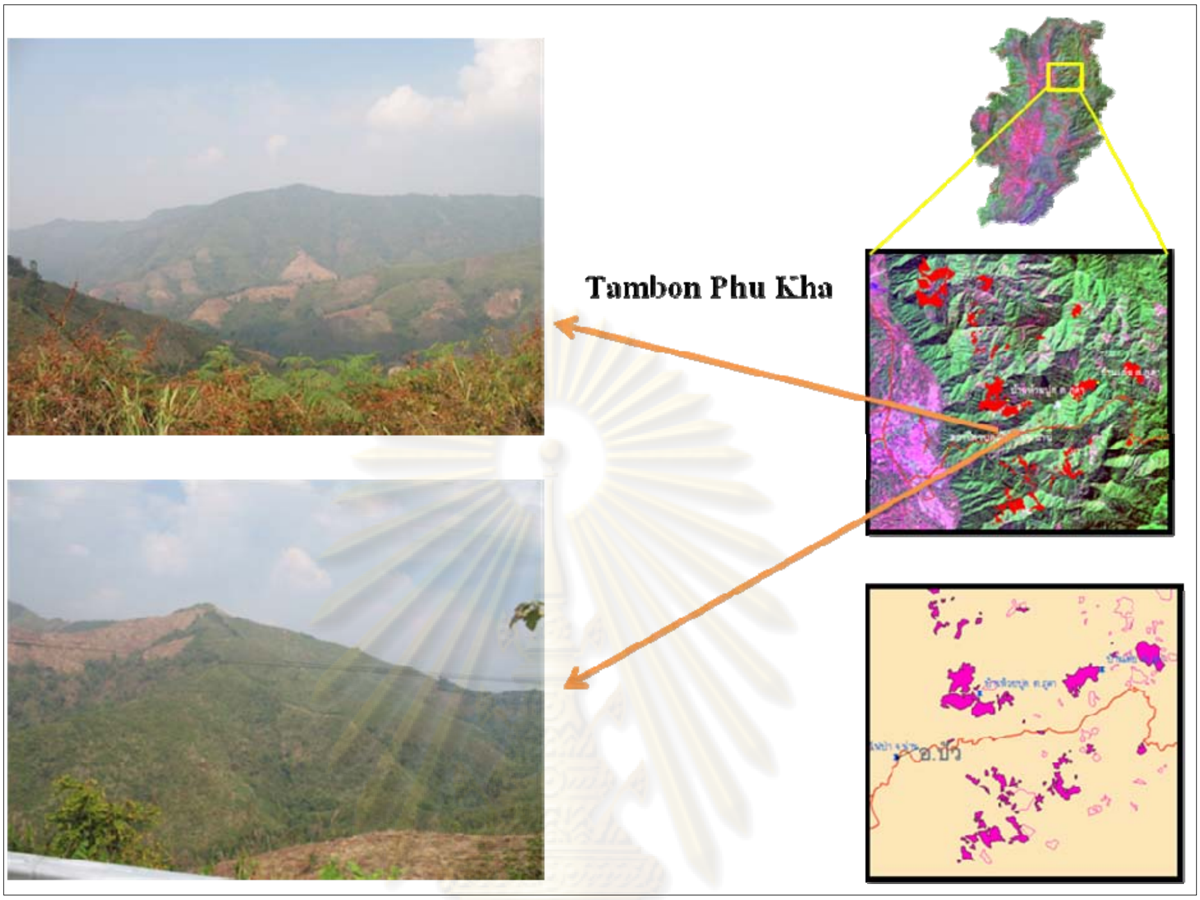

Figure 3-15 Field investigation located in Tambon Phu Kha, Amphoe Pua, Changwat Nan.

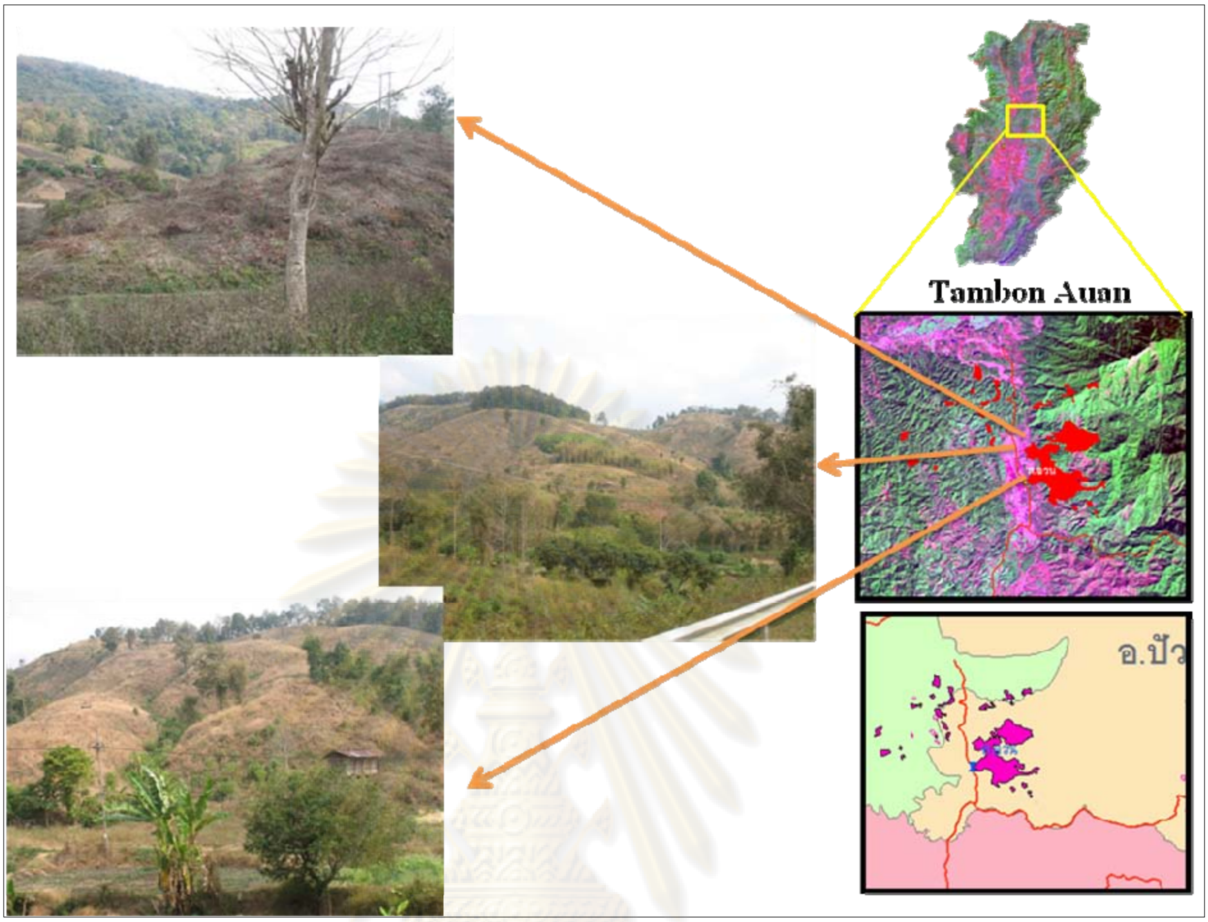

Figure 3-16 Field investigation located in Tambon Auan, Amphoe Pua, Changwat Nan.

CHAPTER IV

ANALYSIS AND RESULTS

The satellite images and dNBR index were used in this research to detect the occurrence of forest fire during 1999 – 2007. The final result shows changing in spatial patterns and dynamic behaviors of forest fire in upper Nan watershed, as well as the forest fire risk areas in upper Nan watershed.

4.1 The occurrences of forest fire in the study area

From the results of burned scar assessment using 16 scenes of Landsat 5-TM imageries (Figure 4-1, 4-2, 4-3, 4-4 and 4-5 and Table 4-1) the largest forest fire area shows in 2001(106.9 Km^2) whereas the smallest area shows in 1999 (37 Km^2).

As was mention in the literature review, fires cause mosaic patterns by burning at different intensities in different places and by burning different areas in different years (Fuller, 1991). The burned scars maps in the upper Nan watershed during 1999-2007 (Figure 4-5) also show the trends of forest fire in the study area. There was a significant increase in the burned area in 2001. However, the burned areas were slightly decreased in 2004 and 2007, respectively. Moreover, the sizes of forest fire polygons in 1999 are small but they became larger in 2001, 2004 and 2007. Finally, it could be noticed that most forest fire patched are distributed on high mountainous and steep slope that are mainly in the northern part of the study area.

Figure 4-1 Burned scars map in the upper Nan watershed in 1999

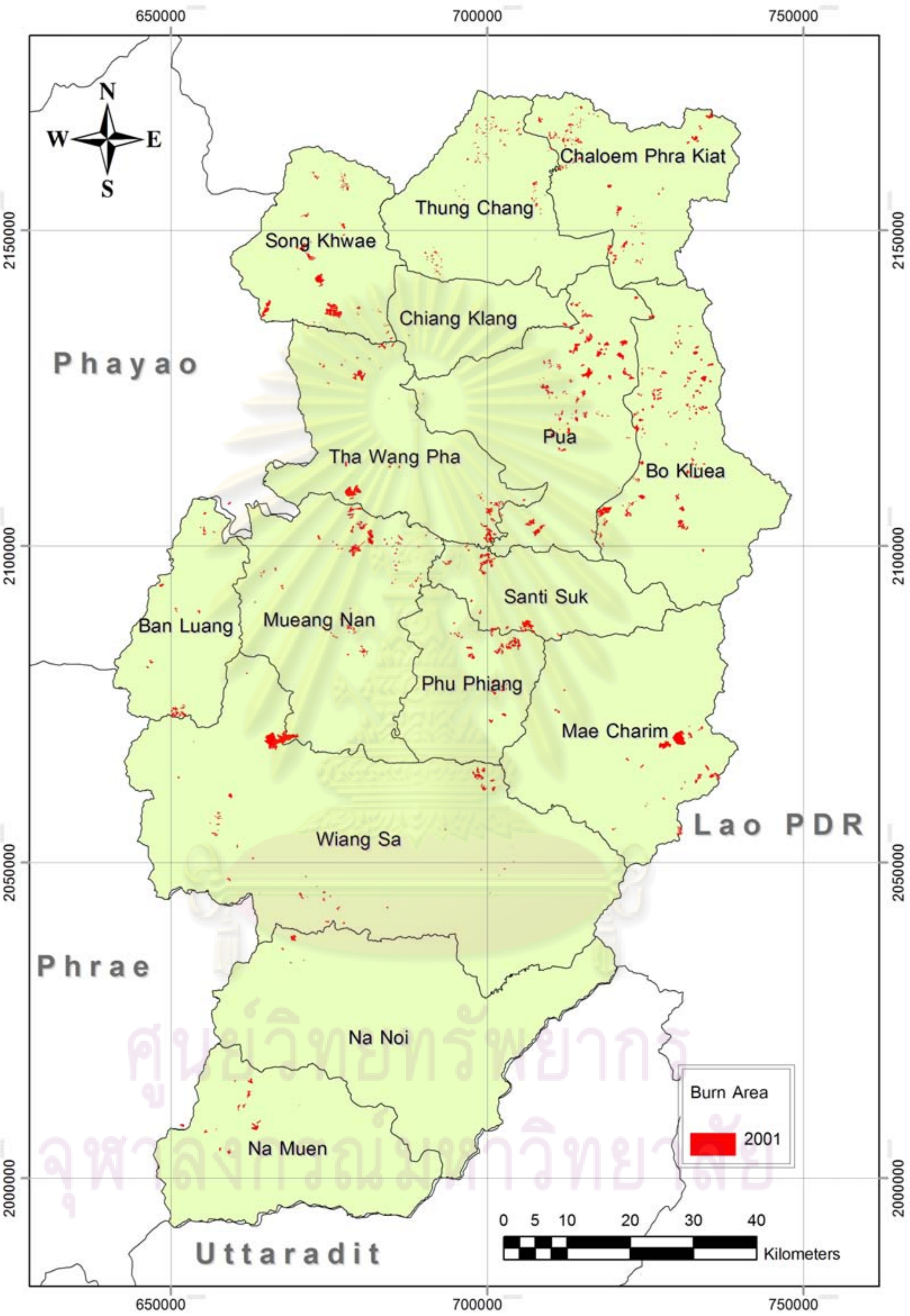

Figure 4-2 Burned scars map in the upper Nan watershed in 2001

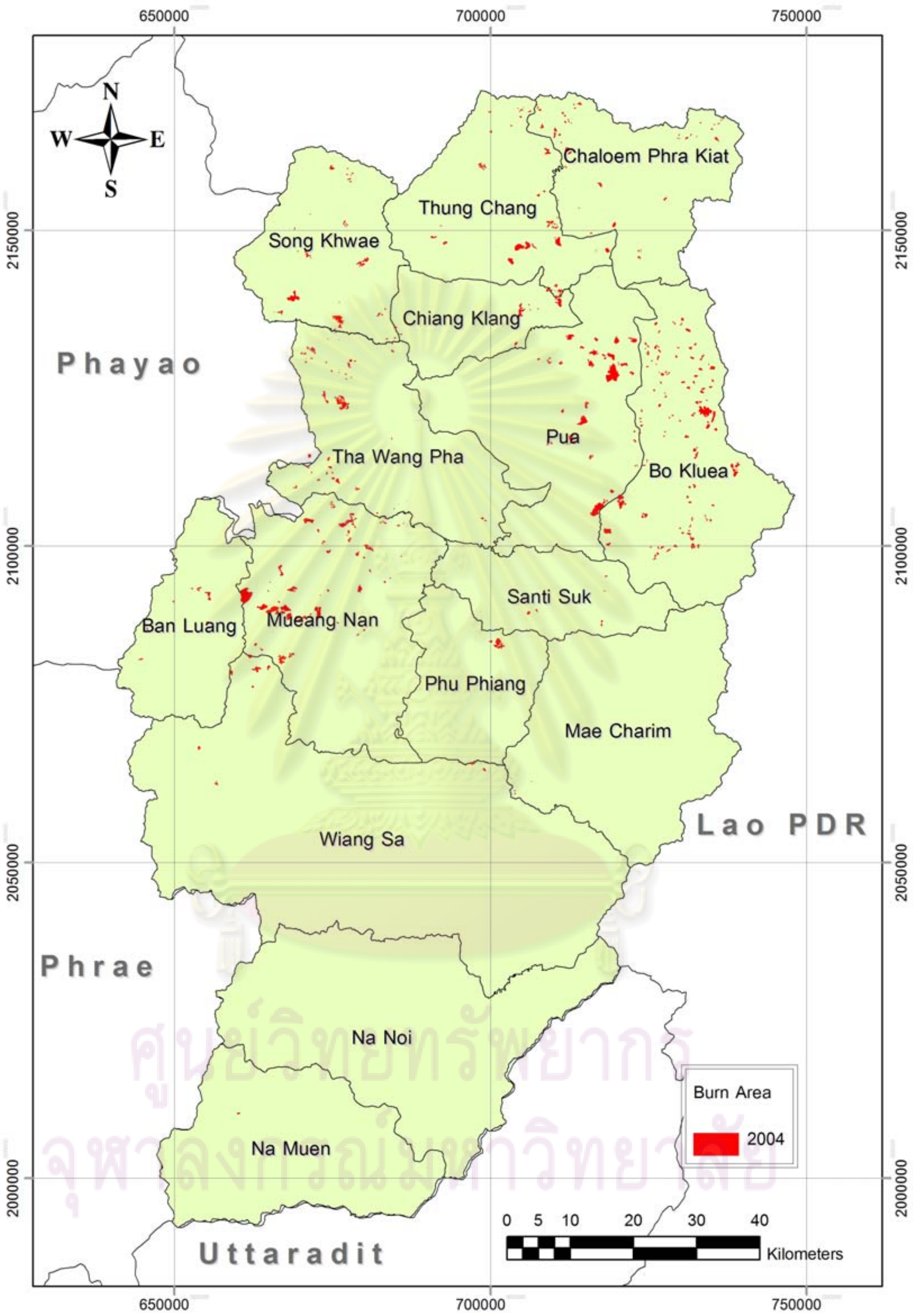

Figure 4-3 Burned scars map in the upper Nan watershed in 2004

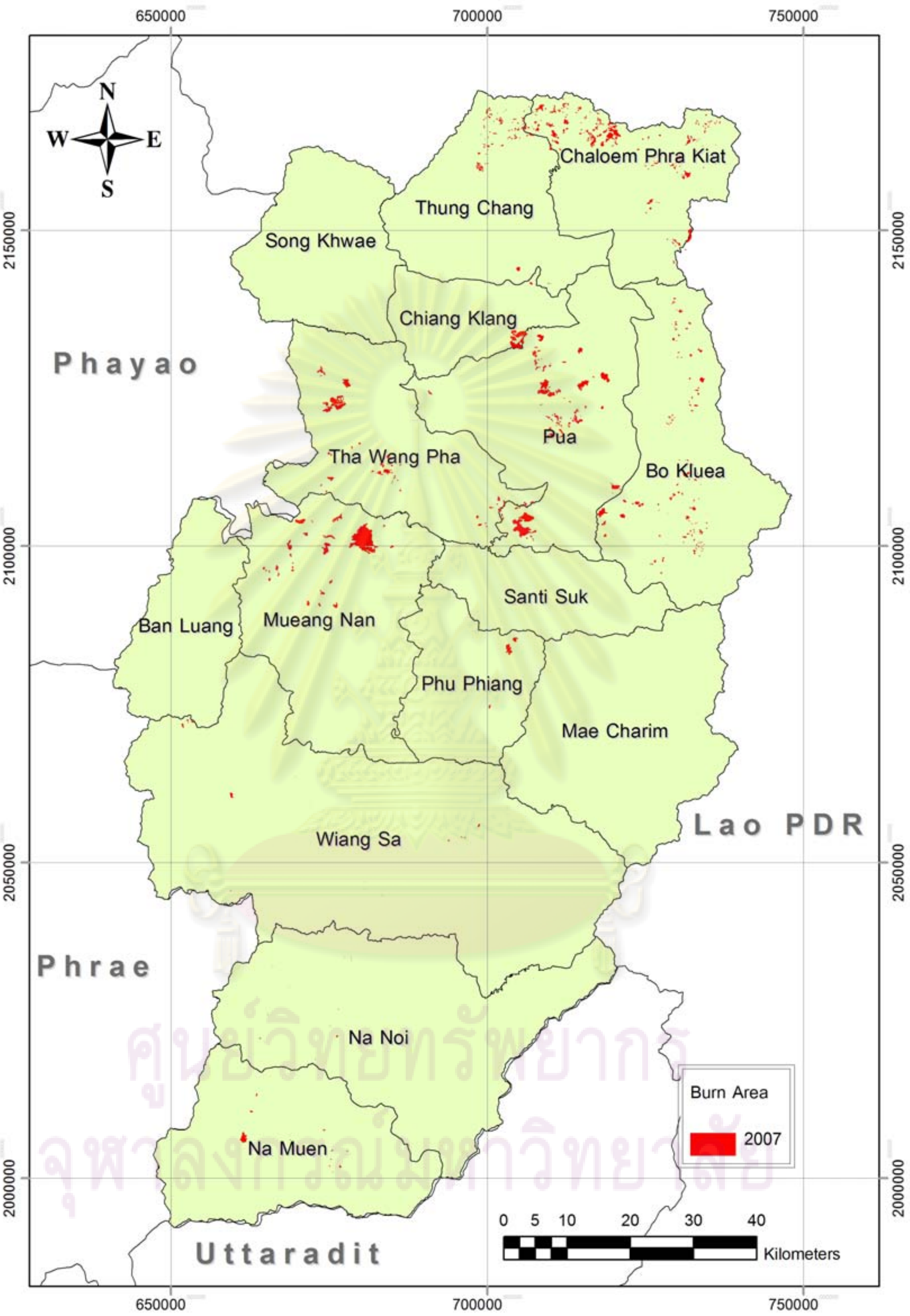

Figure 4-4 Burned scars map in the upper Nan watershed in 2007

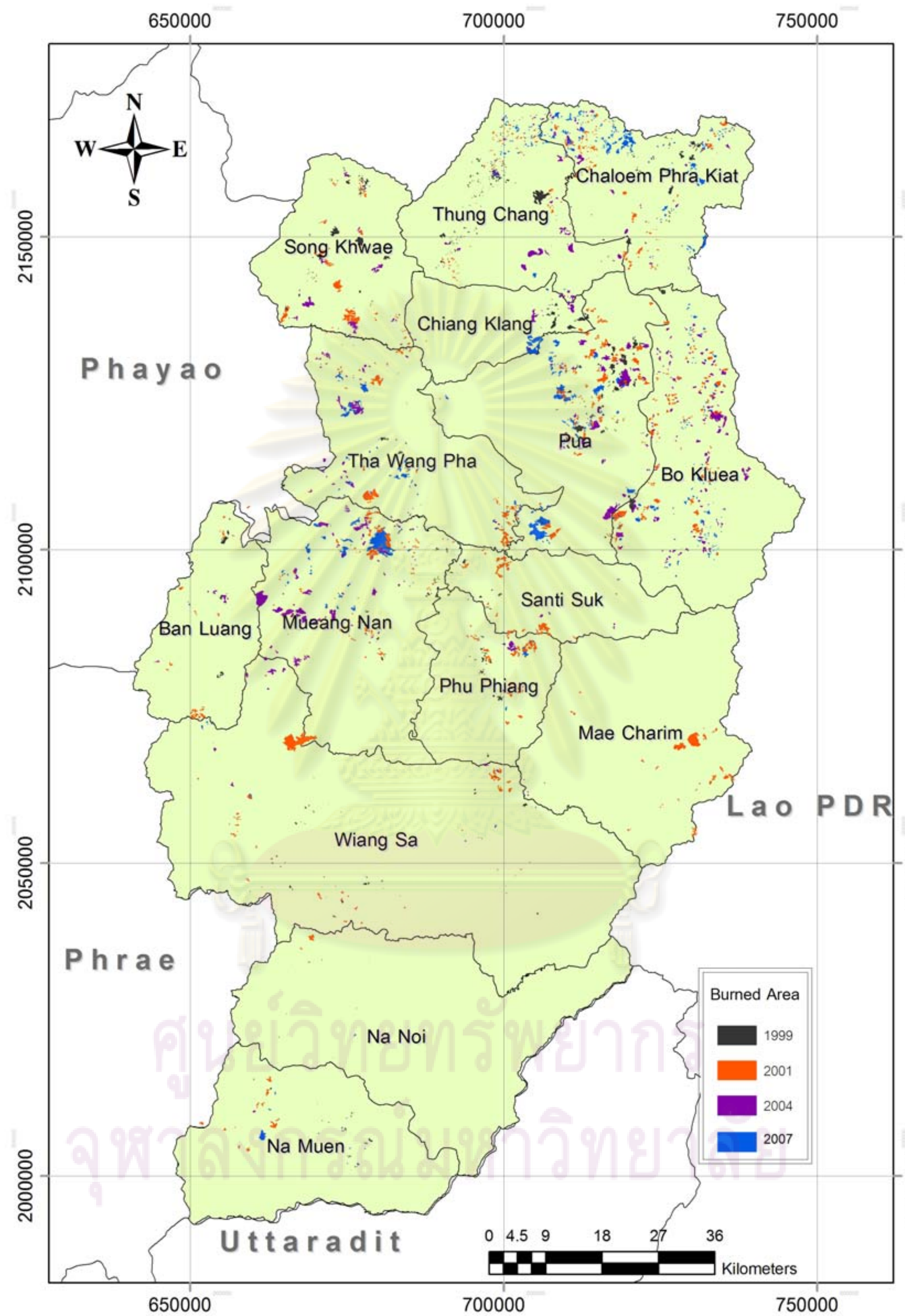

Figure 4-5 Burned scars map in the upper Nan watershed during 1999-2007

Table 4-1 Burned scar areas in upper Nan watershed during 1999-2007

Amphoe	Area (Km^2)	Burned area									
		1999		2001		2004		2007		Total	
		(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%	(Km^2)	%
Mueang Nan	956.67	1.3	0.13	8.9	0.93	18.6	1.95	16.3	1.70	45.1	4.71
Chiang Klang	319.41	2.0	0.64	0.3	0.08	2.1	0.67	4.1	1.29	8.6	2.69
Tha Wang Pha	689.05	1.0	0.14	9.3	1.35	6.1	0.88	9.5	1.38	25.8	3.74
Thung Chang	647.28	6.3	0.98	3.7	0.56	7.6	1.18	3.9	0.60	21.5	3.32
Na Noi	1257.74	0.0	0.00	0.7	0.06	0.0	0.00	0.2	0.01	0.9	0.07
Pua	916.46	9.3	1.01	16.5	1.80	13.2	1.44	20.0	2.18	58.9	6.43
Wiang Sa	2147.27	1.5	0.07	11.3	0.52	1.6	0.07	0.8	0.04	15.1	0.70
Mae Charim	984.40	0.0	0.00	7.8	0.80	0.1	0.01	0.0	0.00	8.0	0.81
Ban Luang	41.34	1.5	3.72	2.8	6.73	1.0	2.52	0.0	0.00	5.4	12.97
Na Muen	816.84	0.7	0.09	2.2	0.27	0.1	0.01	1.5	0.18	4.5	0.55
Santisuk	401.25	0.7	0.18	6.1	1.53	0.6	0.15	0.0	0.00	7.5	1.86
Bo Kluea	854.35	1.1	0.12	13.9	1.63	18.6	2.18	8.2	0.96	41.7	4.88
Song Khwae	521.00	5.0	0.95	10.3	1.98	5.7	1.09	0.0	0.00	21.0	4.02
Chaloem Phra Kiat	609.01	4.4	0.73	7.3	1.20	4.1	0.68	14.6	2.39	30.5	5.00
Phu Phiang	455.04	2.2	0.48	5.9	1.30	1.6	0.35	1.4	0.31	11.1	2.44
Total	11617.11	37.0	0.32	106.9	0.92	81.1	0.70	80.4	0.69	305.4	2.63

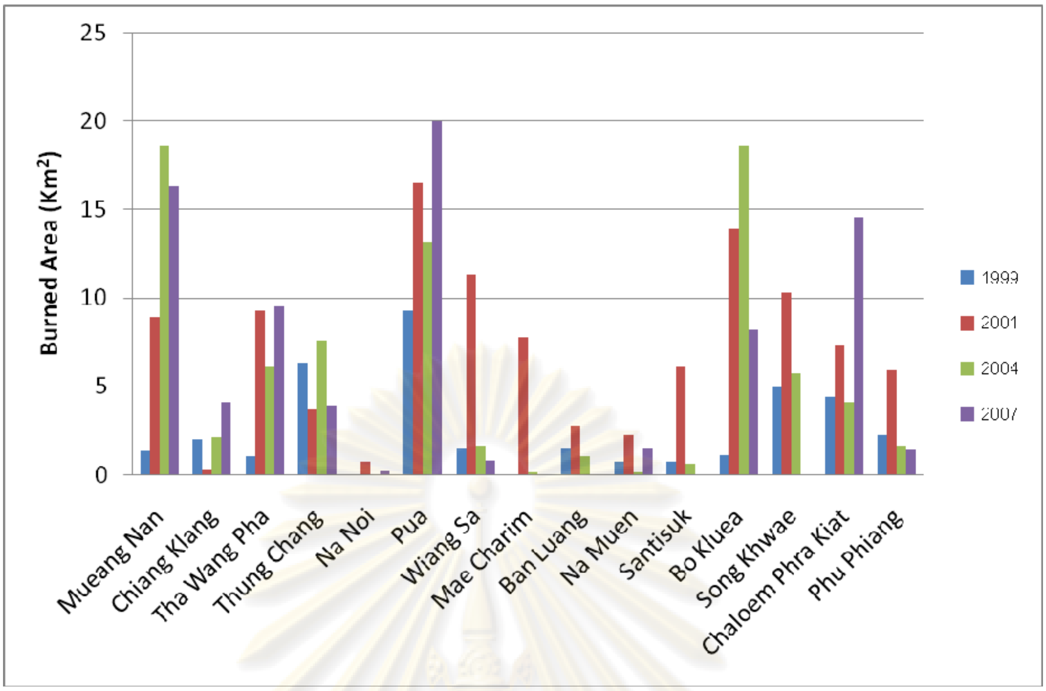

Figure 4-6 Graph shows burned area in the upper Nan watershed during 1999-2007 (Km^2).

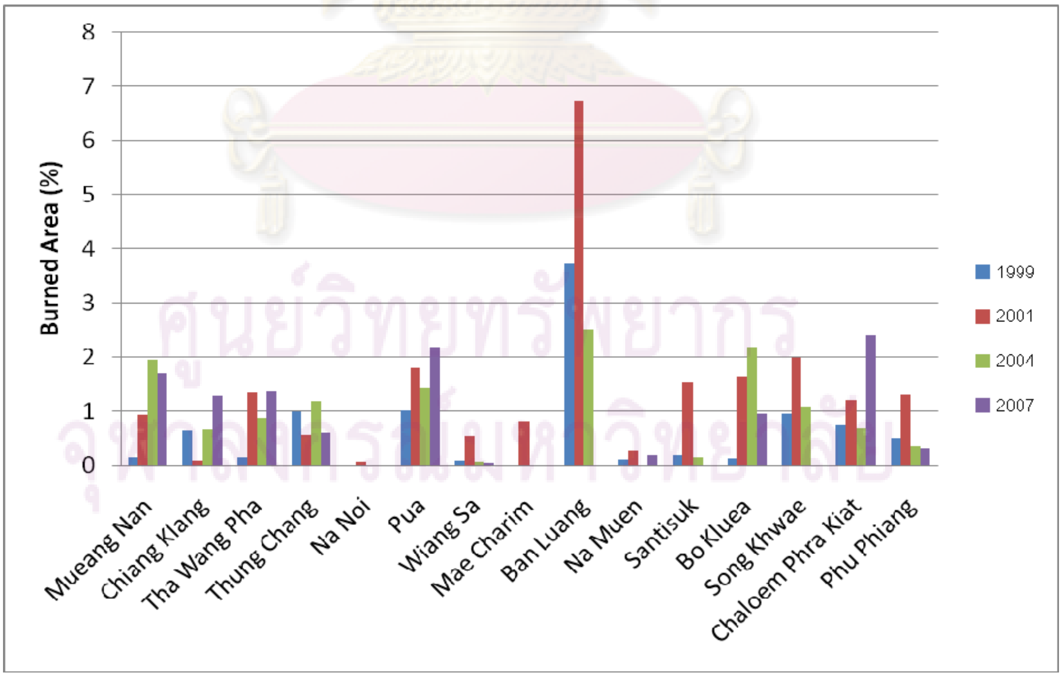

Figure 4-7 Graph shows percentage of burned area in the upper Nan watershed during 1999-2007.

The forest fire area when plotted in a time sequence from 1999 to 2007 shows trends of forest fire. These trends can be used to predict the forest fire area in the near future. According to the administrative area, the trend of forest fire occurrence is increasing in Amphoe Pua, Amphoe Mueang Nan, Amphoe Chiang Klang, Amphoe Bo Kluea, Amphoe Song Khwae and Amphoe Charoem Phra Kiat (Figure 4-6). However, longer time period should have been studied in order to confirm the trends of forest fire in this research.

In conclusion, the results of this research reveal that most of the forest fires were occurred in Amphoe Pua (58.9 Km^2), Amphoe Mueang Nan (45.1 Km^2), Amphoe Bo Kluea (41.7 Km^2), Amphoe Charoem Phra Kiat (30.5 Km^2) and Amphoe Tha Wang Pha (25.8 Km^2) (Figure 4-6). Furthermore, when focus on the burned areas that are expressed as a percentage of the total area, the high percentage were occurred in Amphoe Ban Luang (12.97%), Amphoe Pua (6.43%), Amphoe Bo Kluea (4.88%), Amphoe Mueang Nan (4.71%) and Amphoe Song Khwae (4.02%) (Figure 4-7).

4.2 Relationship between burned areas and slope

The correlation ratios were performed on the relationship between the detected burned areas and each parameter's range. The ratio between the area of the detected burned scar (hereafter to be called b, for convenience) and the area of the non-detected burned scar (hereafter to be called a, for convenience) was calculated as probability of forest fire susceptibility in each parameter's range. The b/a ratio equal 1 defines an average value, greater than 1 means a high correlation, and less than 1 means a low correlation. A high correlation indicates a high probability of the forest fire susceptibility in each forest fire influencing parameter. Such relationships in the upper Nan watershed were briefly concluded below.

As mentioned in the previous chapter, fire travels most rapidly up slopes and less down slopes. Gentler slope is expected to have low areas of burned scars because of generally lower effect associated with topography.

Forest fire susceptibility in this thesis was preliminary analyzed by univariant probability method to present the spatial relationship between the burned scar locations and each of available forest fire influencing parameters (Pradhan and Awang, 2006). For slope as a parameter, the areas of burned scar for a given interval of slope angle were noted as shown in Figures 4-8, 4-9 and 4-10 and Table 4-2 and 4-3. The ratio were determined by calculating the burned scar areas for each 5 degree interval of slope angle, then ratios of areas which burned scars were detected and areas which burned scars are not detected (hereafter to be called b/a ratio, for convenience) were calculated. The b/a ratio indicated the susceptibility or probability of each interval of slope angle to forest fire.

For area in slope below 5%, the b/a ratio was 0.38, indicating a very low probability. From 5 to 10%, the b/a ratio was 1.17, indicating a high probability. From 10 to 15%, the b/a ratio was 0.89, indicating a moderate probability. From 15 to 20%, the b/a ratio was 1.38, indicating a high probability. From 20 to 25%, the b/a ratio was 1.23, indicating a high probability. From 25 to 30%, the b/a ratio was 0.76, indicating a moderate probability. From 30 to 35%, the b/a ratio was 0.45, indicating a low probability. For the slope that greater than 35% the b/a ratio was 1.53, indicating a very high probability.

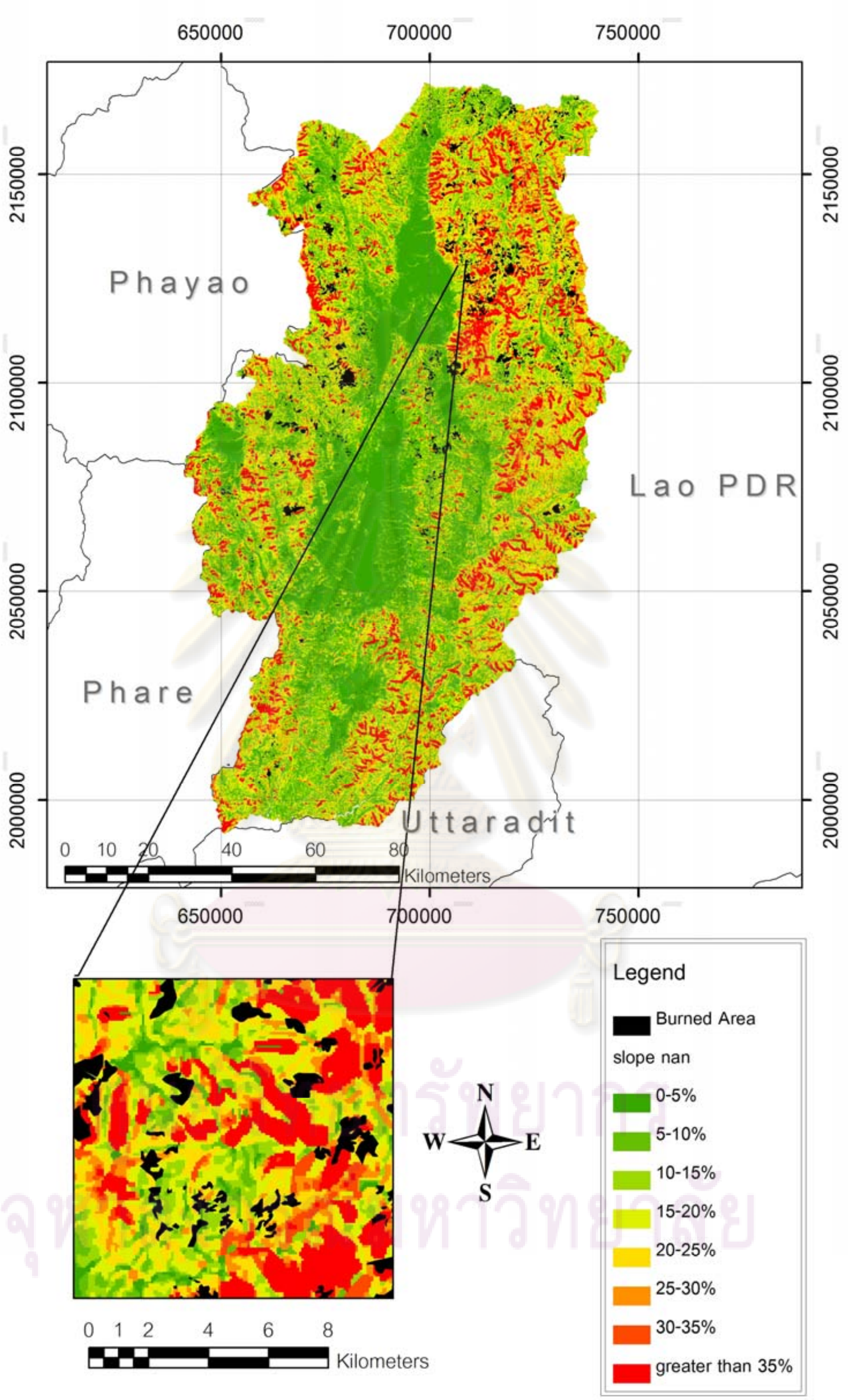

Figure 4-8 Slope map overlain with burned scars (grouped in black color) in upper Nan watershed.

Table 4-2 Burned scar occurred in each slope class in upper Nan watershed

Slope	Area (Km^2)				
	1999	2001	2004	2007	Total
0-5%	3.60	6.44	2.89	8.94	21.87
5-10%	10.05	27.60	17.27	15.37	70.29
10-15%	5.66	18.34	14.57	12.69	51.26
15-20%	7.10	16.52	21.88	20.24	65.73
20-25%	1.08	15.27	10.99	11.52	38.86
25-30%	0.71	4.10	4.42	3.25	12.48
30-35%	0.61	0.26	1.06	1.46	3.40
>35%	8.20	18.43	8.16	6.97	41.75
Total	37	106.95	81.24	80.45	305.64

Table 4-3 Relation of burned scars and slope in upper Nan watershed

Slope %	Burned scar did not occur		Burned scar occur		b/a
	Area (km^2)	Ratio (%), a	Area (km^2)	Ratio (%), b	
0-5%	2222.65	18.69	21.87	7.16	0.38
5-10%	2346.26	19.73	70.29	23.00	1.17
10-15%	2248.48	18.90	51.26	16.77	0.89
15-20%	1851.80	15.57	65.73	21.51	1.38
20-25%	1231.07	10.35	38.86	12.71	1.23
25-30%	640.03	5.38	12.48	4.08	0.76
30-35%	294.13	2.47	3.40	1.11	0.45
greater than 35%	1060.27	8.91	41.75	13.66	1.53
Total	11894.69	100.00	305.64	100.00	

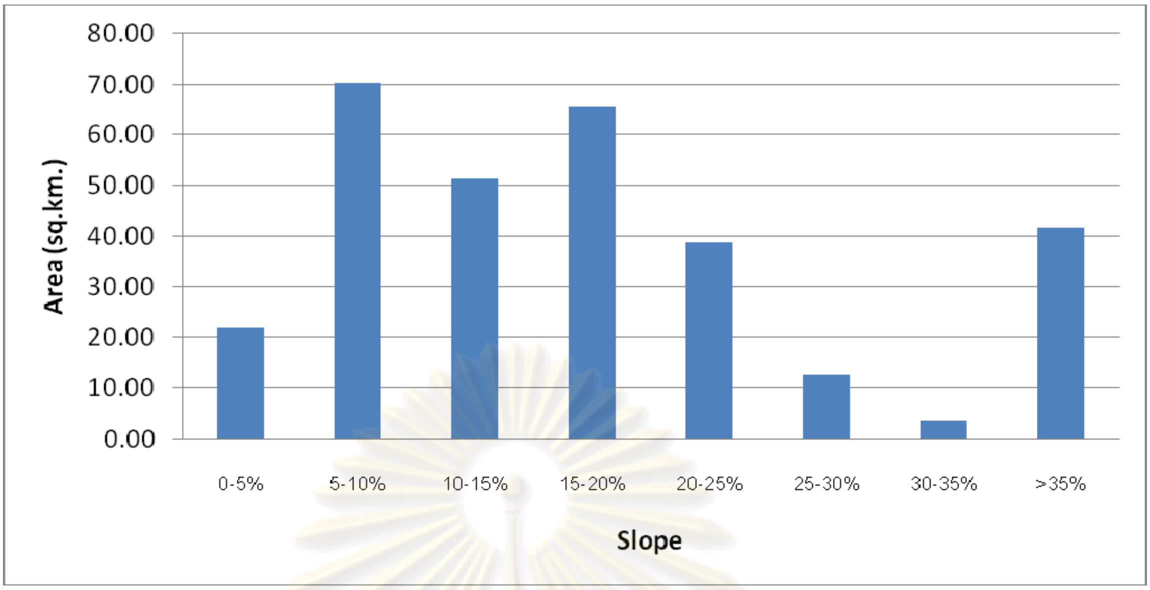

Figure 4-9 Histogram distribution of burned scars on slope

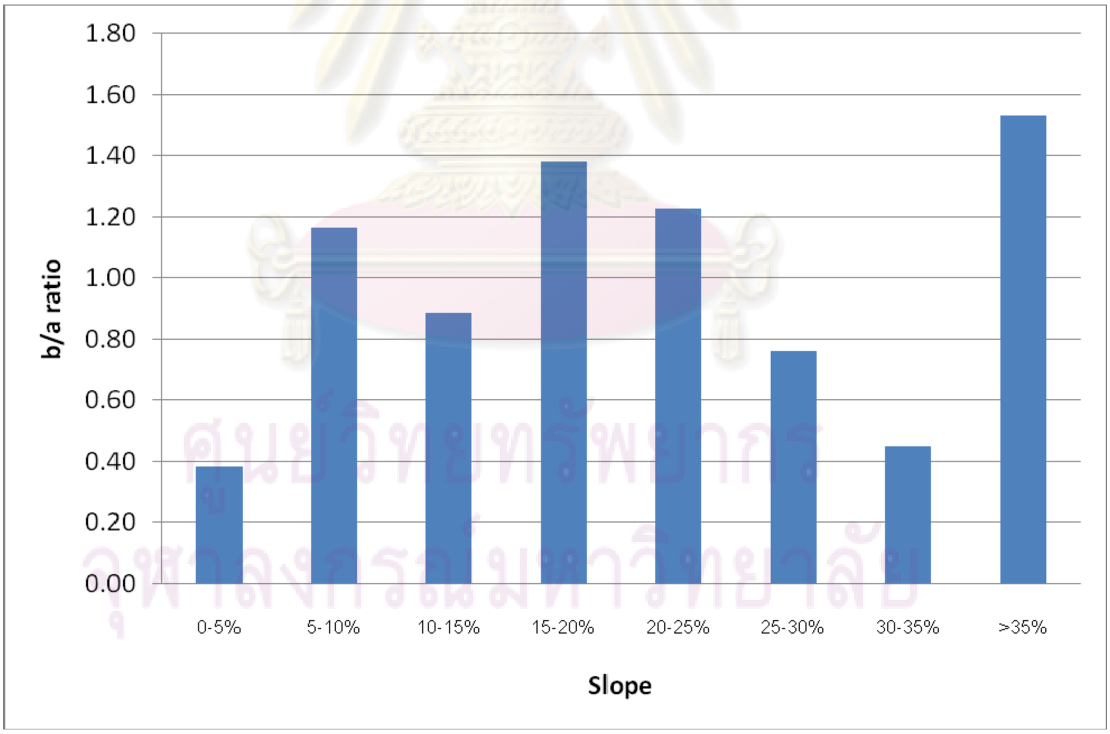

Figure 4-10 Histogram distribution of b/a ratio on slope

4.3 Relationship between burned areas and aspect

In case of aspect or direction that a slope facet, the frequencies were determined by calculating the burned scars areas for a given slope aspect and are presented in Figures 4-11, 4-12 and 4-13 and Table 4-4 and 4-5. Theoretically, the aspect is an essential component in forest fire analysis because some directions of slope facets are affected the warmer condition due to the sunlight. Theoretically, in south, southeastern and southwestern aspects are more prone to fire.

For the area in east aspect, the b/a ratio was 0.89, indicating a moderate probability. In north aspect, the b/a ratio was 0.38, indicating a very low probability. In northeast aspect, the b/a ratio was 1.17, indicating a high probability. In northwest aspect, the b/a ratio was 1.53, indicating a very high probability. In south aspect, the b/a ratio was 1.23, indicating a high probability. In southeast aspect, the b/a ratio was 1.38, indicating a high probability. In southeast aspect, the b/a ratio was 0.76, indicating a moderate probability. In west aspect, the b/a ratio was 0.45, indicating a low probability.

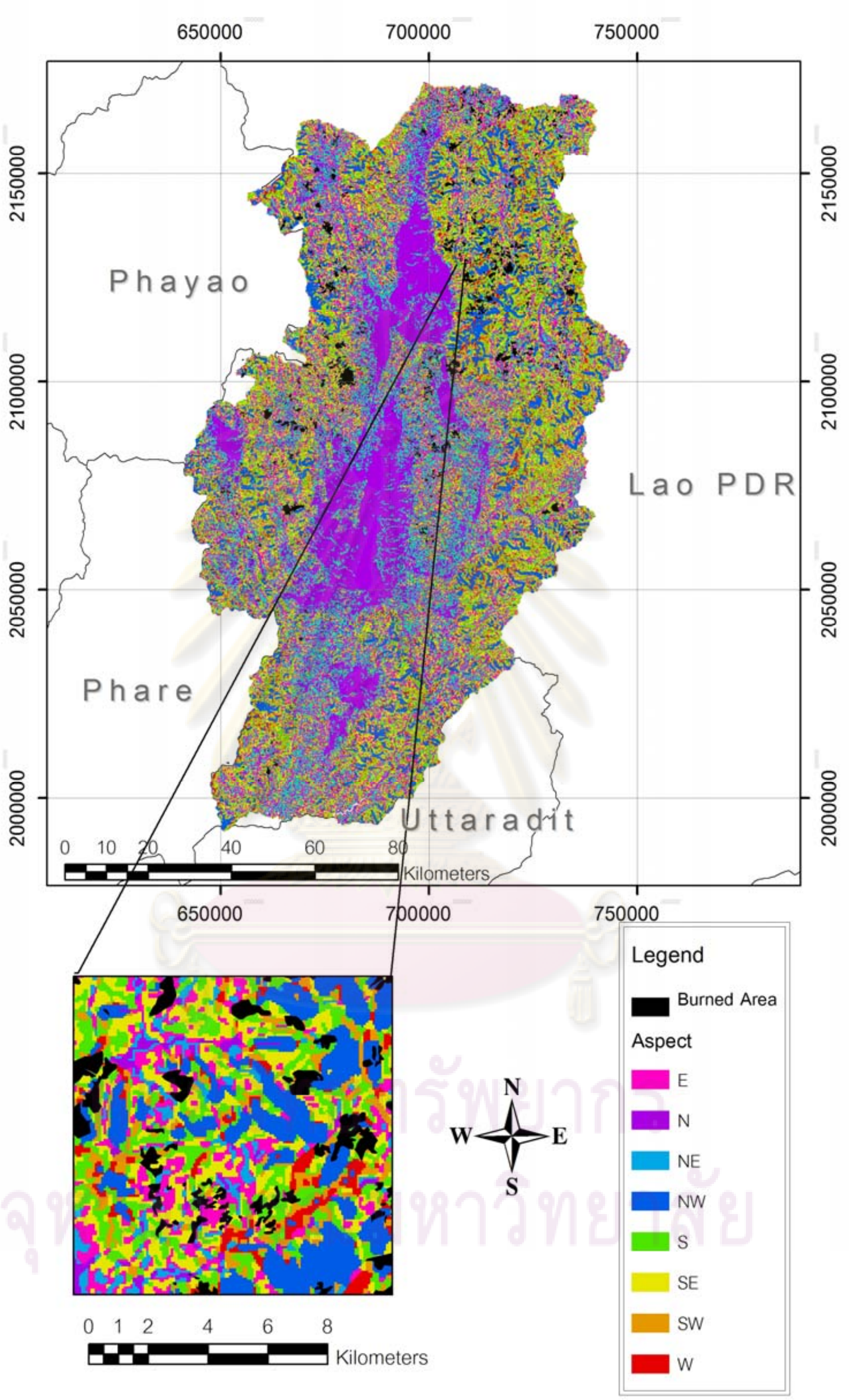

Figure 4-11 Aspect map overlain with burned scars (grouped in black color) in upper Nan watershed

Table 4-4 Burned scar occurred in each aspect class in upper Nan watershed

Aspect	Area (Km^2)				
	1999	2001	2004	2007	Total
E	5.66	18.34	14.57	12.69	51.26
N	3.60	6.44	2.89	8.94	21.87
NE	10.05	27.60	17.27	15.37	70.29
NW	8.20	18.43	8.16	6.97	41.75
S	1.08	15.27	10.99	11.52	38.86
SE	7.10	16.52	21.88	20.24	65.73
SW	0.71	4.10	4.42	3.25	12.48
W	0.61	0.26	1.06	1.46	3.40

Table 4-5 Relation of burned scars and aspect in upper Nan watershed

Aspect	Burned scar did not occur		Burned scar occur		b/a
	Area (Km^2)	Ratio (%), a	Area (Km^2)	Ratio (%), a	
E	2248.48	18.90	51.26	16.77	0.89
N	2222.65	18.69	21.87	7.16	0.38
NE	2346.26	19.73	70.29	23.00	1.17
NW	1060.27	8.91	41.75	13.66	1.53
S	1231.07	10.35	38.86	12.71	1.23
SE	1851.80	15.57	65.73	21.51	1.38
SW	640.03	5.38	12.48	4.08	0.76
W	294.13	2.47	3.40	1.11	0.45
Total	11894.69	100.00	305.64	100.00	1.00

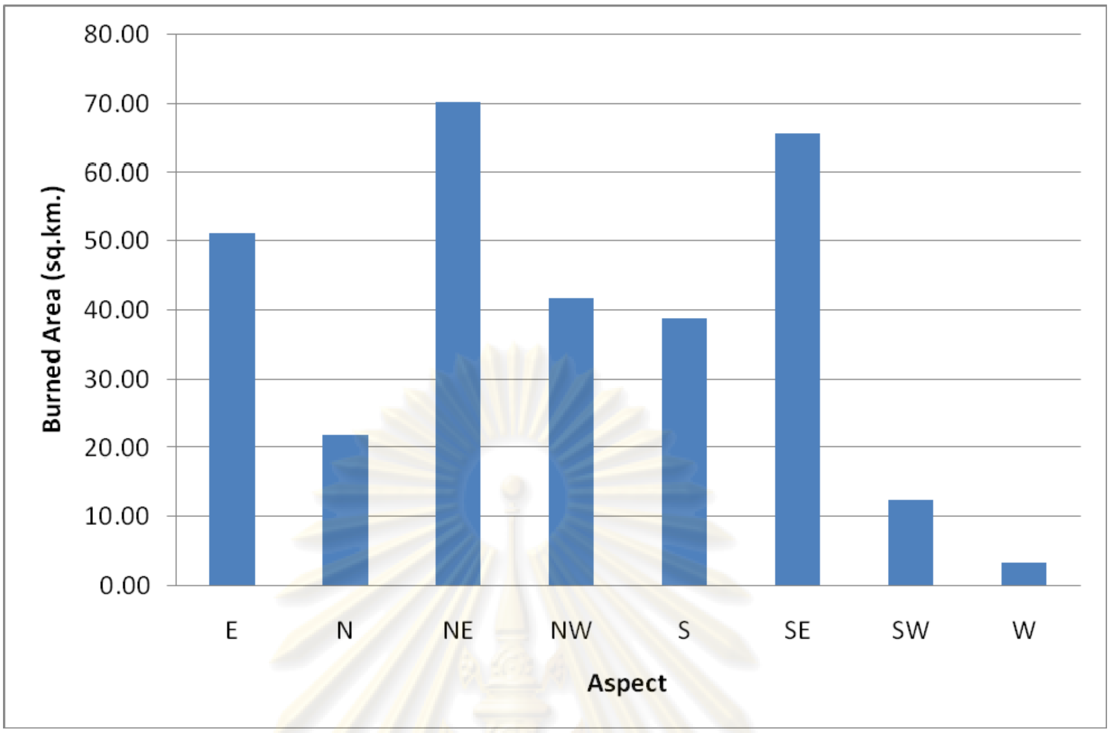

Figure 4-12 Histogram distribution of burned scars on aspect

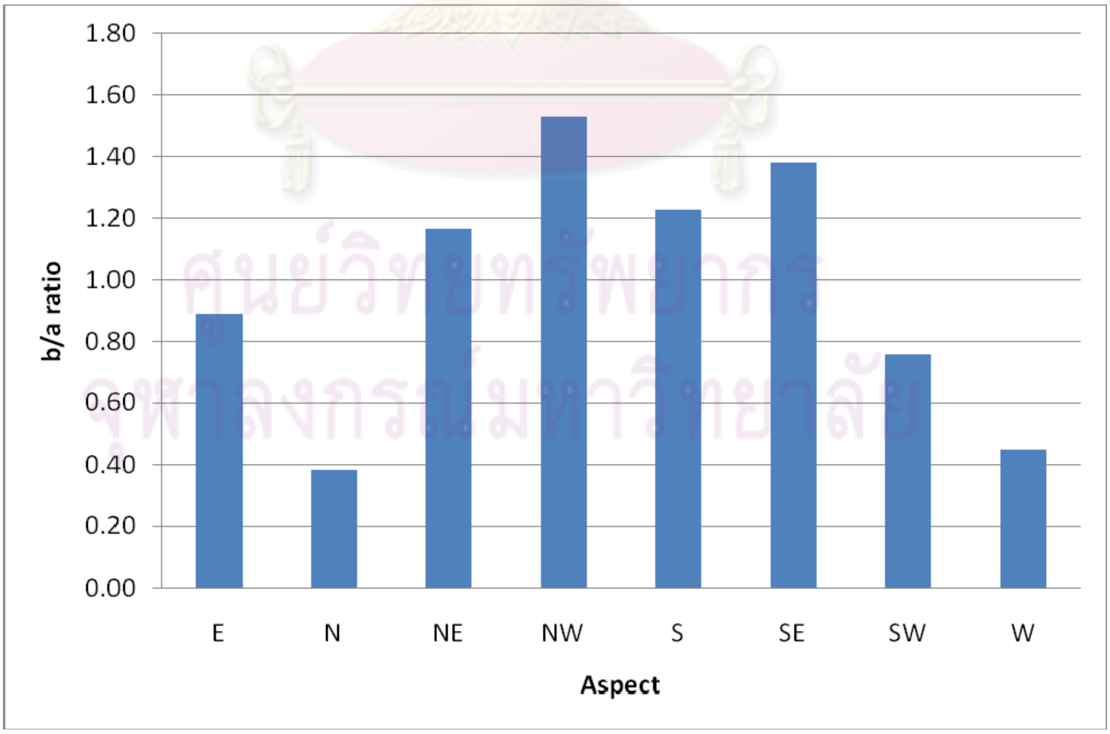

Figure 4-13 Histogram distribution of b/a ratio on aspect

4.4 Relationship between burned areas and distance from road

In relationship between burned areas and buffering distance from road, the frequencies were determined by calculating the burned scar areas for the different range of buffering distance from road (Figures 4-14, 4-15 and 4-16 and Table 4-6 and 4-7). It is noted that low probabilities were commonly observed in the area which buffering distance from road was in the ranges of less than 100 m and between 100-200 m that the b/a ratios were 0.46 and 0.49, respectively. Moderate probabilities were commonly observed in the area which buffering distance from road was in the ranges between 200-300 m and 300-400 m, that the b/a ratios were 0.53, and 0.57, respectively. Whereas a high probability was generally observed the area which buffering distance from road was more than 400 m that b/a ratio was 1.13.

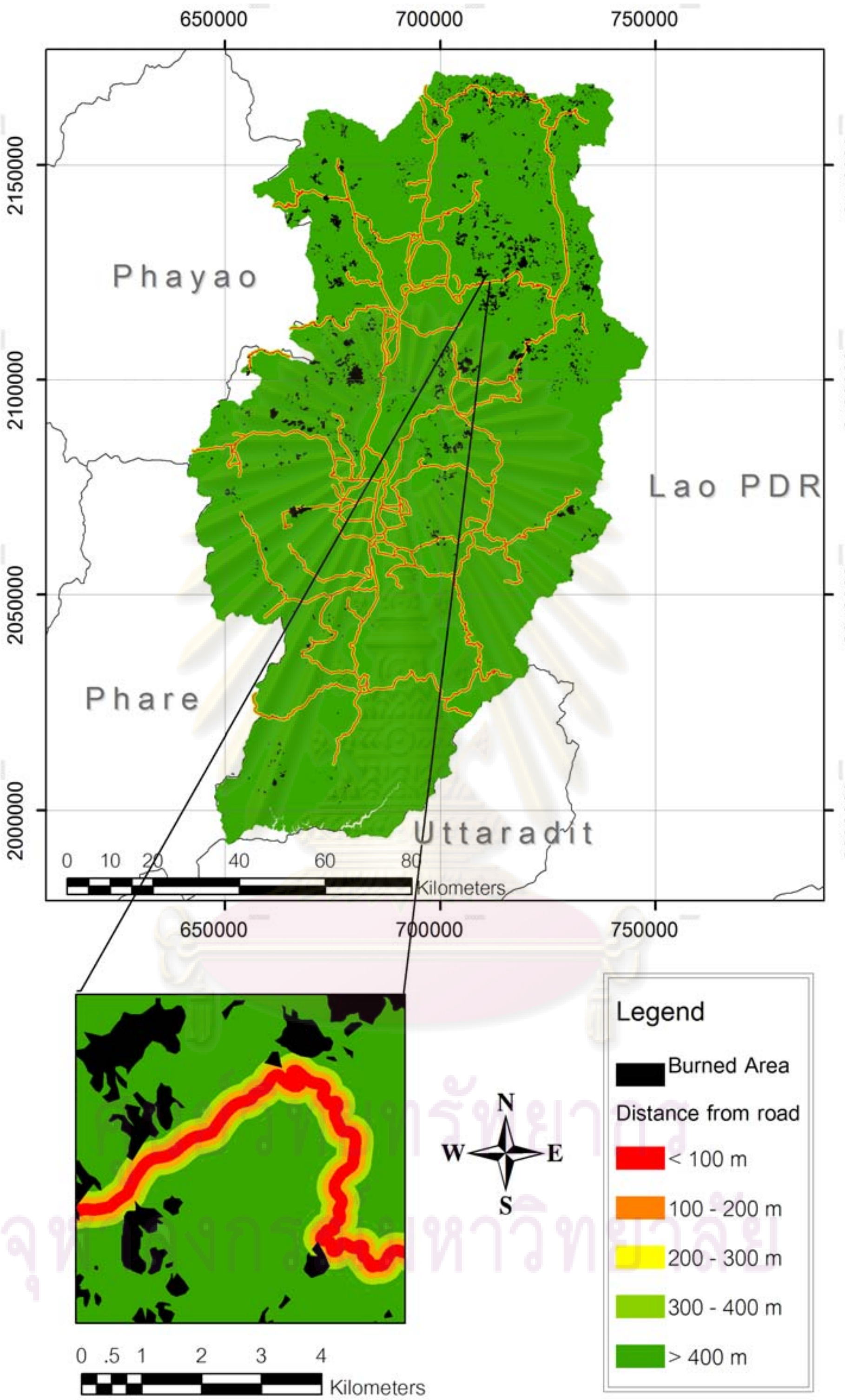

Figure 4-14 Buffering distance from road map overlain with burned scars (grouped in black color) in upper Nan watershed

Table 4-6 Burned scar occurred in each buffering distance from road in upper Nan watershed

Distance from road	Area (Km^2)				
	1999	2001	2004	2007	Total
< 100 m	0.36	1.92	0.34	0.75	3.38
100 - 200 m	0.88	3.83	0.81	1.60	7.12
200 - 300 m	1.49	5.80	1.34	2.64	11.27
100 - 200 m	2.22	7.95	1.93	3.89	15.99
> 400 m	34.42	99.07	79.28	76.41	289.18

Table 4-7 Relation of burned scars and buffering distance from road in upper Nan watershed

Distance from road	Burned scar did not occur		Burned scar occur		b/a
	Area (Km^2)	Ratio (%), a	Area (Km^2)	Ratio (%), a	
< 100 m	306.90	2.25	3.38	1.03	0.46
100 - 200 m	602.28	4.41	7.12	2.18	0.49
200 - 300 m	887.50	6.50	11.27	3.45	0.53
300 - 400 m	1162.67	8.51	15.99	4.89	0.57
> 400 m	10702.15	78.34	289.18	88.45	1.13
Total	13661.51	100.00	326.94	100.00	

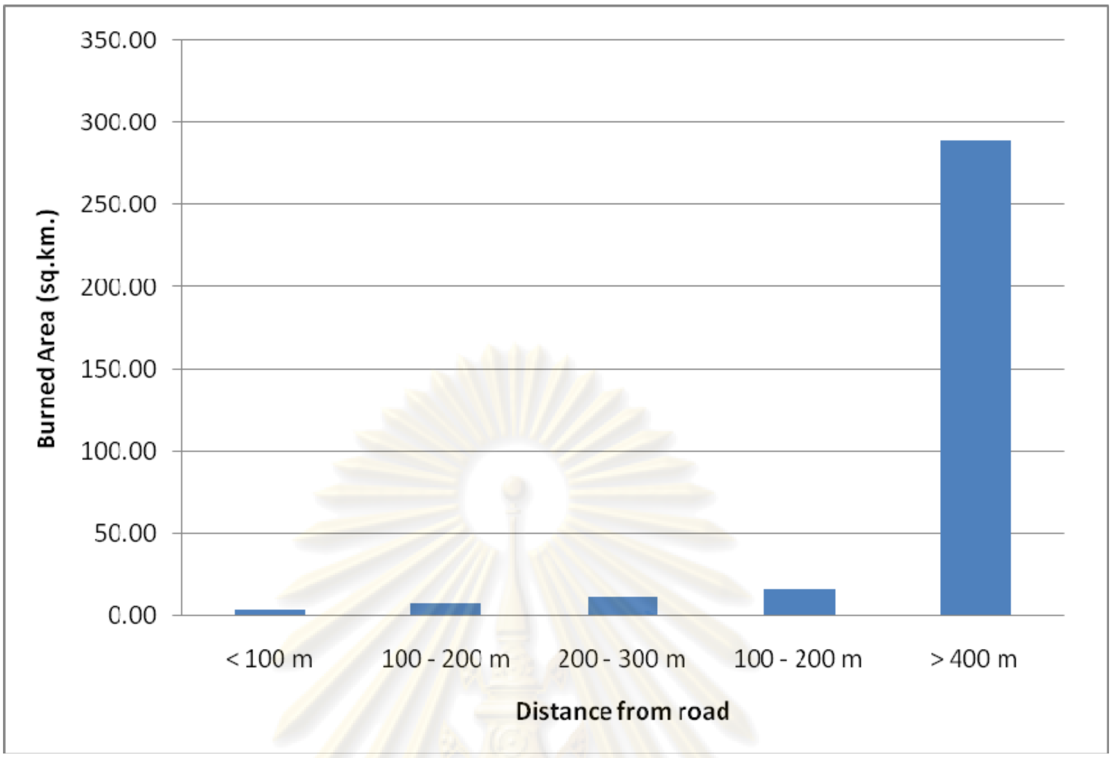

Figure 4-15 Histogram distribution of burned scars on buffering distance from road

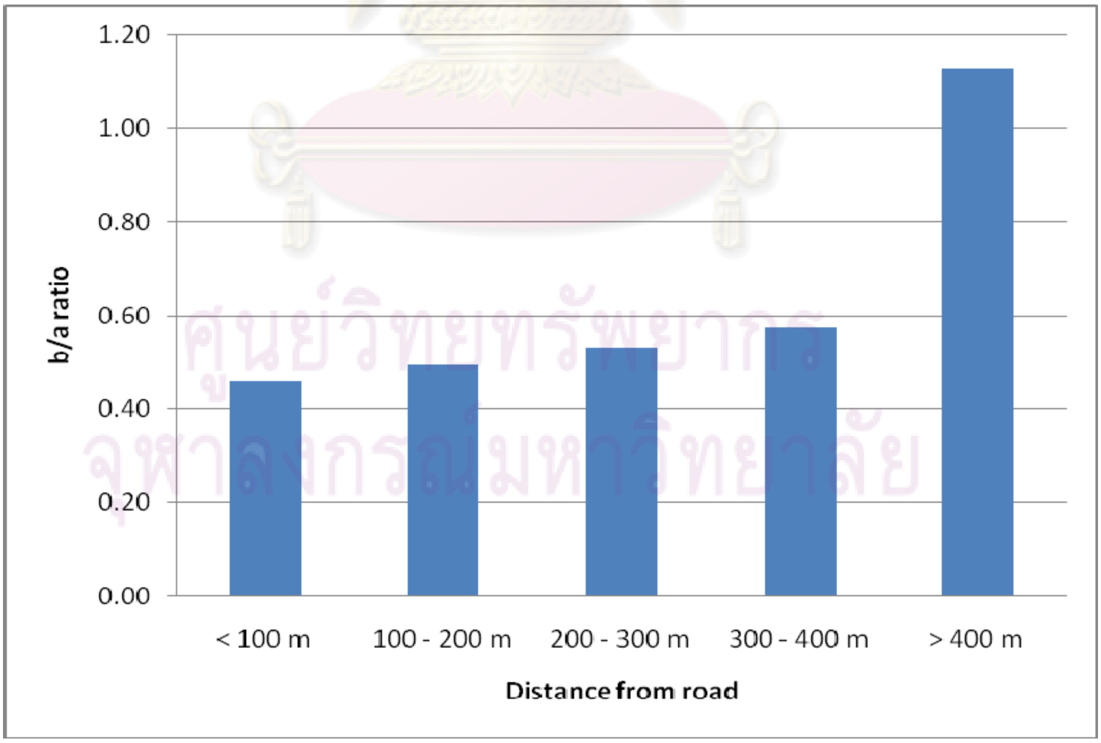

Figure 4-16 Histogram distribution of b/a ratio on buffering distance from road

4.5 Relationship between burned areas and distance from settlement

In relationship between burned areas and buffering distance from settlement, the frequencies were determined by calculating the burned scar areas for the different range of buffering distance from settlement (Figures 4-17, 4-18 and 4-19 and Table 4-8 and 4-9). It is noted that moderate probabilities were observed in the area which buffering distance from settlement was in the ranges of more than 4,000 m. and less than 1,000 m. that the b/a ratios were 0.57 and 0.86, respectively. Whereas high probabilities were generally observed in the area which buffering distance from settlement were in the range of between 3,000-4,400 m, between 2,000-3,000 m, and between 1,000-2,000 m that b/a ratio were 1.29, 1.30 and 1.29, respectively.

It is noted that the buffering distance from settlement is concluded to be ones of significant relevant parameters that will be used in forest fire zone analysis.

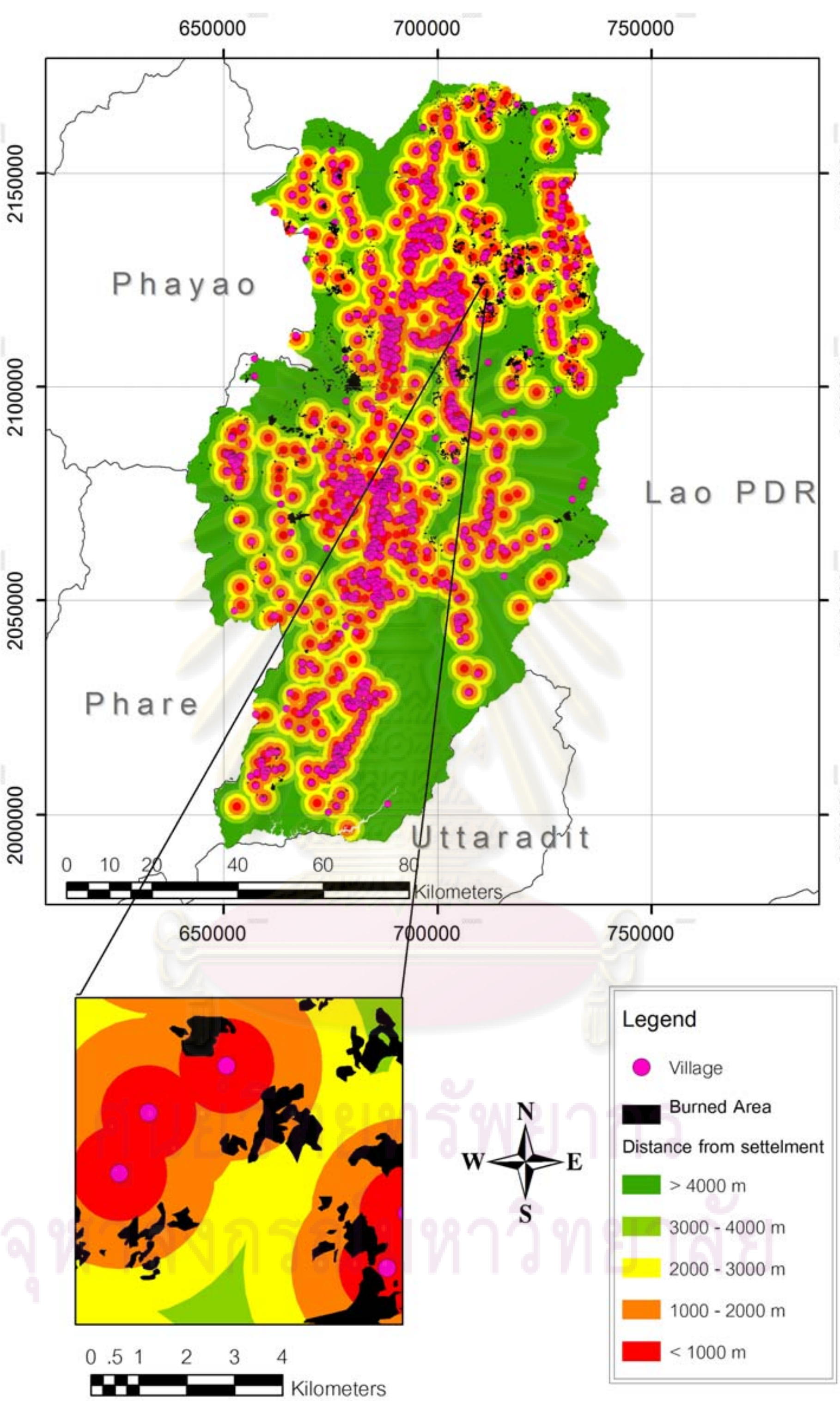

Figure 4-17 Buffering distance from settlement map overlain with burned scars (grouped in black color) in upper Nan watershed

Table 4-8 Burned scar occurred in each buffering distance from settlement in upper Nan watershed

Distance from settlement	Area (Km^2)				
	1999	2001	2004	2007	Total
< 1000 m	6.92	11.96	8.14	10.95	37.98
1000 - 2000 m	13.41	27.77	20.47	22.77	84.43
2000 - 3000 m	8.90	26.52	19.89	19.55	74.86
3000 - 4000 m	4.13	22.78	14.82	10.50	52.22
> 4000 m	3.29	17.75	17.89	16.54	55.46

Table 4-9 Relation of burned scars and buffering distance from settlement in upper Nan watershed

Distance from settlement	Burned scar did not occur		Burned scar occur		b/a
	Area (Km^2)	Ratio (%), a	Area (Km^2)	Ratio (%), a	
< 1000 m	1722.26	14.52	37.98	12.45	0.86
1000 - 2000 m	2547.32	21.47	84.43	27.69	1.29
2000 - 3000 m	2244.30	18.92	74.86	24.55	1.30
3000 - 4000 m	1576.65	13.29	52.22	17.13	1.29
> 4000 m	3774.52	31.81	55.46	18.19	0.57
Total	11865.05	100.00	304.94	100.00	

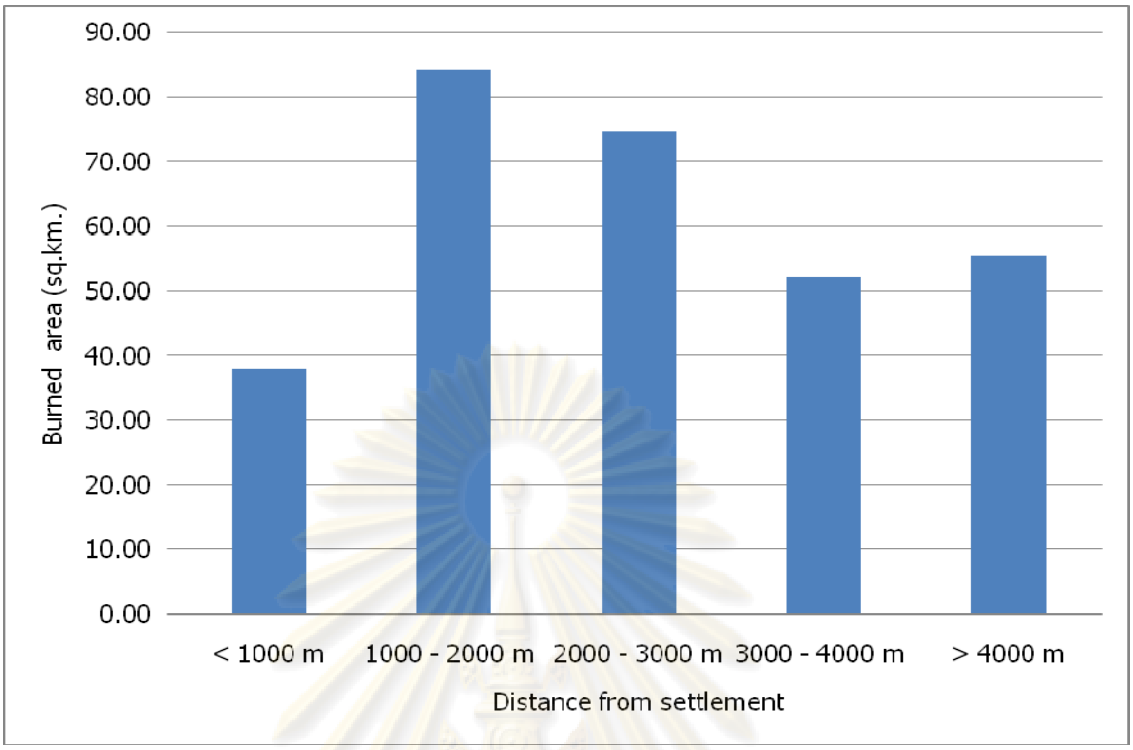

Figure 4-18 Histogram distribution of burned scars on buffering distance from settlement

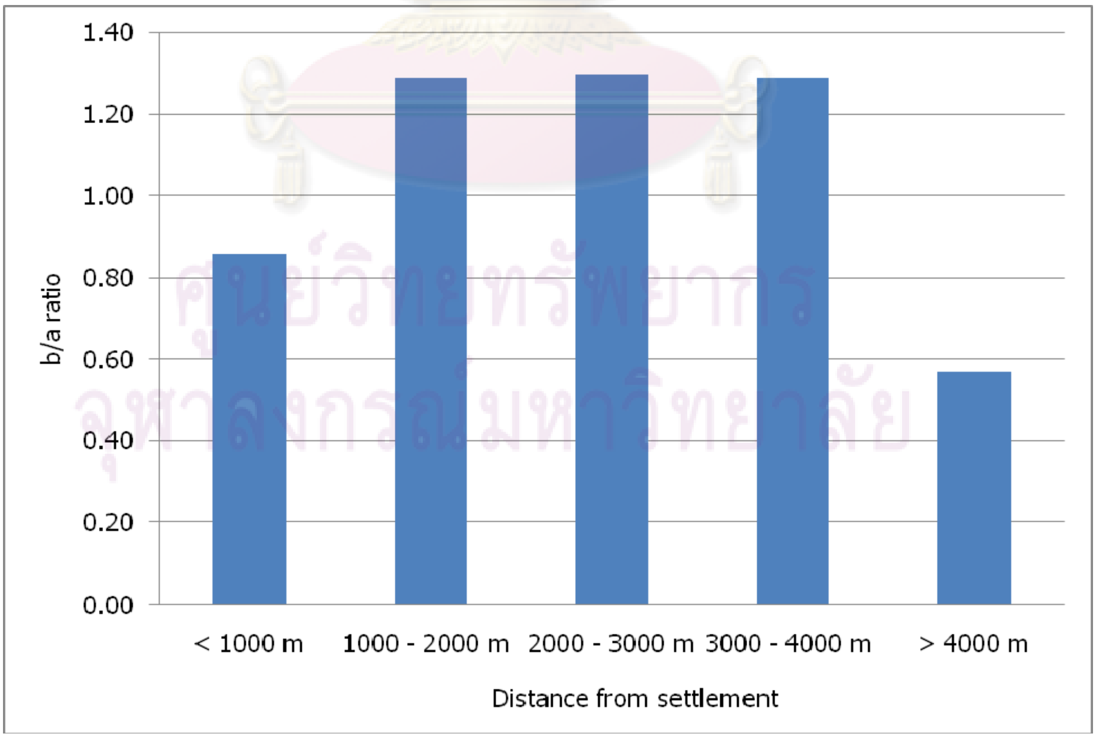

Figure 4-19 Histogram distribution of b/a ratio on buffering distance from settlement

4.5 Relationship between burned areas and vegetation

The vegetation in upper Nan watershed derived from interpretation of remote sensing imageries acquired on 20th and 29th December 2006. The vegetation types were classified according to the moisture context that has an influence on breaking out forest fire. The areas of burned scars for a given vegetation type were also determined (as shown in Table 4-10, and Figure 4-20, 4-21, and 4-22). It was note that high probabilities were observed in fresh-like and fresh vegetation that the b/a ratios were 1.44 and 1.18, respectively. Moderate probabilities were observed in moist and dry vegetation that the b/a ratios were 0.99 and 0.59, whereas a very low probability was generally observed in very dry vegetation that the b/a ratio was 0.25.

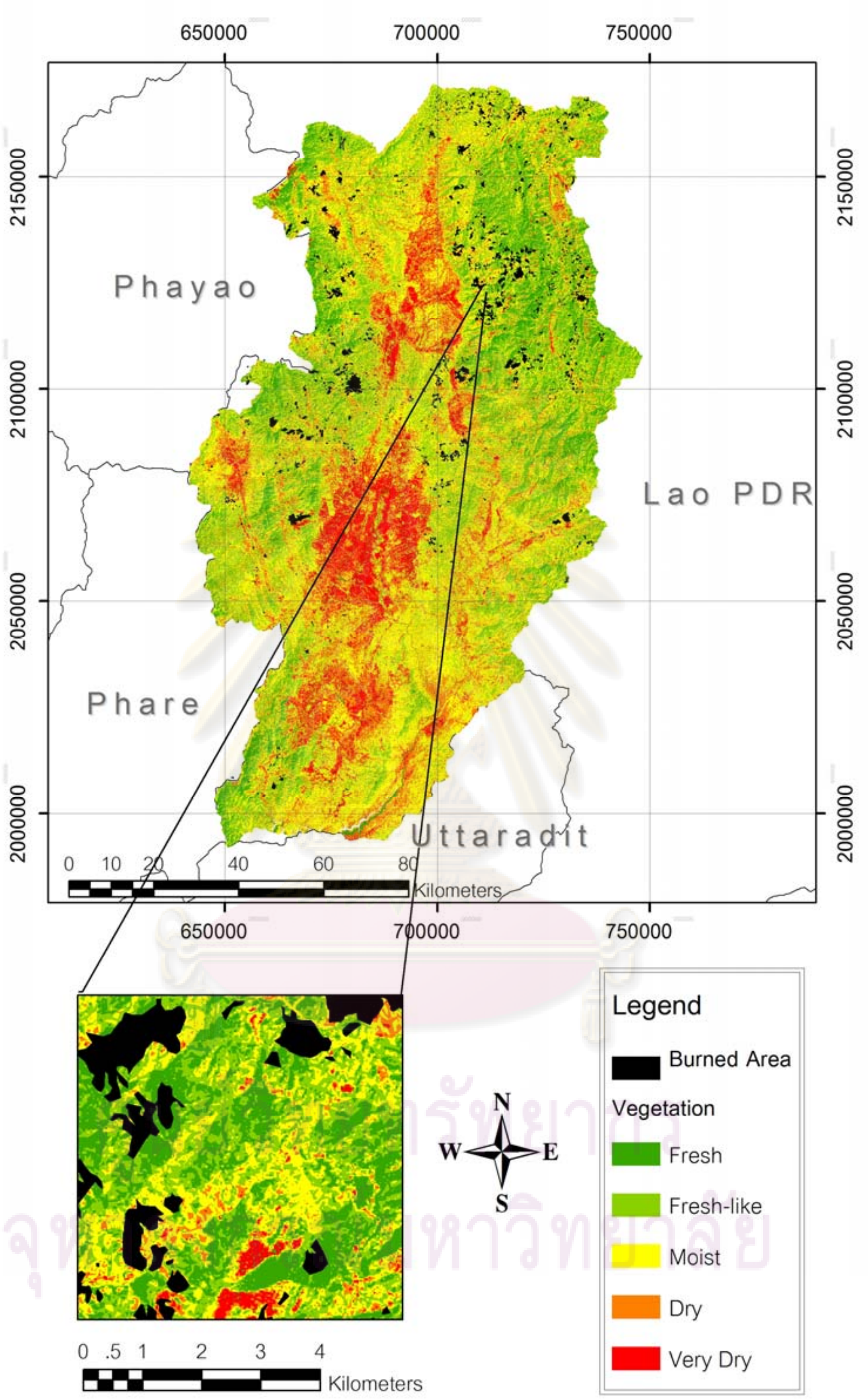

Figure 4-20 Vegetation map overlain with burned scars (grouped in black color) in upper Nan watershed

Table 4-10 Relation of burned scars and vegetation in upper Nan watershed

Vegetation type	Burned scar did not occur		Burned scar occur		b/a
	Area (km^2)	Ratio (%), a	Area (km^2)	Ratio (%), b	
Fresh	1325.82	10.97	10.42	12.98	1.18
Fresh-like	3136.33	25.95	30.09	37.47	1.44
Moist	4599.65	38.05	30.17	37.57	0.99
Dry	2051.70	16.97	8.00	9.96	0.59
Very Dry	974.78	8.06	1.62	2.02	0.25
	12088.28	100.00	80.31	100.00	

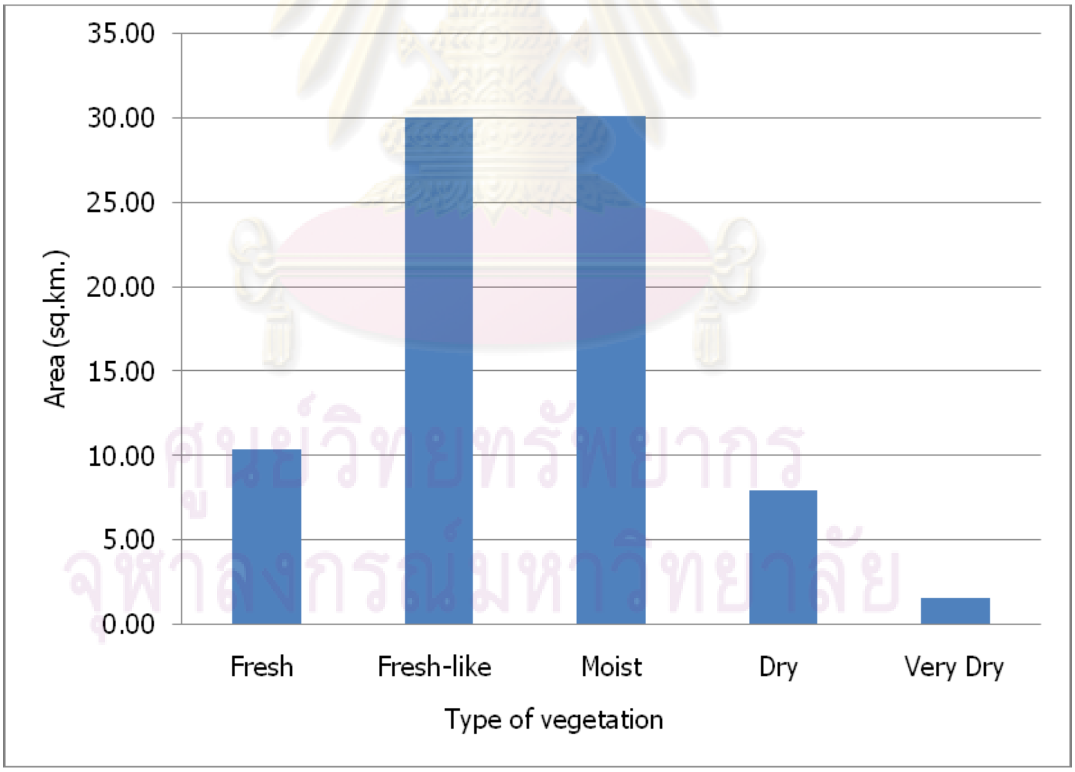

Figure 4-21 Histogram distribution of burned scars on vegetation

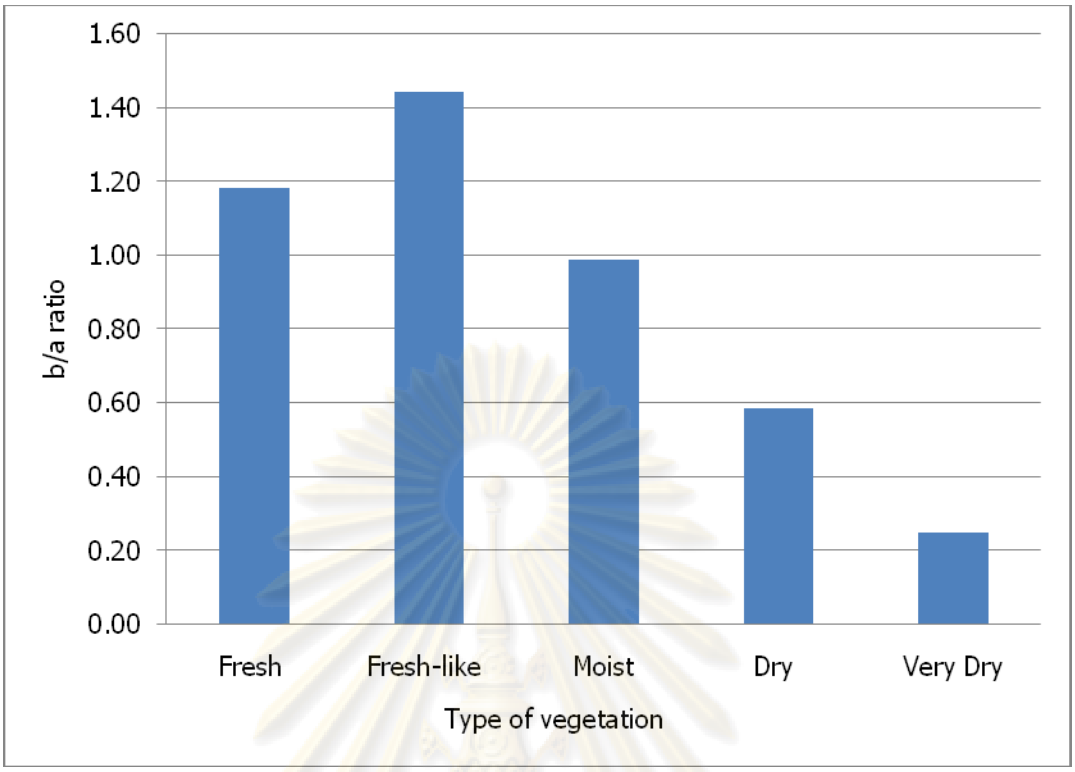

Figure 4-22 Histogram distribution of b/a ratio on vegetation

4.6 Relationship between burned areas and land cover

The land cover in upper Nan watershed derived from interpretation of remote sensing imageries acquired on 20th and 29th December 2006. The areas of burned scars for a given type of land cover were also determined (as shown in Table 4-11, and Figure 4-23, 4-24, and 4-25). It was note that a high probability was observed in forest areas that the b/a ratio was 1.32. A moderate probability was observed in built-up areas and agricultural areas that the b/a ratios were 0.71 and 0.65, whereas a very low probability was generally observed in water body areas that the b/a ratio was 0.32.

The results reveal that burned scars are mainly occurs in forest areas, built-up areas and agricultural areas respectively. The land cover type that have no data are not mentioned here because it is the area that cover with clouds and unclassified.

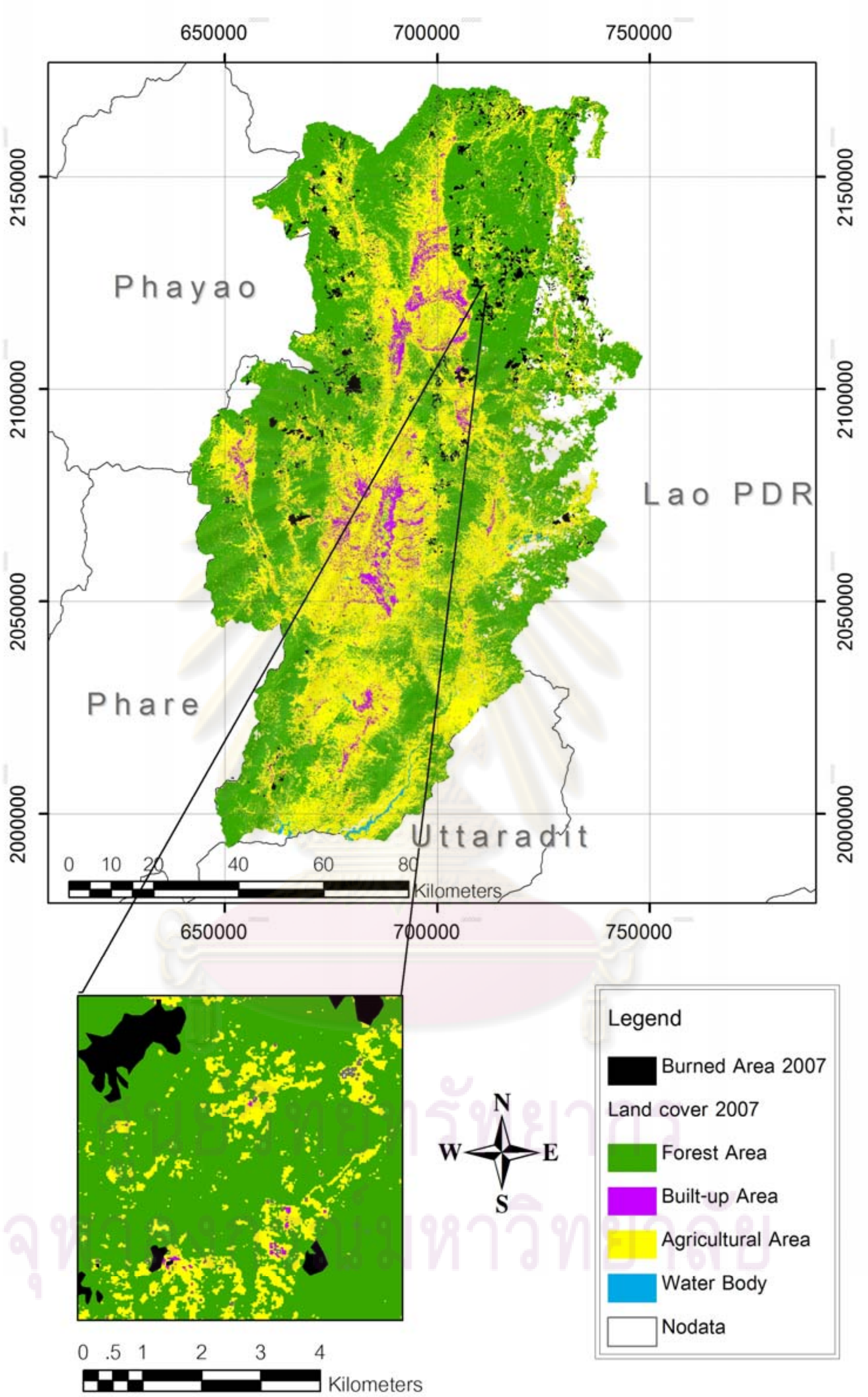

Figure 4-23 Land cover map overlain with burned scars (grouped in black color) in upper Nan watershed

Table 4-11 Relation of burned scars and land cover in upper Nan watershed

Land Cover Type	Burned scar did not occur		Burned scar occur		b/a
	Area (km^2)	Ratio (%), a	Area (km^2)	Ratio (%), b	
Forest Area	6235.91	51.55	54.42	68.29	1.32
Built-up Area	434.46	3.59	2.02	2.53	0.71
Agricultural Area	4846.27	40.06	20.70	25.98	0.65
Water body	53.81	0.44	0.11	0.14	0.32
Nodata	527.48	4.36	2.44	3.06	0.70
	12097.93	100.00	79.70	100.00	

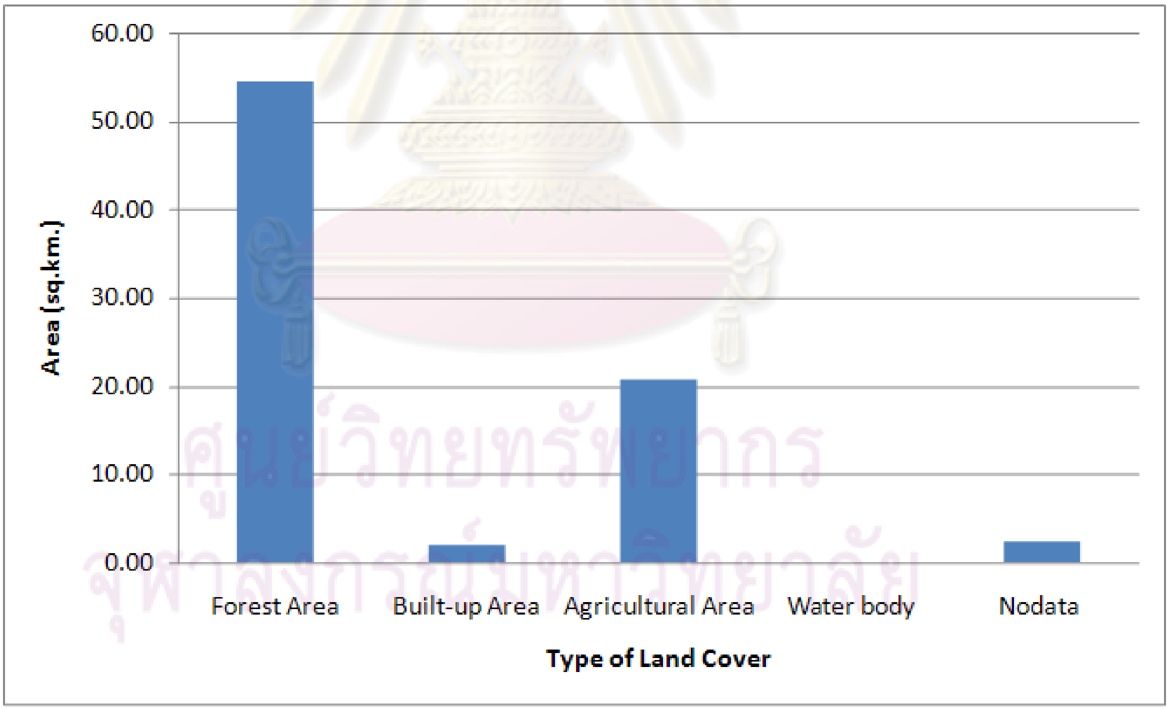

Figure 4-24 Histogram distribution of burned scars on land cover

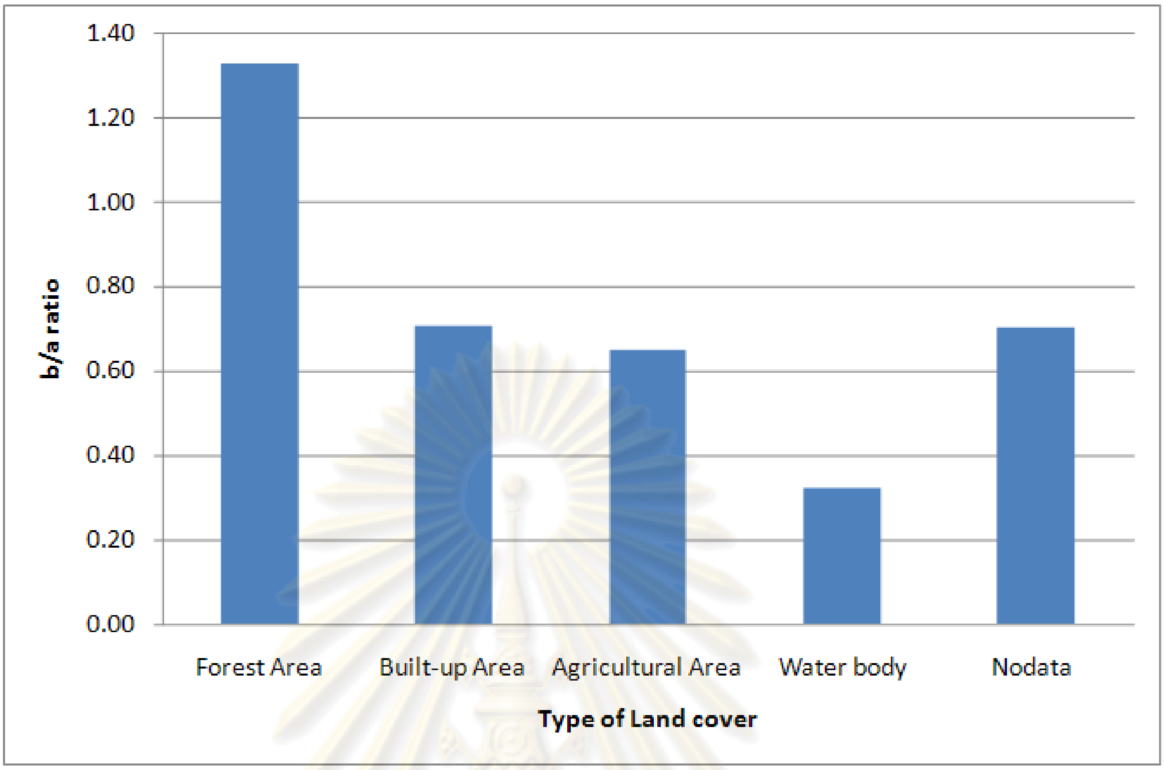

Figure 4-25 Histogram distribution of b/a ratio on land cover

4.7 Forest fire risk analysis

Strino et al. (2007) pointed out that the link between remote sensing results and an efficient forestry GIS can work as a tool for an operational and practically oriented monitoring system for forest damage assessment and management. This method looks for finding a relation between several data to define the different range of the fire risk areas. The idea of this method can be showed in the following diagram (Figure 4-26).

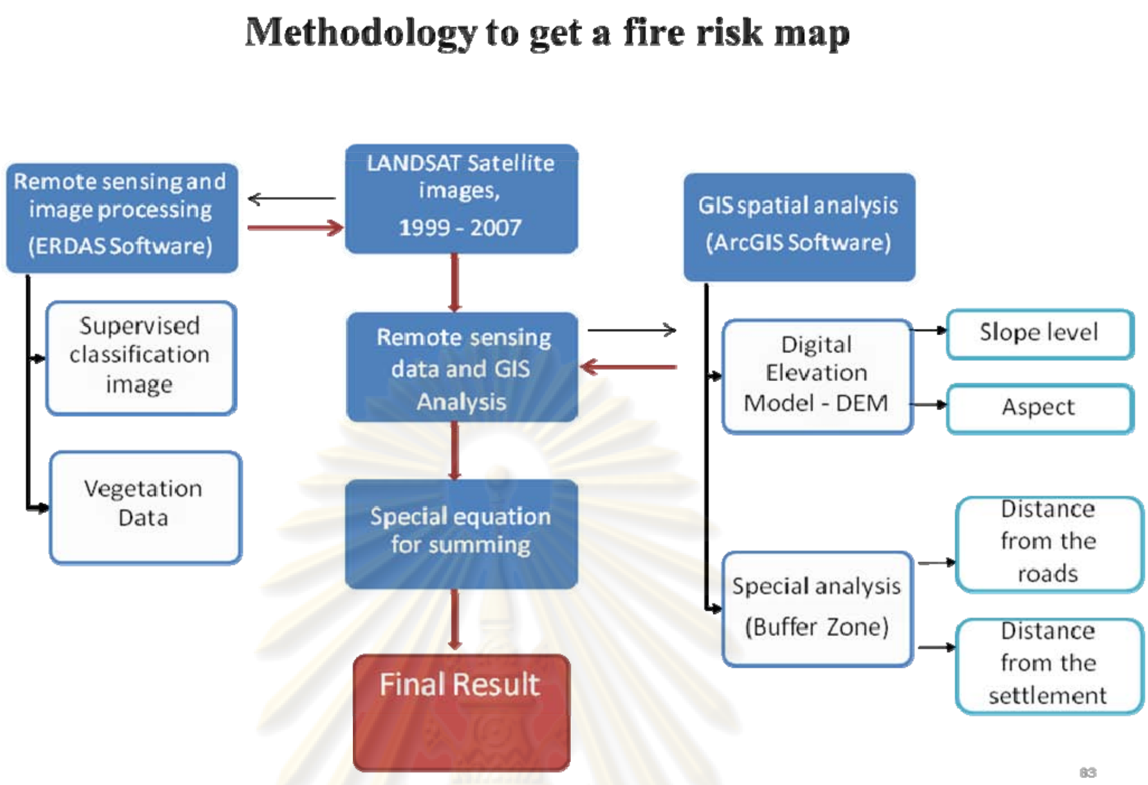

Figure 4-26 Methodology to get a forest fire risk map

(Adapted from Strino et al., 2007)

The target of digital land cover supervised classification is to link the spectral characteristics of the image to an information class value, which can be displayed as a map in order that researcher can evaluate the landscape in an accurate and cost effective manner .In this research, there are two different kind of classification applied, the first classification type consist in to obtain the artificial areas such as the residential, and road that could be important to understand the risk level as nearer they are from forests.

The Landsat TM imageries were used for defining and identifying the burned areas and for estimating the vegetation loss. Besides the satellite data, the topography will be important in this research. The data collected for this research were as follows: vegetation, slope, aspect, transportation and human settlement.

Vegetation

The vegetation types were classified according to the moisture context that has an influence on breaking out forest fire. For example, the vegetation type that is very dry is the most flammable whereas the fresh type is inflammable. Therefore, to compare images from different dates is to classify the two images separately and to compare the statistical results. The classification of satellite images were used in land cover analyses and in determining change between the land use before the fire and that after the fire. In order to obtain more accurate conclusions, mathematical operations in the GIS analysis were formed.

The classification of vegetation index (NDVI), were carried out using image analysis techniques, and image classification techniques with ERDAS IMAGINE 8.5 and ArcGis 9.2. The vegetation can be classified as fresh, fresh-like, moist, dry and very dry(Córdova, 2009).

The input information on forest fire influencing factors indicates the weights in the fire risk in an area. The factors were analyzed in the following order of importance: vegetation type, slope, aspect, distance from roads and settlements. First classes represent high risk areas and last classes represent minor risk areas. Each class has different weights.

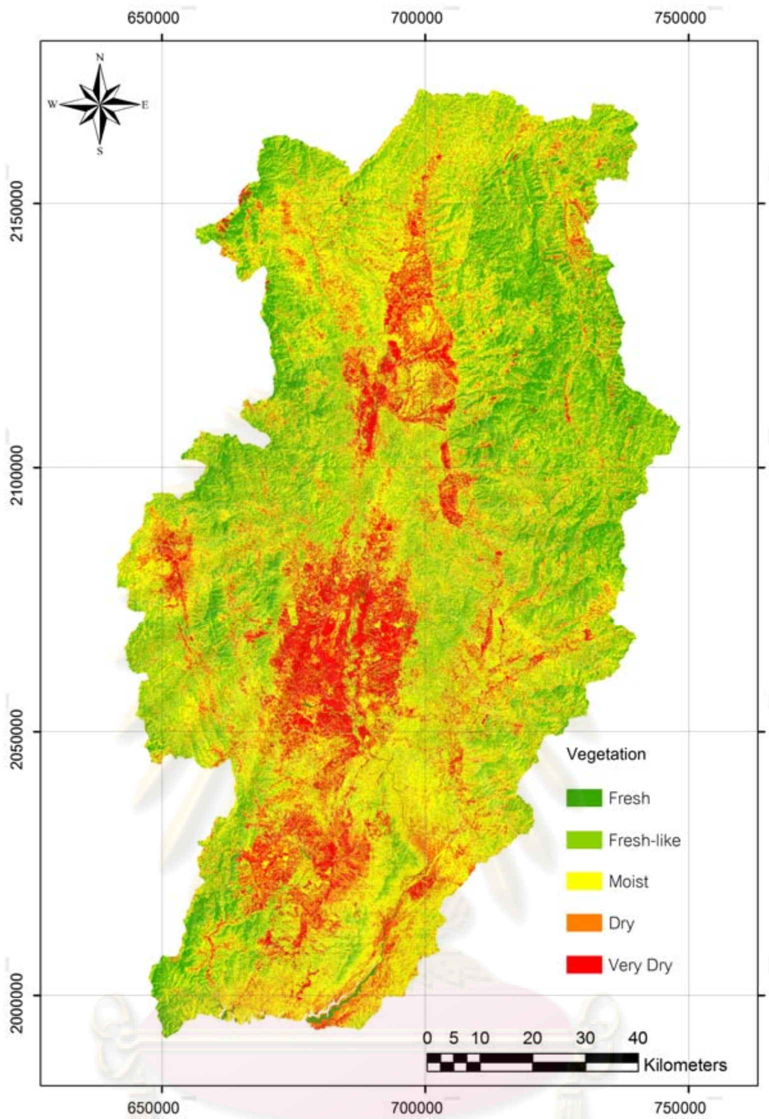

Figure 4-27 The vegetation map of the study area

Table 4-12 Percentage of Vegetation Index

Vegetation Index	Area (Km^2)	Area (%)
Fresh	1336.24	10.98
Fresh-like	3166.42	26.02
Moist	4629.83	38.05
Dry	2059.69	16.93
Very Dry	976.40	8.02
Total	12168.58	100.00

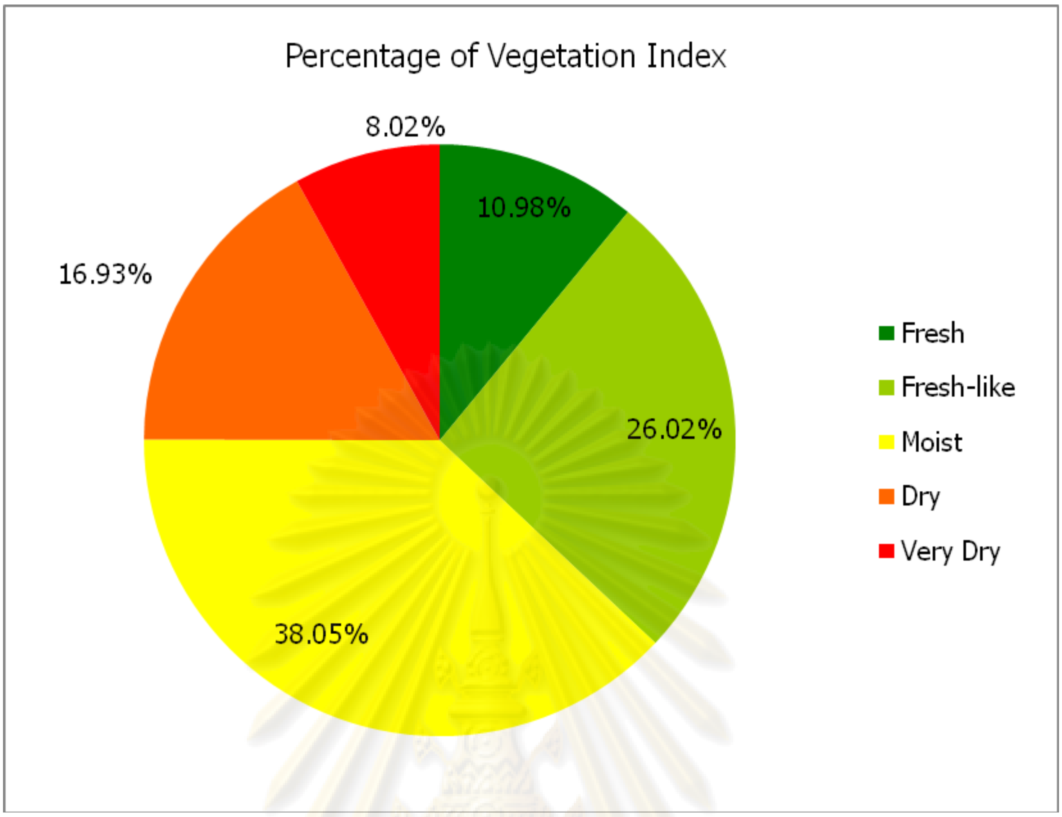

Figure 4-28 Percentage of vegetation index

- Topography

Topography is an important physiographic factor which is related to wind behavior, and therefore affects the fire ignitions of the area (Andrews and Chase, 1989). The structure of upper Nan watershed is mountainous and with a great number of high slope areas. Slope and aspect data retrieved from Land Development Department (LDD). In this research, the Slope influence behavior of fire was evaluated the second highest weight. From the literature review fire moves most rapidly up slopes and less down slopes. Slope classes were created according to this rule. From figure 4-29, the slope range illustrate the fire risk level, the high risk level could shown by the red color reducing to the green one. Aspect was assigned equal weight with slope. Because the sunlight is much more reflected on the slopes in the south, fire breaks out fast and spreads in the south sides. From figure 4-31, sun path and time affect always over the green areas and as we knew the southern said is longer and high of the sunlight during the day for that reason show has high fire risk zones.

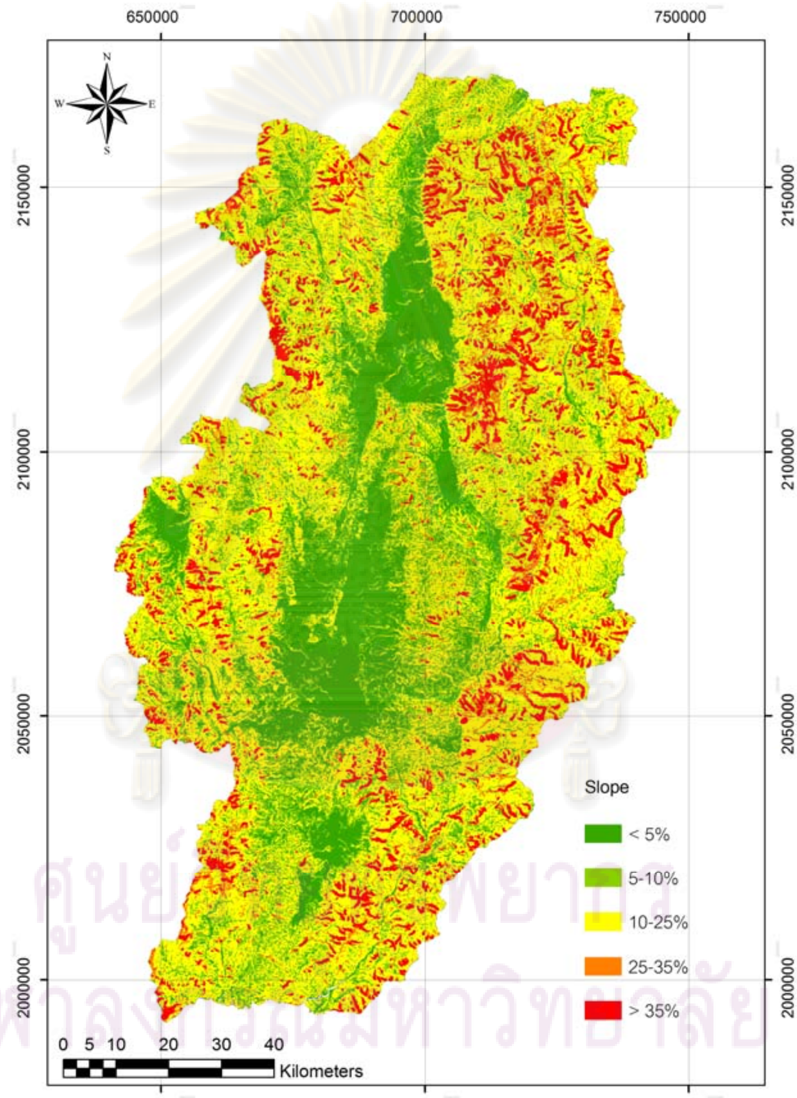

Figure 4-29 The slope map of the study area

Table 4-13 Percentage of slope index

Slope %	Area (Km^2)	Area (%)
< 5%	2244.52	18.40
5-10%	2416.55	19.81
10-25%	5487.20	44.98
25-35%	950.04	7.79
> 35%	1102.02	9.03
Total	12200.33	100.00

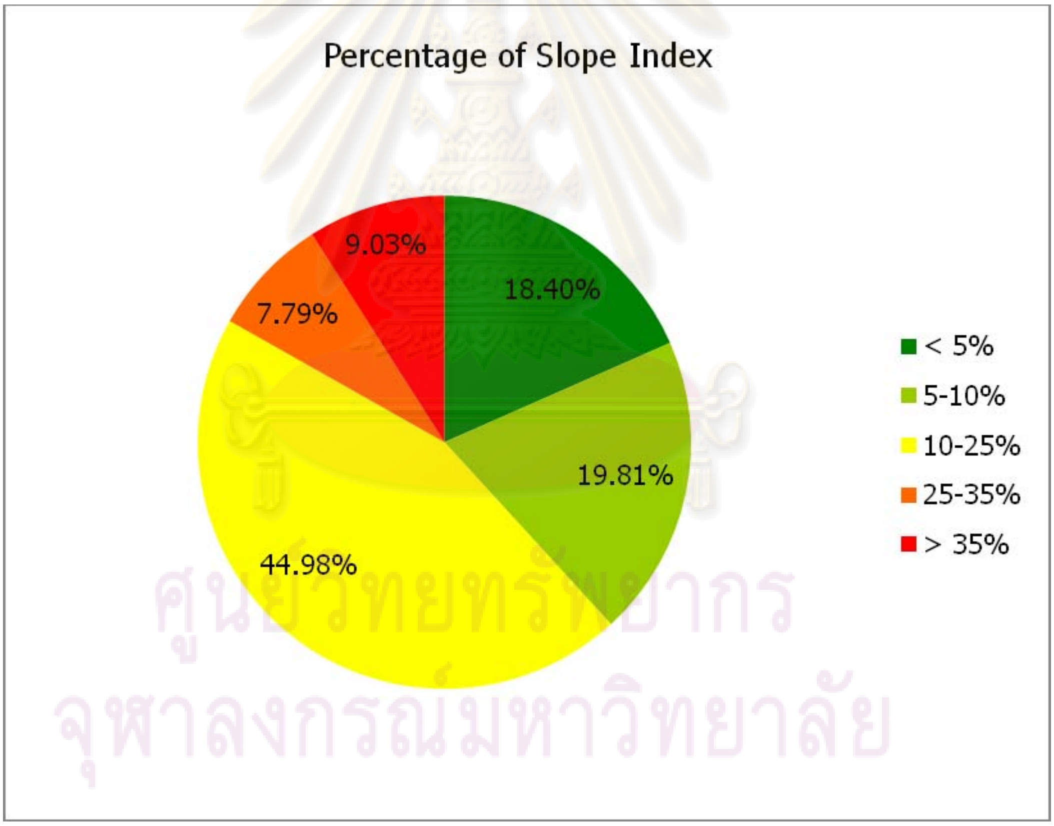

Figure 4-30 Percentage of slope index

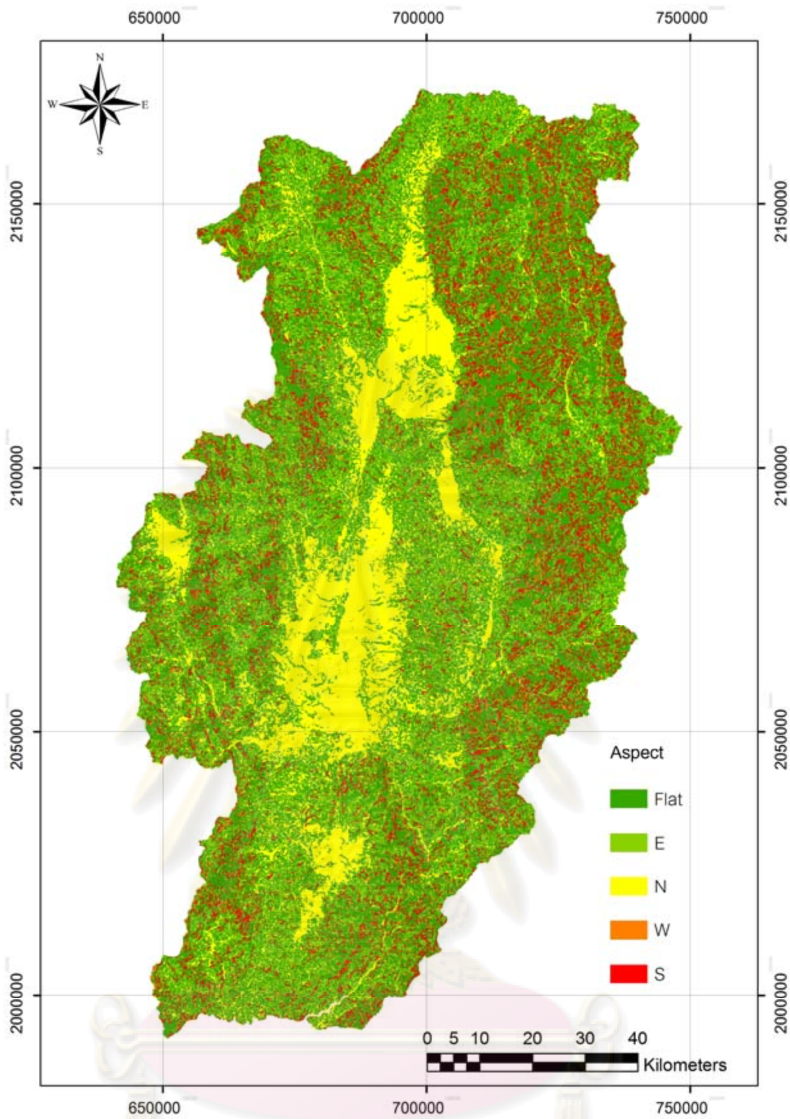

Figure 4-31 The aspect map of the study area

Table 4-14 Percentage of aspect index

Aspect	Area (Km^2)	Area (%)
Flat	6088.62	49.91
E	2299.74	18.85
N	2244.52	18.40
W	297.52	2.44
S	1269.92	10.41
Total	12200.33	100.00

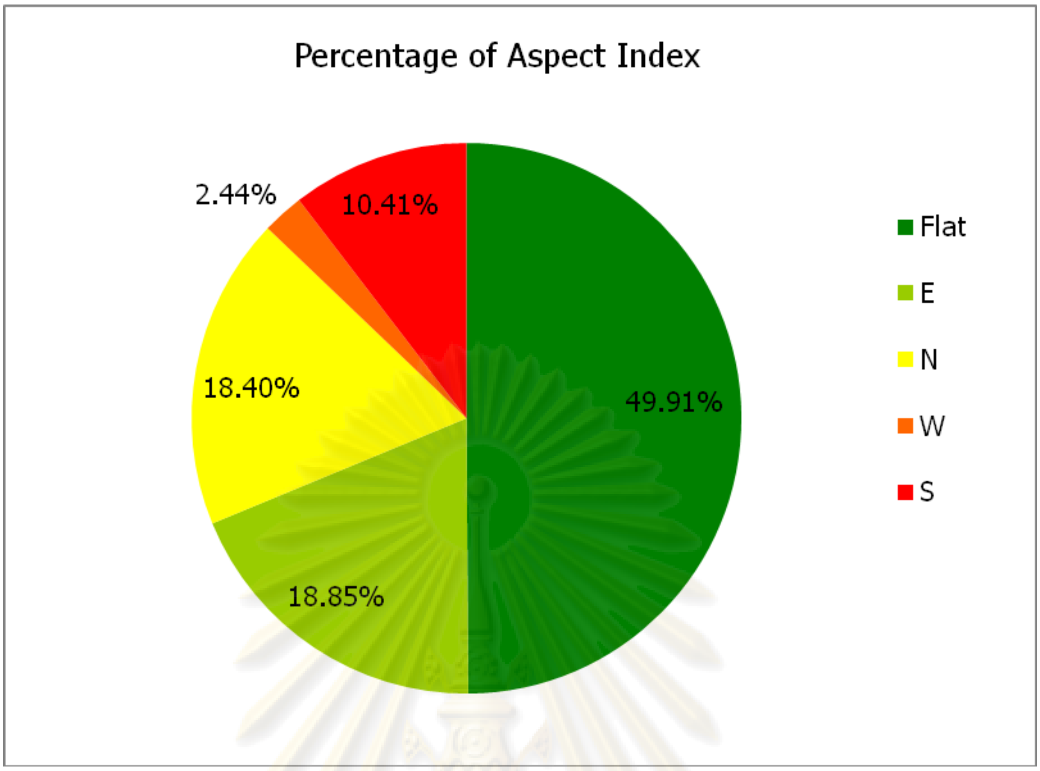

Figure 4-32 Percentage of aspect index

- Distance from roads

Forests can be resulted by the movements of humans, animals and vehicles. Therefore, forests that are near roads are fire risk areas. Distance from roads were evaluated the third highest weight (Strino et al., 2007). In this research, the main roads that are already surrounding by the agriculture areas are selected. The risk factor decreases farther from these areas. It means that a zone close to these areas was evaluated with higher rating.

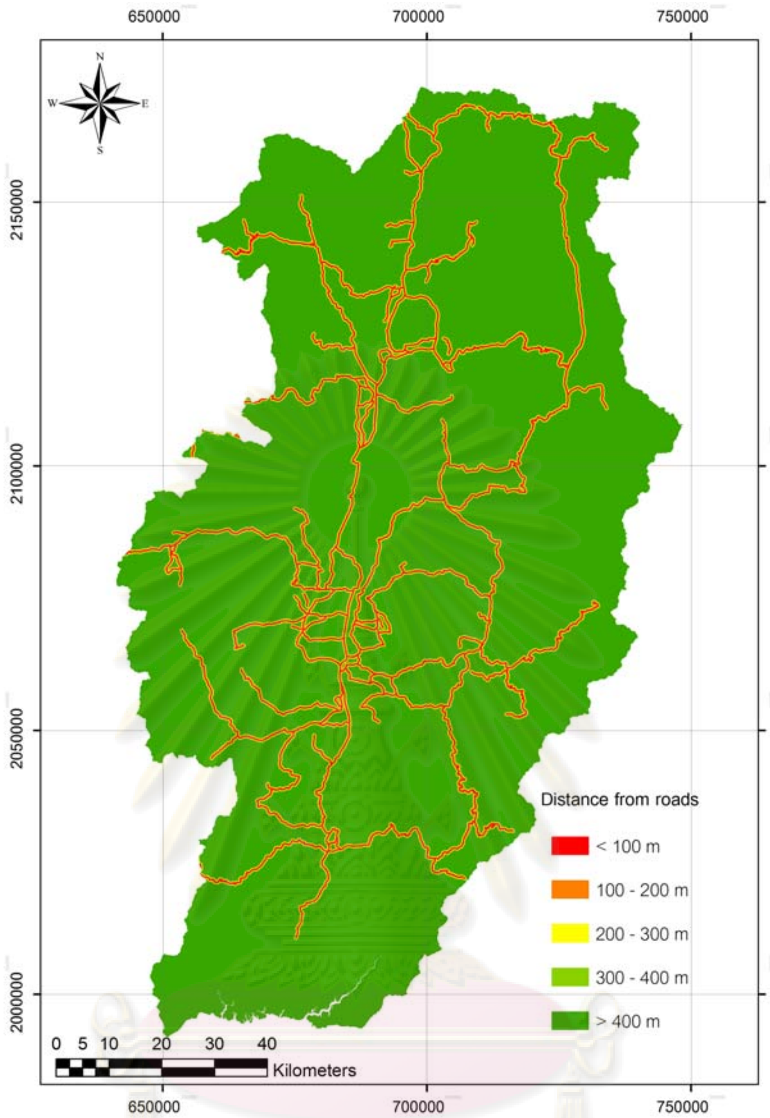

Figure 4-33 The map show distance from main roads in the study area

Table 4-15 Percentage of distance from road index

Distance from road	Area (Km^2)	Area (%)
< 100 m	310.27	2.22
100 - 200 m	609.40	4.36
200 - 300 m	898.77	6.43
300 - 400 m	1178.67	8.43
> 400 m	10991.33	78.57
Total	13988.44	100.00

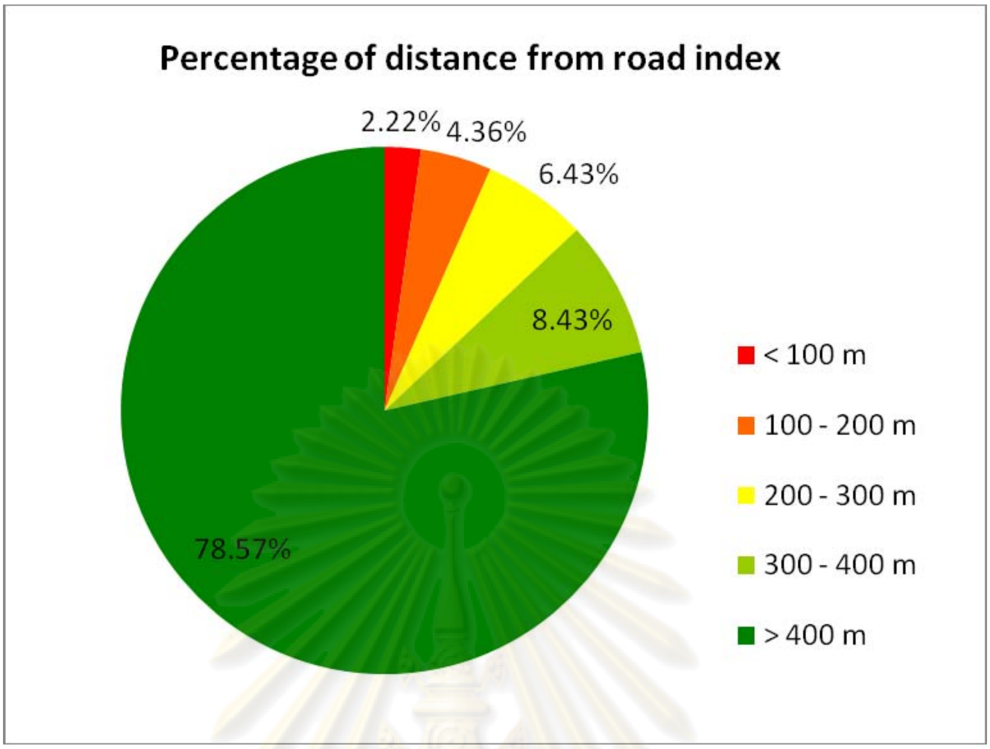

Figure 4-34 Percentage of distance from road index

- Distance from settlement

Forests which located near settlement areas are considered to be more fire risk areas. Due to the people who live in these areas, there is a higher possibility to create accidental fire. Moreover, some crowded settlements are located within the forest in the study area. That is the reason why it is interesting to study them. Distance from settlements were evaluated the third highest weight (Strino et al., 2007). In this case human plays an important role for the fire risk in the vegetation zones. From figure 4-35, the buffer zone range that was applied around the urban areas so close areas have high risk of fire.

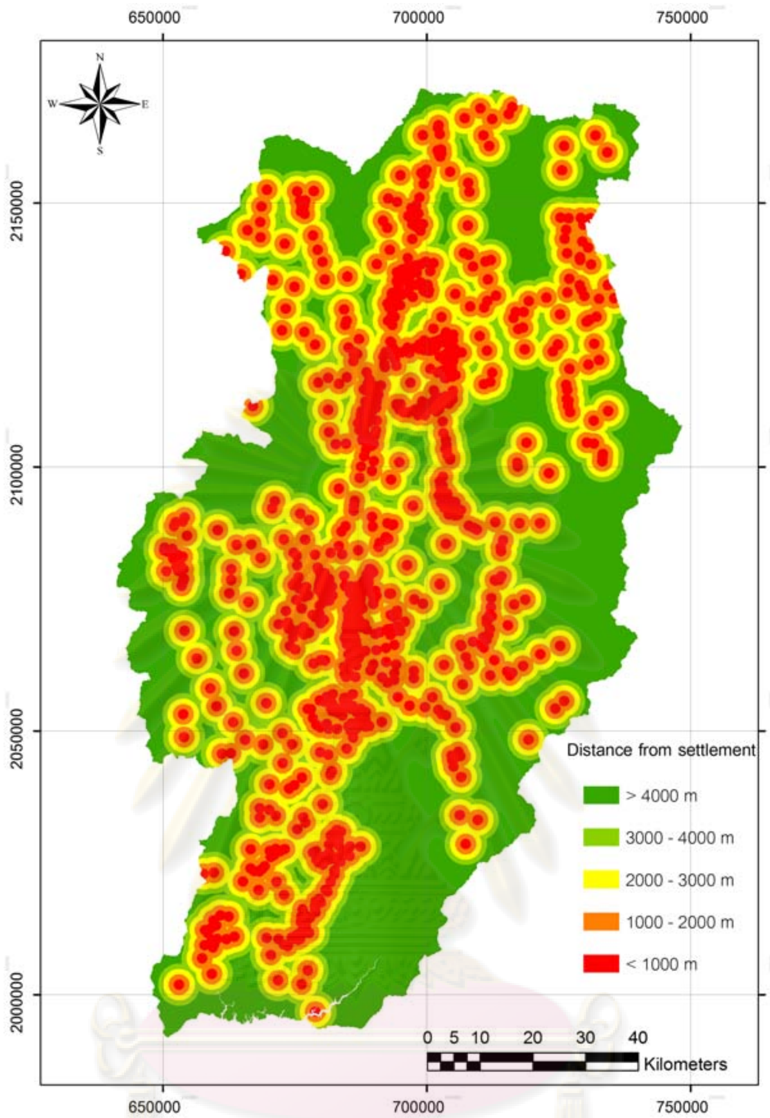

Figure 4-35 The map show distance from settlement in the study area

Table 4-16 Percentage of distance from settlement index

Distance from settlement	Area (Km^2)	Area (%)
> 4000 m	3829.97	2.22
3000 - 4000 m	1628.87	4.36
2000 - 3000 m	2319.17	6.43
1000 - 2000 m	2631.75	8.43
< 1000 m	1760.24	78.57
Total	12170.00	100.00

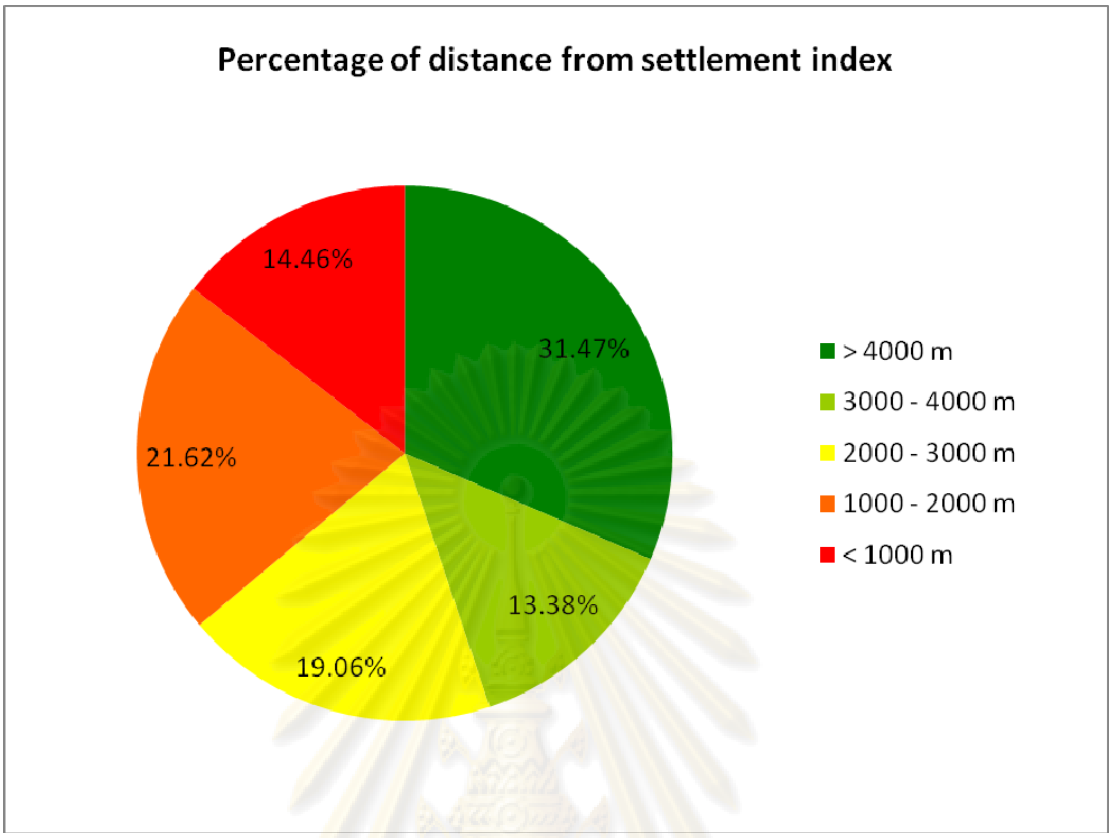

Figure 4-36 Percentage of distance from settlement index

The equation used in GIS analysis function to determine forest fire risk places can be shown below:

FRZ = 7*V + 5*(S+A) + 3*(DR+DU)…….............. (Equation 4-1)

In this equation,

FRZ = index of forest fire risk zones.

V = vegetation type with 5 classes.

S = the slope factor with 5 classes.

A = the aspect variable with 5 classes.

DR = the distance factor from road with 5 classes.

DU = the distance factor from settlement with 5 classes.

In Table 4-17, the weight of main parameters, namely vegetation, slope, aspect, distance roads and distance settlements were used in the above equation and were evaluated according to their relations with fire forest risk detection areas (Strino et al., 2007). GIS analysis function was used to combine the maps and develop functions to analyze those main parameters. Finally, the fire risk zone map was synthesized and produced.

Based on equation 4-1 , the five vector layers are converted into raster layers and in ArcGIS 9.2 software these layers are intregrated in map calculation function using weighted sum command in spatail analyst tool. The weighted sum function is done by overlaying several raster layers, multiplying each layer by their given weight and summing them together. After the process above, the final result fire risk base map appears (Figure 4-37). Based on the statistics of different weight classses, the map is reclassified into five areas as very low, low, moderate, high, and very high. The forest fire risk map shows in Figure 4-38.

Table 4-17 The main parameters, with its weight and resulting classes, that were used to analyze the fire rating risk classes (Strino et al., 2007).

Parameters	Weight	Classes	Factors	Fire Rating Classes
Vegetation	7	Very Dry	5	Very High
		Dry	4	High
		Moist	3	Medium
		Fresh-Like	2	Low
		Fresh	1	Very Low
Slope	5	> % 35	5	Very High
		% 35 – 25	4	High
		% 25 – 10	3	Medium
		% 10 – 5	2	Low
		< % 5	1	Very Low
Aspect	5	South	5	Very High
		West	4	High
		East	3	Medium
		North	2	Low
		Flat	1	Very low
Distance roads	3	< 100 m	5	Very High
		100 – 200 m	4	High
		200 – 300 m	3	Medium
		300 – 400 m	2	Low
		> 400 m	1	Very Low
Distance settlements	3	< 1000 m	5	Very High
		1000 – 2000 m	4	High
		2000 – 3000 m	3	Medium
		3000 – 4000 m	2	Low
		> 4000 m	1	Very low

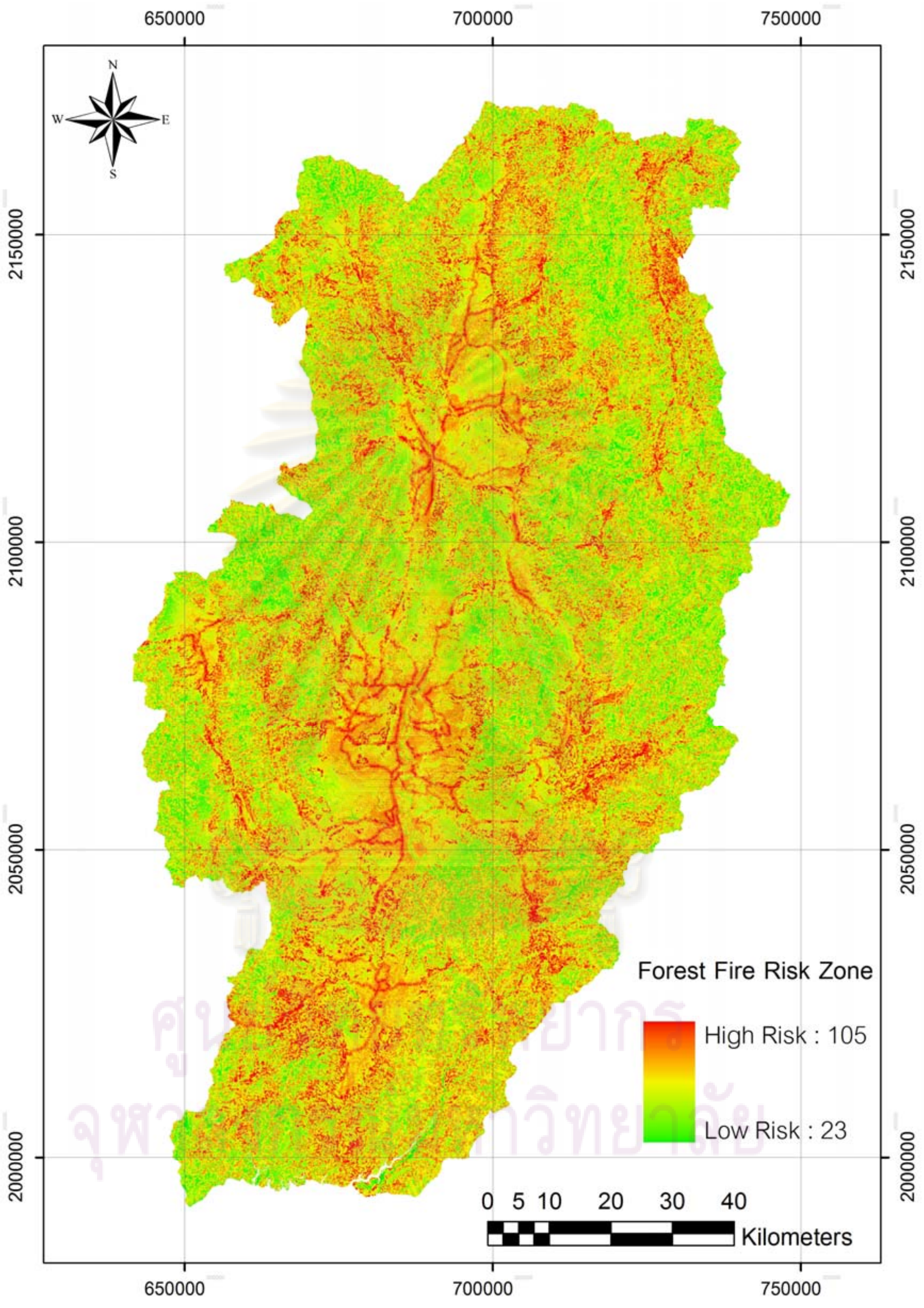

Figure 4-37 Forest fire risk map in upper Nan watershed (Strino’s parameter)

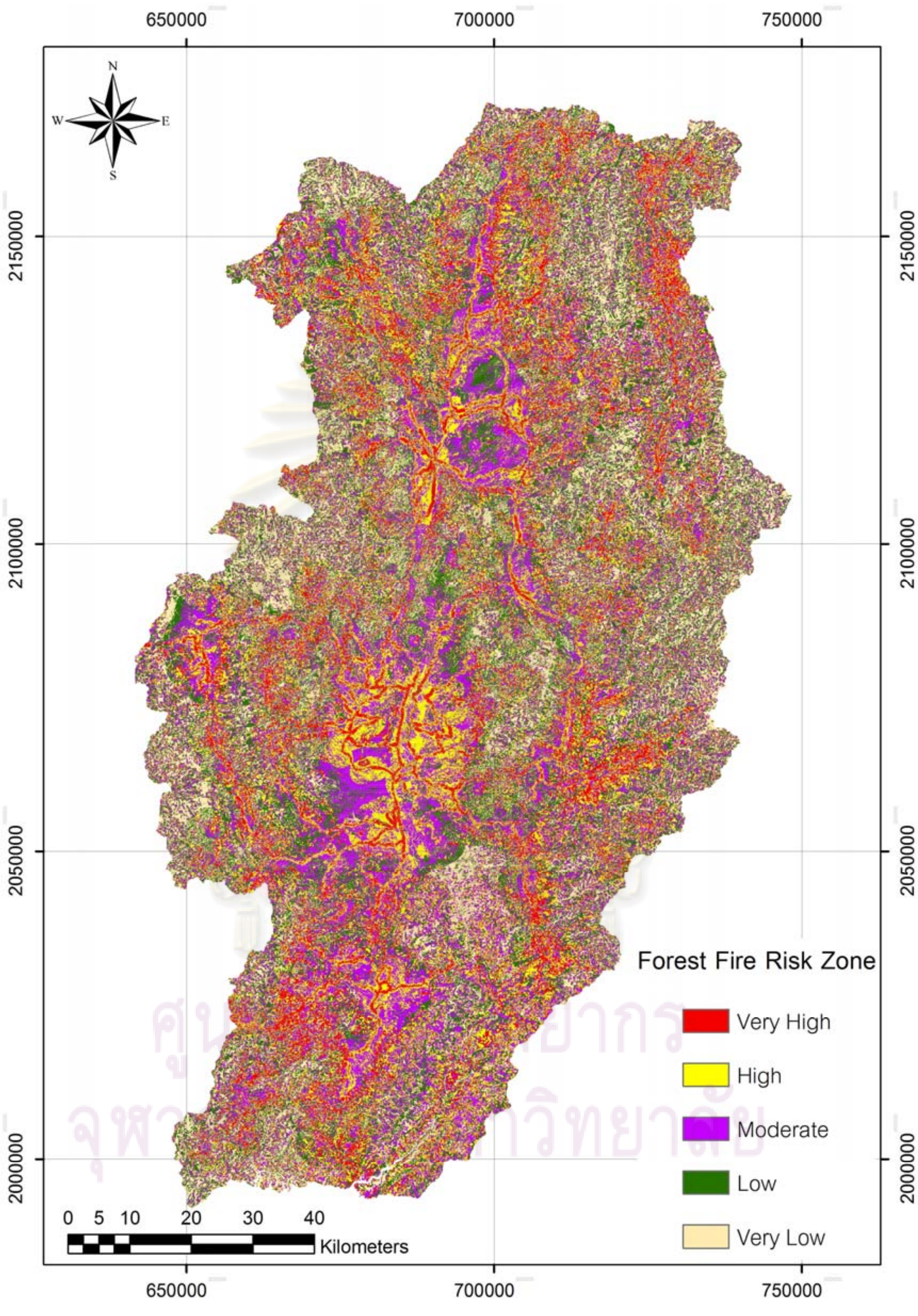

Figure 4-38 Forest fire risk map in upper Nan watershed

which is reclassified into 5 classes (Strino's parameter)

In the map calculation function the value ranges from 23-105. After reclassify using Jenks Natural Breaks method in ArcGIS 9.2 software, the areas under very low, low, moderate, high, and very high are 16.2%, 24.5%, 27.1%, 22%, and 10.2% respectively.(Figure 4-39)

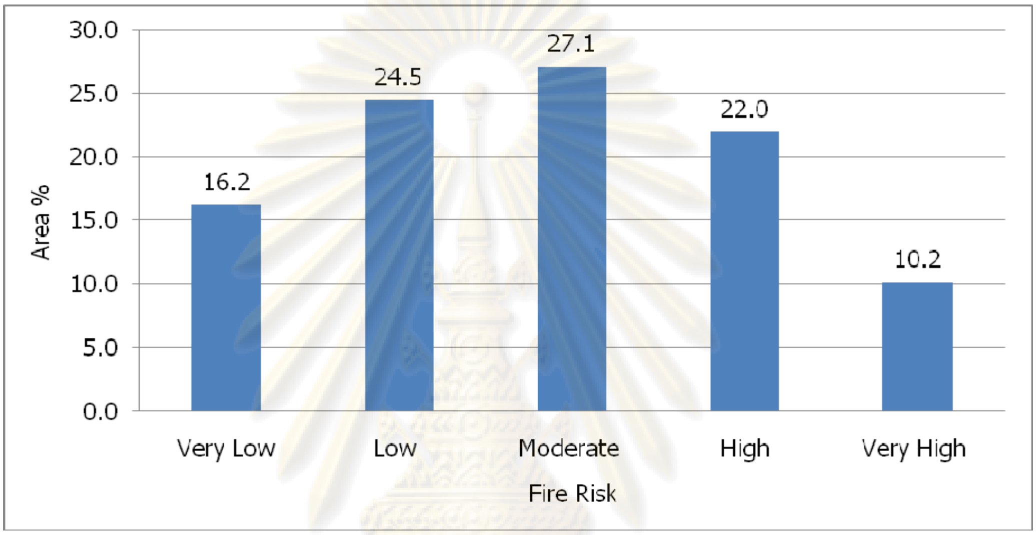

Figure 4-39 Graph shows fire risk area (Strino's parameter).

Table 4-18 The main parameters, with its weight and modified resulting classes, that were used to analyze the fire rating risk classes (Adapted from Strino et al., 2007).

Parameters	Weight	Classes	Factors	Fire Rating Classes
Vegetation	7	Very Dry	1	Very Low
		Dry	2	Low
		Moist	3	Medium
		Fresh-Like	5	Very High
		Fresh	4	High
Slope	5	> % 35	5	Very High
		% 35 – 25	2	Low
		% 25 – 10	3	Medium
		% 10 – 5	4	High
		< % 5	1	Very Low
Aspect	5	South	5	Very High
		West	2	Low
		East	3	Medium
		North	1	Very Low
		Flat	4	High
Distance roads	3	< 100 m	1	Very Low
		100 – 200 m	2	Low
		200 – 300 m	3	Medium
		300 – 400 m	4	High
		> 400 m	5	Very High
Distance settlements	3	< 1000 m	2	Low
		1000 – 2000 m	4	High
		2000 – 3000 m	5	Very High
		3000 – 4000 m	4	High
		> 4000 m	3	Medium

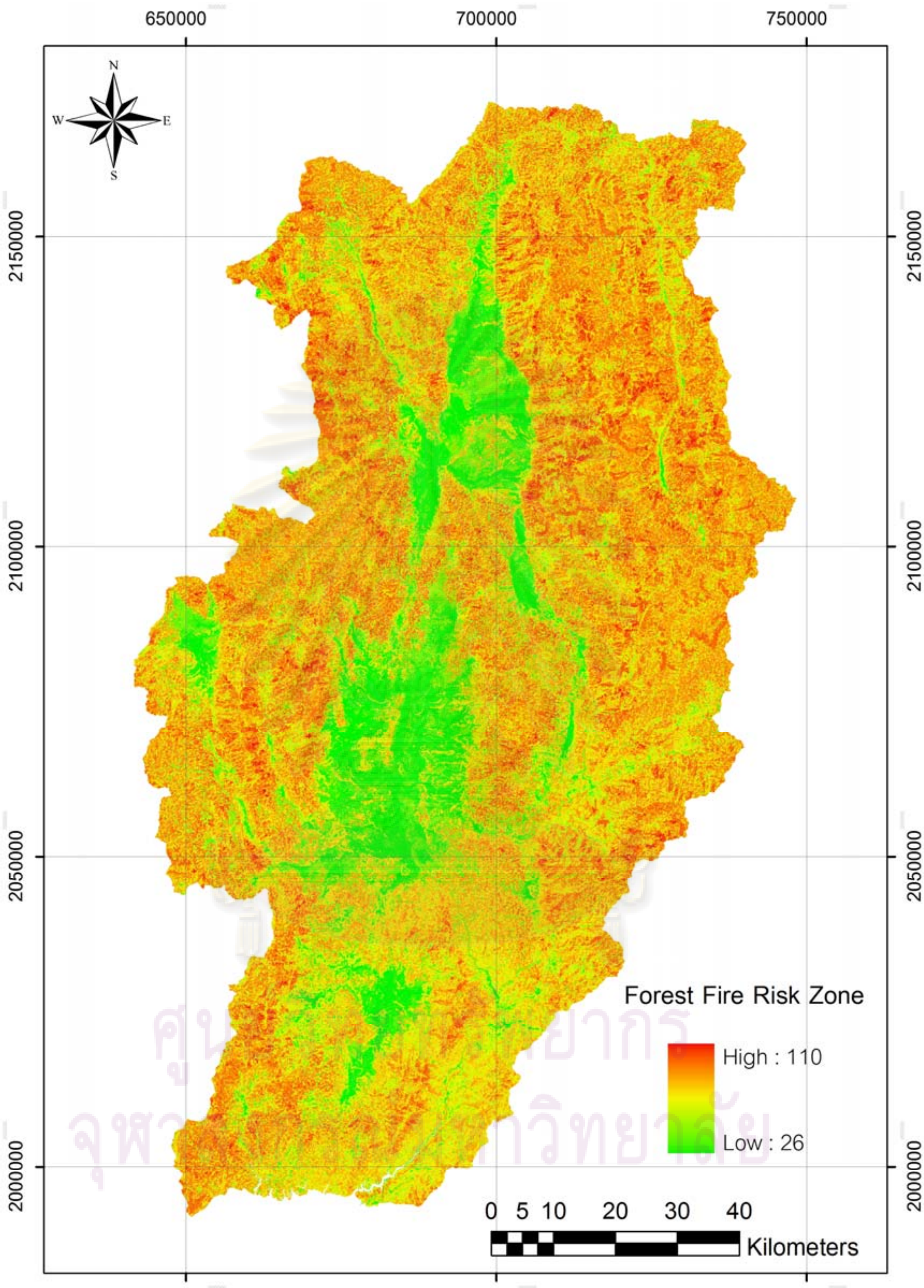

Figure 4-40 Forest fire risk map in upper Nan watershed (Parameter from this study)

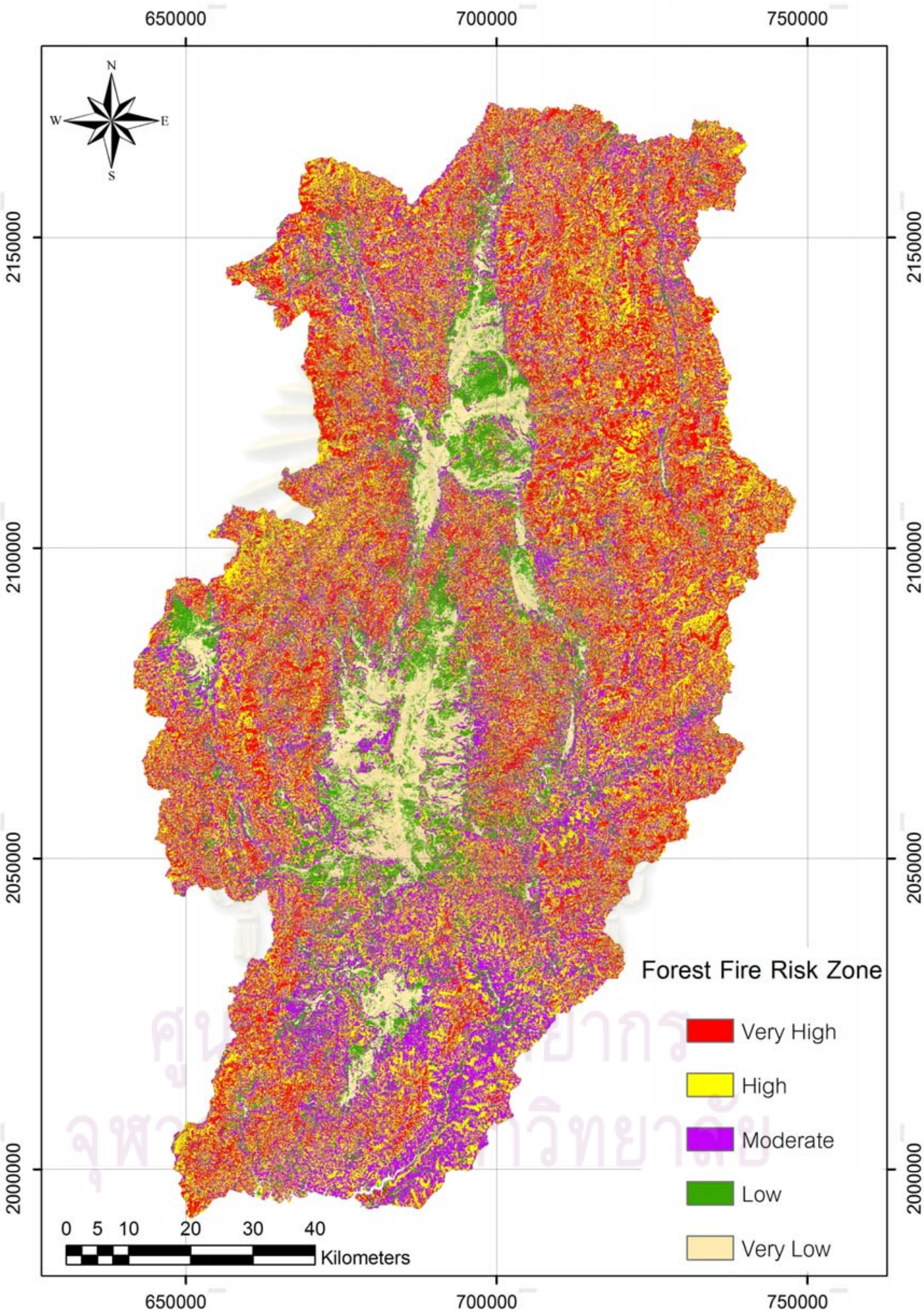

Figure 4-41 Forest fire risk map in upper Nan watershed

which is reclassified into 5 classes (Parameter from this study)

The criteria used for forest fire risk modelling in this research affirmed that vegetation is the most important factor in the modelling. As fuel is the main factor in the occurrence of fire the fuel or vegetation index has been given weight of seven. Slope and aspect is given weight of five. The roads and settlement index was given weight of three. The road and settelment are given the lowest weight because these act both as hazard and barrier to fire management.

As mention previously, the spatial relationships between burned scar occurrence locations and the significant forest fire influencing parameters were derived from the probability method. Later, these significant influencing parameters were used to modify the fire rating risk classes in order to analyze the forest fire risk zone (Table 4-18).

After modified the value of fire rating classes, the value in the map function calculation ranges from 26-110. The forest fire risk map shows in Figure 4-40. After reclassify, the areas under very low, low, moderate, high, and very high are 7.9%, 11.7%, 26.5%, 33.4%, and 20.5% respectively (Figure 4-41 and 4-42).

This forest fire risk map shows that very high and high risk areas are occurred in the high mountainous and steep topographic areas on both sides of the watershed. Very low and low risk areas are occurred in the flood plain area on the center of the watershed which the land cover are the urban and agricultural areas.

The final results from this research can be used as a spatial data for decision making in handling, monitoring, and controlling the forest fires in order to enhance the fire management efficiency. In the absence of a scale map temperature, rainfall moisture content, humidity and wind velocity of the study area, an attempt has been made to use the remote sensing technology and the GIS software to generate the forest fire risk map of the area.

Validation of the model and its operation will require much more input than what was available and discussed in this research. With limits options and time it was attempted to do justice to the fire risk modelling, the model has been attempted to validated within itself using the weights assigned to different layers.

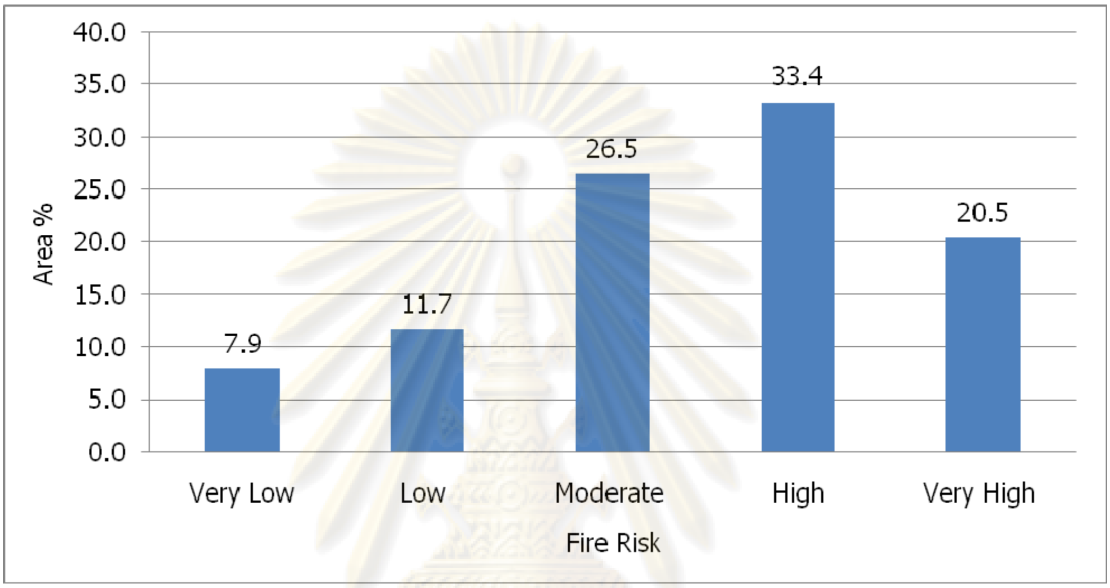

Figure 4-42 Graph shows fire risk area (Parameter from this study).

Moreover, the polygons of forest fire burned scar were used to overlain on both forest fire risk maps (Figure 4-43 and 4-44). The forest fire burned scars were grouped into 3 sizes, small size (the polygons which are less than 0.1 km^2), medium size (the polygons which are between 0.1 – 1 km^2) and large size (the polygons which are more than 1 km^2). The graph of forest fire patch size in each forest fire risk area calculated from Strino's parameter shows that there is no relation between the forest fire burned scars and the forest fire risk areas (Figure 4-45). However, the graph of forest fire patch size in each forest fire risk area calculated from the parameter in this study shows correlation between the forest fires burned scars and the forest fire risk areas (Figure 4-46).

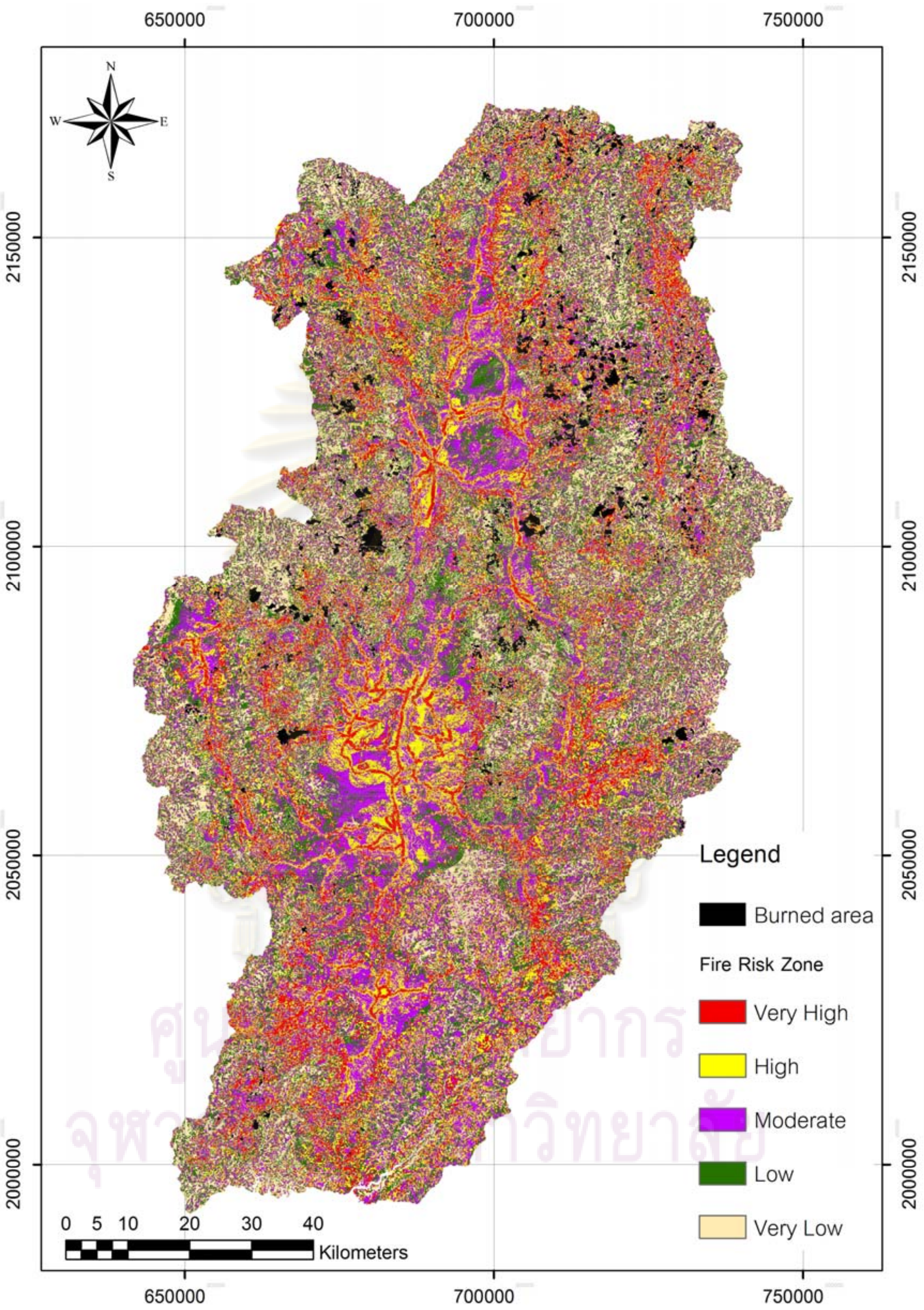

Figure 4-43 Burned scars overlain on forest fire risk map in upper Nan watershed (Strino's parameter)

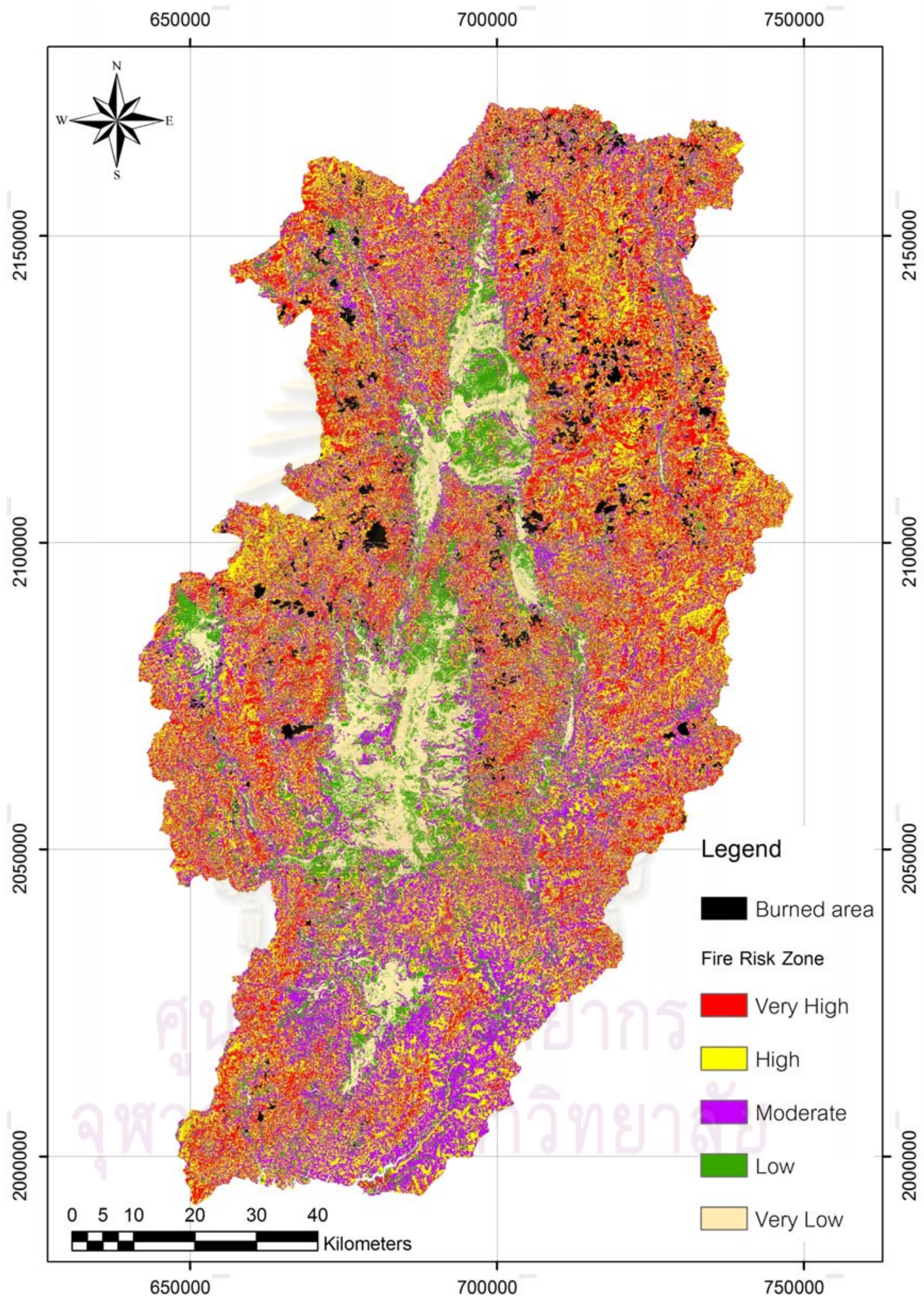

Figure 4-44 Burned scars overlain on forest fire risk map in upper Nan watershed (Parameter from this study).

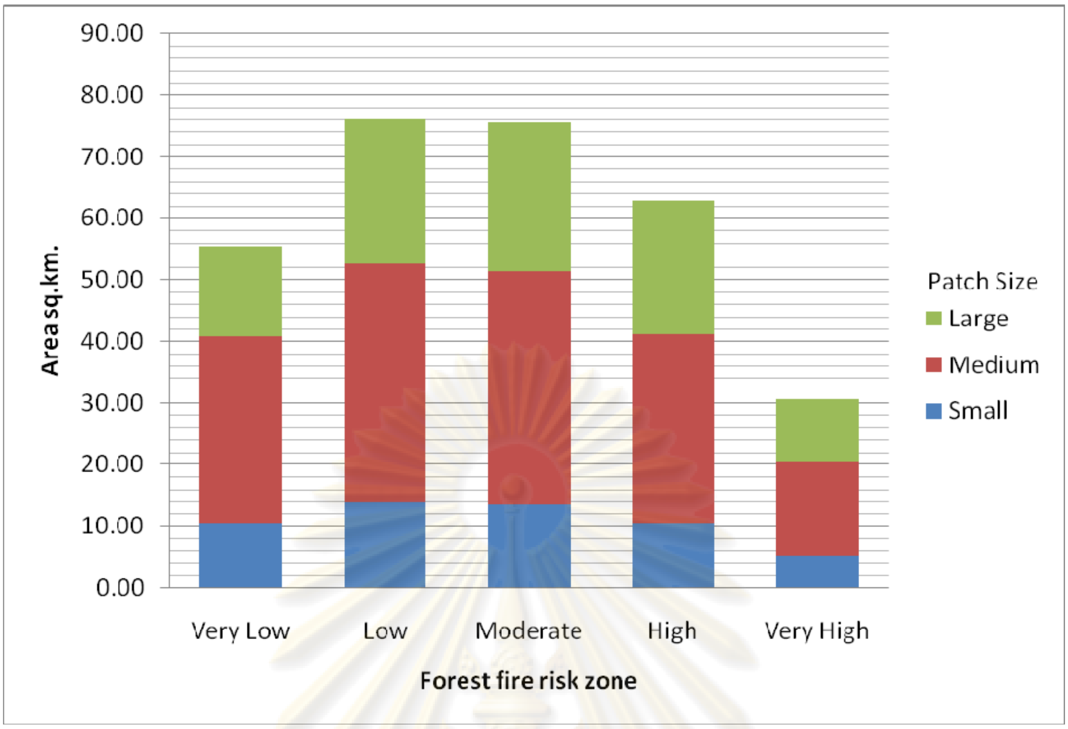

Figure 4-45 Graph shows forest fire patch size in each forest fire risk area

(Strino's parameter)

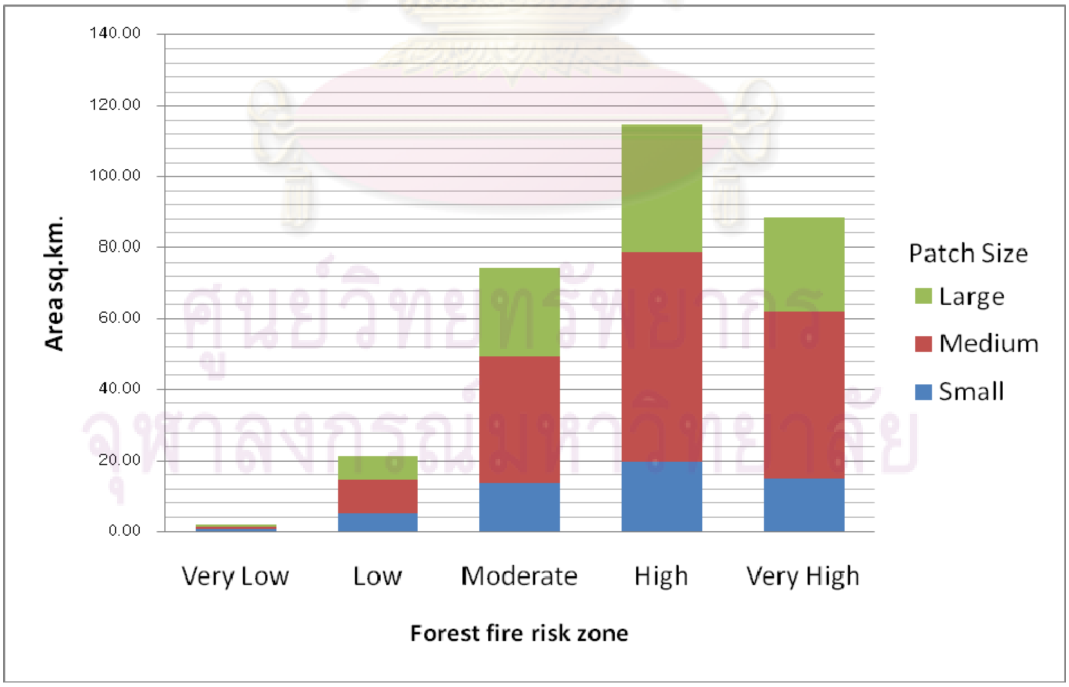

Figure 4-46 Graph shows forest fire patch size in each forest fire risk area

(Parameter from this study)

CHAPTER V

DISCUSSIONS AND CONCLUSIONS

5.1 Discussions

In this part, the results of the study methods as previously mentioned are discussed in three categories. Firstly, the forest fire susceptibility results are proposed and discussed. Secondly, the results from forest fire risks analysis are discussed. Finally the problems and recommendations in this research are discussed.

- Forest fire susceptibility.

In this research, a statistical approach to estimating the forest fire burn area using remote sensing technique and the GIS was performed. For the forest fire susceptibility analysis, the detected burn scar locations and the forest fire related database were constructed for the upper Nan watershed. Using the constructed database, forest fire susceptibility analysis was done by probability method. It is remarked that the probability method is simple, and the process of input, calculation and output could be understood easily. Moreover, there is no need to convert the database to any other format, as the large amount of data can be processed in the GIS environment quickly and easily.

The relationship of burn area and relevant parameters was analyzed for forest fire susceptibility assessment using the probability method and forest fire susceptibility map as mentioned above. In the upper Nan watershed, burn scar locations detected in multi-temporal satellite image as well as in field investigation were put into a GIS database. Besides, various maps were constructed from the burn area relevant parameters derived from the database as illustrated in Chapter 4.

The significant influencing parameters involved in the forest fire susceptibility analysis are slope, aspect, distance from road, distance from settlement, vegetation and land cover. Using the parameters above, probability method was applied to analyze the forest fire risk areas. The analyzed results were used to reconstruct the GIS database, then to maps.

- Forest fire risks analysis.

The forest fire susceptibility map and relevant maps as previously proposed in Chapter 4 might be of great help to planners and engineers for choosing suitable locations to implement developments in the upper Nan watershed. Besides, forest fire risk map that was reclassified into five areas as very low, low, moderate, high, and very high was also illustrated in Figure 4-41 as the forest fire risk map in the upper Nan watershed. It was noted that the very low to very high risk area were occurred here.

The causes of forest fire in the upper Nan watershed are numerous. Gatherers of non-timber products in forest start fire to clear litter, grass and undergrowth on the surface floor to facilitate access to the forest. In order to prepare agricultural land after harvesting or clear cutting of industrial plantations, local farmers usually start fire without any control over them.

The national fire management and science communities require remote sensing mapping and characterization of vegetation because remotely sensed data is relatively reliable, timely and cost effective. In this research Landsat imageries have been used to estimate forest cover and burn area that occurred after forest fire.

Accuracy assessment was performed based on the field data collected during the field investigation. This included data obtained from field survey and fire registered by the fire-fighting group of Nan forest fire control station. It was found that the composition of forest cover is changing in those areas where forest fire occurred.

- Problems and recommendations

There are some problems in carrying out this research. The 30 meters resolution of the satellite data prohibits the interpretation capabilities result in reducing the classification accuracy. Moreover, the presence of clouds in the study area is the limitation for the classification of forest fires in this study. It is recommended that multi-resolution data, such as IKONOS and SPOT can be also used. It is also recommended to acquire and analyze multitemporal satellite data to prepare historic forest fire maps. The analysis can show the origin, occurrence and extent of forest fire events.

The results from this research can be used as basic data to assist forest fire and forest management planning. Figure 5-1 is an example for the map in details that can be used to helps planning forest fire management in the specific area. The map shows the occurrences of forest fires in Tambon Sakad, Amphoe Pua, Changwat Nan during 1999-2007. The map also shows the increasing trends of forest fires from 1999 to 2007. In 1999, the forest fires occurred in the southern part of the study area, after that they moved to the eastern and northern part of the study area in 2001 and 2004. However, in 2007 most of the forest fires occurred in the eastern part of the study area. Moreover, it can be noticed that the sizes of forest fire polygons in each year are became larger.

For the research to be more generally applied, more forest fire data related such as temperature, rainfall, humidity and wind velocity that are not available in the study as well as the advance and specific methods will be needed to be used in detail for more accurate results in the future.

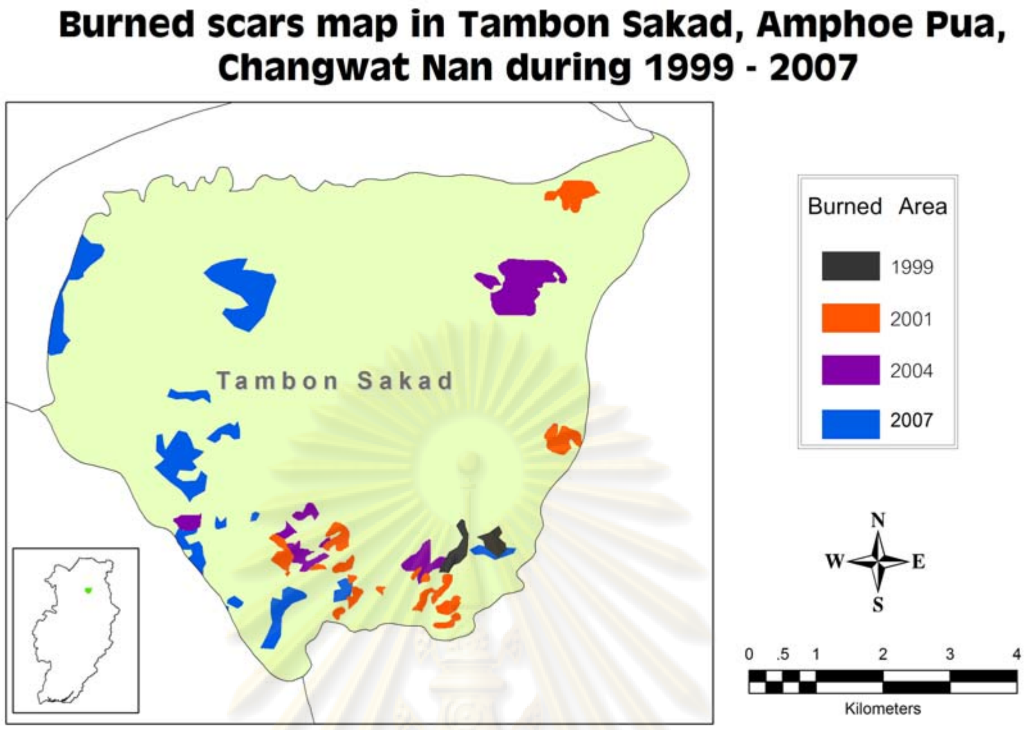

Figure 5-1 Burned scars map in Tambon Sakad, Amphoe Pua, Changwat Nan during 1999-2007.

5.2 Conclusions

In this research, three data input, which are thematic (GIS and remote sensing) data preparation, field investigation, and laboratory analysis were used to study the spatial pattern and dynamic behavior of forest fire in the upper area of Nan watershed during 1999 – 2007. Furthermore, the purpose is to analyze the parameters influencing the forest fire and associated forest fire occurrence during 1999-2007 and to determine the forest fire risk areas in upper Nan watershed in the upper Nan watershed, Changwat Nan, Northern Thailand.

The input data used for forest fire assessment consists of several data categories of spatial data from the available resources, digitizing from available maps, and prepared from image interpretation and field investigation data. Thematic maps of the input data produced in this thesis consist of vegetation, slope, aspect, distance from road, and distance from settlement. These input data were further used to analyze the forest fire risk by the statistic analysis.

The burn scars maps show a significant increase in the burn area in 2001 after that the burn areas were slightly decreased in 2004 and 2007. Furthermore, the sizes of forest fire polygons in 1999 are small but they became larger in 2001, 2004 and 2007. It could be noticed that most forest fire patched are distributed on high mountainous and steep slope that are mainly in the northern part of the study area. It was concluded from the burn scar map that most of the forest fires were occurred in Amphoe Pua (58.9 Km^2), Amphoe Mueang Nan (45.1 Km^2), Amphoe Bo Kluea (41.7 Km^2), Amphoe Charoem Phra Kiat (30.5 Km^2) and Amphoe Tha Wang Pha (25.8 Km^2). However, when focus on the burn areas that are expressed as a percentage of the total area, the high percentage were occurred in Amphoe Ban Luang (12.97%), Amphoe Pua (6.43%), Amphoe Bo Kluea (4.88%), Amphoe Mueang Nan (4.71%) and Amphoe Song Khwae (4.02%).

To investigate the parameters influencing the forest fire and associated forest fire occurrence, the relationship of burn areas and each relevant parameter was analyzed for forest fire susceptibility assessment using the univariant probability method and forest fire susceptibility map. A key assumption using this approach is that the potential (occurrence possibility) of burn area would be comparable to the actual frequency of burn area and relationships between each parameter are independent. In upper Nan watershed, burn scar locations detected from Landsat satellite image interpretation and field surveys were formed into a GIS database. Various maps were constructed from the forest fire relevant parameters derived from the database. The parameters involved in the forest fire susceptibility analysis are forest fire inventory of burn scar locations, slope, aspect, land cover, distance from road and distance from settlement. Using these parameters, probability method was applied to analyze the forest fire risk. The analyzed result was used to reconstruct the GIS database, and mapped. Furthermore, calculation of forest fire susceptibility was applied to analyze the forest fire risk area in the watershed.

Based on equation from Strino et al. (2007), the five layers are converted into raster layers and intregrated in map calculation function. After reclassify using Jenks Natural Breaks method in ArcGIS 9.2 software, the areas under very low, low, moderate, high, and very high are 16.5%, 39%, 24.2%, 15.1%, and 5.1%, respectively.

The significant forest fire influencing parameters derived from the probability method were used to modify the fire rating risk classes. . After reclassify, the areas under very low, low, moderate, high, and very high are 7.9%, 11.7%, 26.5%, 33.4%, and 20.5%, respectively. This forest fire risk map shows that very high and high risk areas are occurred in the high mountainous and steep topographic areas on both sides of the watershed. Very low and low risk areas are occurred in the flood plain area on the center of the watershed which the land cover are the urban and agricultural areas.

In recent years, GIS and Remote Sensing have emerged as a powerful tool in collaboration with multitemporal remote sensing data for studying and monitoring the impact of many environmental factors. Many government agencies now use a wide range of computer-based information systems to handle geographic parts of their business, especially mapping, by integrating spatial data collected from different sources, and in different formats, into GIS. In this way, it is possible to address the critical questions of how economics, meteorological, hydrological and other processes interact with geographically disposed natural resources like forests.

Because of its rich biological diversity, the Upper Nan Watershed forests are very important, and forest fires are the most significant factor that threatening them. Today, the concept of sustainable management of forest has changed considerably. Moreover, advanced forest management systems play a vital part in organizing, maintaining, accessing and reporting on all factors of forest information required to support management planning functions such as control, scheduling and monitoring resources for the future.

Forestry in Thailand has to change quickly to adapt to this new concept; however, there is still a significant gap between what is possible, in terms of knowledge and management from the new techniques such as remote sensing, and traditional forestry techniques. To reduce this gap is only possible if it is can be shown that digital remote sensing techniques are at least as accurate and economically viable as current operational tools, and that GIS can play a decisive role in the management and assessment stages of a forest management strategy. An integrated management system could have an important role in the planning, review and improvement of current methods, principally through better modelling.

Although in recent years technologies using GIS and remote sensing have greatly increased in Thailand, many of these GIS and remote sensing applications are not fully integrated with organization processes as well as being used to their greatest potential in resources analysis. Success will also require the government initiative in data management and in the integration of data flows within and between agencies. The results presented here suggest that co-operative forest management program that monitors assesses and reports on the long-term status, changes and trends in forest ecosystem health, based on the new technologies, should be initiated, developed and incorporated within the regional forest service or public sector.

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APPENDIX

Photographs illustrating locations of the field investigation

(sample locations referred to Figure 3-14, 3-15 and 3-16).

Tambon Pha Thong, Amphoe Tha Wang Pha, Changwat Nan.

Nan Forest Fire Control Station,Tambon Phu Kha, Amphoe Pua, Changwat Nan.

Tambon Phu Kha, Amphoe Pua, Changwat Nan.

Tambon Sila Phet, Amphoe Pua, Changwat Nan.

Tambon Uan, Amphoe Pua, Changwat Nan.

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Ms. Chanita Duangyiwa was born in Chainat, Thailand on November 4, 1983. In 2006 she received a Bachelor of Arts degree in Geography with second class honors from Department of Geography, Faculty of Arts, Chulalongkorn University. After then she entered the Earth Sciences program, Department of Geology, Faculty of Science, Chulalongkorn University for a Master of Science degree study.