

BURNED AREA ASSESSMENT USING BAMS: A CASE STUDY OF UPPER NORTHERN REGION, THAILAND

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Abstract

Currently, the burned area statistics of Thailand use only fire suppression data from forest fire control station reports. However, forest fire phenomena are varied and some places are difficult to assess with ground surveys. The specific objectives of the study are: (1) to identify burned areas using burned area mapping software (BAMS) and assess the accuracy and (2) to quantify and analyze the characteristics of the burned areas of the Upper Northern region of Thailand. BAMS is supervised burned area mapping software based on Landsat data and two-phase supervised classification by using multi-temporal differences (pre- and post-fire scenes) of spectral indices. The research methodology consisted of 4 components comprising (1) data collection and preparation, (2) burned area extraction using BAMS, (3) accuracy assessment, and (4) overlay analysis.

The results showed that in 2014, March had the most burned areas (1550.83 km²), followed by April (509.14 km²) and February (296.06 km²). Overall accuracy for 2 Landsat scenes, Path 130 Row 47 (Date 13 March 2014) and Path 131 Row 47 (Date 20 March 2014), with Department of National Parks, Wildlife and Plant Conservation (DNP) ground fire records in March 2014 were 93.23% and 90.72%, respectively. Based on overlay analysis, Chiang Mai had the highest total of burned areas (511.96 km²) followed by Lampang (466.92 km²) and Mae Hong Son (400.28 km²). In addition, there were 31 of 32 national parks affected by forest fires in 2014, the exception being Si Satchanalai National Park. The top 3 national parks which were most affected by forest fires were Op Luang, Mae Ping, and Mae Yom. Likewise, there were 21 of 22 wildlife sanctuaries affected by forest fires in 2014, the exception being Lamnam Nan Fang Khwa

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Wildlife Sanctuary. The top 3 wildlife sanctuaries which were most affected by forest fires were Lumnai Pai, Salawin, and Tham Chao Ram. According to the forest land use data in 2000 of the Royal Forest Department (RFD), the burned areas in 2014 inside the forest areas totaled 1569.52 km² or 66.62% and outside the forest areas totaled 786.51 km² or 33.38%. The types of forest most affected by fire were mixed deciduous forest and dry dipterocarp forest. The results from the study demonstrate that BAMS is suitable for burned area mapping in Thailand. Therefore, the DNP and the RFD under the Ministry of Natural Resources and Environment should apply BAMS as an operational tool to obtain annual burned area maps from Landsat data after the end of the fire season.

Keywords: Forest fire, burned area assessment, burned area mapping software (BAMS), Landsat data, Upper Northern region, Thailand

Introduction

Forest fires are one of the greatest disturbance factors in ecosystems, as severe economic, ecologic, and atmospheric effects are produced. It is very important to know the location of the burned areas at the end of the fire season to evaluate the damage and to plan conservation strategies to avoid deforestation and erosion processes (Bastarrika, 2014). In Thailand, forest fires occur annually during the dry season from November to April with its peak in March. Fires, which are mostly classified as surface fires, mainly take place in dry dipterocarp forest, mixed deciduous forest, and forest plantations. Almost all forest fires in Thailand are man-made, primarily started by rural settlers who live in or adjacent to the forests. The main activities that cause forest fires include the gathering of non-timber products, spreading of agricultural debris burning, hunting, and carelessness (Akaakara, 2000). The Upper Northern region of Thailand is the area most affected by forest fires, both in terms of occurrence statistics and the impact of fire and smoke. The statistics for forest fire occurrences of Thailand between 2012 and 2014 show that the areas damaged by fire in the Upper Northern region covered 24.22 km², 39.06 km², and 30.56 km², respectively. The ranking for burned areas in 9 provinces of the Upper Northern region is Chiang Mai, Mae Hong Son, Lampang, Lamphun, Phrae, Nan, Chiang Rai, Uttaradit, and Phayao,

respectively. However, these statistics were only collected from the fire suppression reports of the (Department of National Parks, Wildlife and Plant Conservation (DNP) (2015). In addition, most of the burned areas are mountainous land and are located nearby neighboring countries, namely Myanmar and Laos and, moreover, are difficult to assess by ground survey (Akaakara, 2000). Nonetheless, the Upper Northern region of Thailand currently faces annual air emissions from forest fires during January to April which impact on the respiratory health and visibility of the people. The Pollution Control Department (PCD) reported that the particle matter with a size smaller than 10 microns, or PM₁₀, was higher than the standard threshold of 120 micrograms per cubic meter found in Chiang Rai in March 2012 with the highest value of 471 micrograms per cubic meter. Meanwhile, the highest values of PM₁₀ occurred in March of 2013 and 2014 in Mae Hong Son with values of 428 and 324 micrograms per cubic meter, respectively (PCD, 2012; 2013; 2014). This evidence shows the serious effect of wildfire on the health of the people.

The assessment of areas burned by forest fires is a very important task for wildfire management. Samran (1999) claimed that the areas burned by forest fires were firstly estimated using helicopter surveys in 1985 and 1994. It was reported that the forest

areas burned by fires were about 35351.11 km² in 1985 and 7636.48 km² in 1994. This report did not provide information about locations or maps of the burned areas.

Later, the Forest Fire Control Office and Forest Research Office of the Royal Forest Department (RFD) established an ad-hoc project for assessing burned areas between 1999 and 2001 using remote sensing and GIS technologies. Under this project, Landsat Thematic Mapper (TM) data were firstly geometrically corrected and then composite image maps were produced at 2 different scales: 1:250000 for the preliminary location of burned areas and 1:50000 for the visual interpretation of the burned areas. Finally, the burned areas were manually digitized to establish GIS data for assessing and mapping the burned areas of the country (Ongsomwang *et al.*, 1999; 2000; 2001). They reported that the areas of burned forest in Thailand in 1999, 2000, and 2001 were 2934.61 km², 933.24 km², and 761.89 km², respectively. They found that the results could provide more reliable information of the burned areas with maps than the estimation by helicopter survey. However, the step-by-step work process was time consuming. After these time periods, the burned areas were estimated using forest fire records by field surveys of the Forest Fire Control Office (DNP, 2015).

Bastarrika *et al.* (2011) and Bastarrika *et al.* (2014) developed a new supervised burned area mapping software based on Landsat data named BAMS (Burned Area Mapping Software). The tool is built from standard ArcGIS libraries. It computes several of the spectral indexes that most commonly used in burned area detection and implements a two-phase supervised strategy to map areas burned between two Landsat multitemporal images. The only input requires from the user is the visual delimitation of a few burned areas, from which burned perimeters are extracted. After the discrimination of burned patches, the user can visually assess the results, and iteratively select additional sampling burned areas to improve the extent of the burned patches. The final result of the BAMS program is a polygon vector layer

containing three categories: (a) burned perimeters, (b) unburned areas, and (c) non-observed areas. Moreover, the most advantage of BAMS is that it can be a tool to generate semi-automatically burned area perimeters using Landsat data (TM, ETM+ and OLI/TIRS sensors). Bastarrika *et al.* (2014) mentioned that more than 25 fire researchers had used the BAMS as a tool for burned area mapping in diverse parts of the world.

Argañaraz *et al.* (2015) applied BAMS to produce burned area map over 82 Landsat TM and ETM+ image in Argentina between 1999 and 2011. The study found that the producer's accuracy ranged from 88% to 97% and user's accuracy ranged from 71% to 96 %. In addition, the burned area product of BAMS was also used to test the performance of global burned area products, such as the study of Nogueira *et al.* (2017). They used burned area product of BAMS to evaluate the ability of two global products: MODIS MCD45A1 and ESA FIRE_CCI (Fire Climate Change Initiative) for the 2002–2009 time period. Herewith, they found that global burned area products provided underestimate total burned area as they missed small fires and burned patch areas. Likewise, Padilla *et al.* (2011) used burned area extracted by BAMS as reference data to validation three different global multi-annual burned area products (GlobCarbon, MCD45 and L3JRC) from 2000 to 2006 in three study areas situated in Brazil, Canada and Portugal. They found that the MODIS product produced better results than L3JRC and Globcarbon, with higher precision and accuracy. Meanwhile, Pleniou *et al.* (2012) applied BAMS to reconstruct the fire history of Attica region, Greece based on a series of Landsat images acquired from 1984 to 2011. The results showed that the fire scar perimeters using BAMS were captured with high accuracy. Regression modeling showed that the differences between the area burned estimated from satellite data and that recorded by the forest service can be explained about 86.3% of the variance.

Unfortunately, BAMS has not been applied to extract burned area in Thailand. Therefore, main objective of the study are (1) to extract burned area using BAMS and its accuracy assessment and (2) to quantify and analyze the characteristic of the burned areas in provincial boundaries, protected forest area, and its relationship with forest types of the Upper Northern region of Thailand. The result of the study can enhance the efficiency of burned area assessment and provide basic required information for forest fire management in Thailand.

Materials and Methods

Study Area

The study area covers 9 provinces in the Upper Northern region of Thailand including Mae Hong Son, Chiang Rai, Chiang Mai, Phayao, Lam Pang, Lamphun, Phrae, Nan, and Uttaradit provinces. It situates between latitudes $17^{\circ} 09' 18''$ N and $20^{\circ} 28' 23''$ N and between longitudes $97^{\circ} 20' 36''$ E and $101^{\circ} 02' 26''$ E. The elevation ranges from 40 to 2565 m above mean sea level. It covers area of 96293.05 km² (Figure 1). In 2014, population is about 6169843. A large part of the Upper Northern region of Thailand is covered by mountains and hills with forests. Minority ethnic hill tribe villages dot many parts of the hills. The land use and land cover type in 2011 of Land Development Department (LDD) shows 62.79% covered by

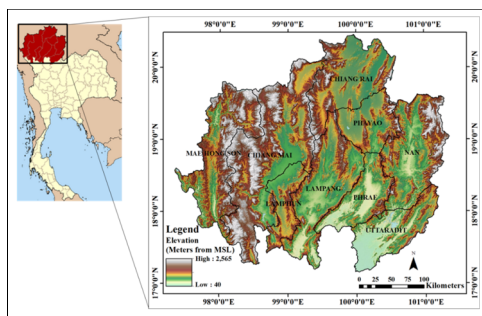


Figure 1. Map of the study area

forest land and 21.83% is an agricultural land. The majorities of forest types are deciduous forest (60.59%) and evergreen forest (34.99%).

Research Methodology

The research methodology and its workflow consists of 4 components: (1) data collection and preparation; (2) burned area extraction using BAMS, (3) accuracy assessment, and (4) overlay analysis (Figure 2).

Data Collection and Preparation

Two main types of data collection and preparation for burned area extraction using BAMS were Landsat data and ground fire survey report of the DNP. Basic information of 36 scenes of Landsat 8 OLI/TIRS in 2014 and its application under BAMS are summarized in Table 1. Meanwhile, ground fire records of the DNP in March 2014 and their attributes (easting and northing coordinates, date, time, place, burned area, and causes of fire), which are converted to GIS database as Shape file format, were here applied to validate the extracted burned area over two main scenes of Landsat data, Path 130 and Row 047 (13 March 2014) and Path

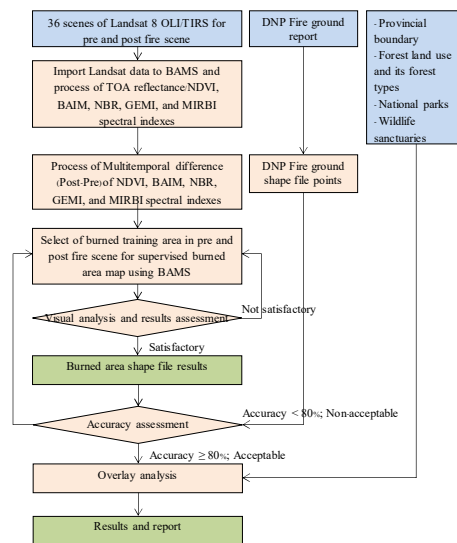


Figure 2. Schematic workflow of research methodology

Table 1. List of Landsat 8 data in this study

No.	Path	Row	Date	Fire development stage	Data source
1	129	047	17 Januray2014	Pre-fire	USGS
2	129	047	18 February 2014	Pre-fire and post-fire	USGS
3	129	047	6 March 2014	Pre-fire and post-fire	USGS
4	129	047	23 April 2014	Post-fire	USGS
5	129	048	17 January 2014	Pre-fire	USGS
6	129	048	18 February 2014	Pre-fire and post-fire	USGS
7	129	048	6 March 2014	Pre-fire and post-fire	USGS
8	129	048	23 April 2014	Post-fire	USGS
9	130	046	24 January 2014	Pre-fire	USGS
10	130	046	9 February 2014	Pre-fire and post-fire	USGS
11	130	046	13 March 2014	Pre-fire and post-fire	USGS
12	130	046	14-Apr-2014	Post-fire	USGS
13	130	047	24 January 2014	Pre-fire	USGS
14	130	047	9 February 2014	Pre-fire and post-fire	USGS
15	130	047	13 March 2014	Pre-fire and post-fire	USGS
16	130	047	14 April 2014	Post-fire	USGS
17	130	048	24 January 2014	Pre-fire	USGS
18	130	048	9 February 2014	Pre-fire and post-fire	USGS
19	130	048	13 March 2014	Pre-fire and post-fire	USGS
20	130	048	14 April 2014	Post-fire	USGS
21	131	046	31 January 2014	Pre-fire	USGS
22	131	046	16 February 2014	Pre-fire and post-fire	USGS
23	131	046	20 March 2014	Pre-fire and post-fire	USGS
24	131	046	21 April 2014	Post-fire	USGS
25	131	047	31 January 2014	Pre-fire	USGS
26	131	047	17 February 2014	Pre-fire and post-fire	USGS
27	131	047	20 March 2014	Pre-fire and post-fire	USGS
28	131	047	21 April 2014	Post-fire	USGS
29	131	048	31 January 2014	Pre-fire	USGS
30	131	048	18 February 2014	Pre-fire and post-fire	USGS
31	131	048	20 March 2014	Pre-fire and post-fire	USGS
32	131	048	21 April 2014	Post-fire	USGS
33	132	047	6 January 2014	Pre-fire	USGS
34	132	047	7 February 2014	Pre-fire and post-fire	USGS
35	132	047	11 March 2014	Pre-fire and post-fire	USGS
36	132	047	28 April 2014	Post-fire	USGS

131 and Row 047 (5 April 2014) in this study. In addition, GIS dataset included provincial boundary, forest protected area and forest land use data and its forest type in 2000 of the RFD were collected to quantify and analyze the characteristic of the burned areas in the Upper Northern region of Thailand.

Burned Area Extraction using BAMS

The burned area extraction using BAMS as suggested by Bastarrika *et al.* (2014) was divided into 5 main steps included (1) generation of reflectance data, (2) computation of burned

area spectral indices, (3) temporal composites and process of multitemporal difference of spectral indices, (4) select burned training area in pre and post fire scene for supervised burned area mapping, and (5) visual analysis and results - assessment. Summaries of each step based on Bastarrika *et al.* (2014) suggestion are as follows:

Step 1 Generation of Reflectance Data

Digital data of Landsat 8 (pre-fire and/or post-fire) were firstly imported to BAMS scene by scene, and they were converted to

TOA reflectance value using following equation:

$$\rho\lambda = (M\rho \cdot Qcal + A\rho)/\cos\theta_s, \quad (1)$$

where:

$\rho\lambda$ = TOA planetary reflectance, without correction for solar angle.

$M\rho$ = Band-specific multiplicative rescaling factor from the metadata

$Qcal$ = Quantized and calibrated standard product pixel values (DN)

$A\rho$ = Band-specific additive rescaling factor from the metadata

θ_s = Solar zenith angle

Step 2 Computation of Burned Area Spectral Indices

Under this step, the most common spectral indices in burned area studies were calculated under BAMS included NDVI, BAIM, GEMI, NBR, and MIRBI using the following equations.

(a) Normalized Difference Vegetation Index (NDVI) (Rouse *et al.*, 1974) as:

$$NDVI = (\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED}) \quad (2)$$

(b) Burned Area Index Modified (BAIM), (Martín *et al.*, 2005) as:

$$BAIM = 1/((\rho_{NIR} - 0.05)^2 + (\rho_{SWIRL} - 0.2)^2) \quad (3)$$

(c) Global Environmental Monitoring Index (GEMI), (Pinty and Verstraete, 1992) as:

$$GEMI = \eta(1 - 0.25\eta) - (\rho_{RED} - 0.125)/(1 - \rho_{RED}) \quad (4)$$

(d) Normalized Burned Ratio (NBR), (Key and Benson, 1999) as:

$$NBR = (\rho_{NIR} - \rho_{SWIRL})/(\rho_{NIR} + \rho_{SWIRL}) \quad (5)$$

(e) Mid-Infrared Burned Index (MIRBI), (Trigg and Flasse, 2001) as :

$$MIRBI = 10 \rho_{SWIRL} - 9.8 \rho_{SWIRS} \quad (6)$$

where:

η is $(2(\rho_{NIR}^2 - \rho_{RED}^2) + 1.5\rho_{NIR} + 0.5\rho_{RED}) / (\rho_{NIR} + \rho_{RED} + 0.5)$,

ρ_{RED} is Red reflectance,

ρ_{NIR} is Near infrared reflectance,

ρ_{SWIRS} is Short wave infrared short reflectance (wavelength center in 1.6 μm),

ρ_{SWIRL} is Short wave infrared long reflectance (wavelength center in 2.2 μm).

These spectral indices represent the most important bi-spectral spaces for burned area mapping consisting of NIR/SWIR (BAIM and NBR), Long SWIR/ Short SWIR (MIRBI), and Red/NIR (GEMI and NDVI). In order to avoid floating variables, the variables NBR, MIRBI, GEMI, and NDVI were created in 16-bits bands by applying a scaling factor of 10000 while the BAIM is truncated directly to an integer number (Bastarrika *et al.*, 2014).

Step 3 Temporal Composition and Processing of Multitemporal Difference of Spectral Indices

Two temporal composites were created in the process: one minimizes the NBR index, which aims to identify the most affected burned areas observed at each time frame of the series. This criterion creates the post-fire image of the time series. The second criterion maximizes the NDVI index, and aims to identify the time frame when each pixel is less affected by fire. The final composite is considered as the pre-fire image of the time series. Herein, difference value of post fire scene and pre fire scene of spectral indices for burned area were extracted including $\Delta BAIM$, ΔNBR , $\Delta MIRBI$, $\Delta GEMI$, and $\Delta NDVI$.

Step 4 Burned Area Mapping Supervised Methodology

Under this step, BAMS applied 10 spectral variables (the post-fire BAIM, NBR, MIRBI, GEMI, and NDVI indexes, plus the

temporal differences of those five indexes) to create threshold values for burned area extraction. For the spectral indexes NDVI, GEMI, and NBR, the fire decreases the pre-fire value, so the software sets a maximum value (the lower the value, the higher the probability of being burned). For BAIM and MIRBI, where the fire increases their pre-fire value, a minimum value is set (a higher value indicates higher probability of being burned). Herein, two independent sets of criteria are defined from burned training areas, one for the seed phase and another for the second phase. For each, the minimum of all the samples are retained for MIRBI and BAIM variables, whereas the maximum values are extracted for the rest (NDVI, GEMI, and NBR). In principle, the thresholds extracted from the two user-defined training areas are applied with the logical operation “AND”.

Step 5 Visual Analysis and Results Assessment

After the burned samples had been selected, the BAMS software automatically extracted the threshold values for both phases and applied the burned area mapping algorithm, adding the result as shape file format into the Table of Content of ESRI ArcGIS software. In this step, the result should be visually assessed before deciding whether more training areas are needed to complete the burned area mapping by

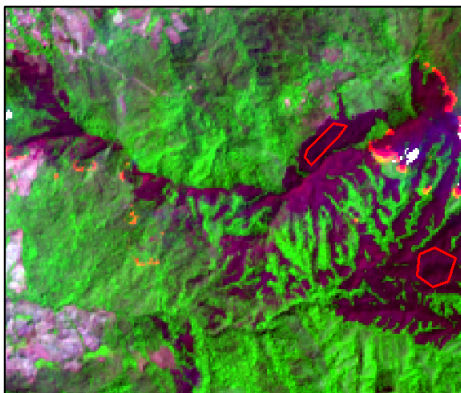


Figure 3. Training area selection for burned area extraction using BAMS

extracting new thresholds values from different iterations

Accuracy Assessment

The DNP ground fire records in March 2014 were here applied for accuracy assessment over two Landsat scenes: Path 130 Row 47 (Date 13 March 2014) and Path 131 Row 47 (Date 20 March 2014). In practice, the DNP ground fire points were overlaid the extracted burned area for calculating percent of correctness. Herein, the acceptance accuracy of burned area extraction is equal or more than 80%.

Assessment of Burned Area

Under this step, the extracted burned areas in 2014 were applied to quantify burned areas in provincial boundary, forest protected area (national parks and wildlife sanctuaries) and to characterize burned area with forest land use data and its forest types in 2000 using overlay analysis.

Results and Discussion

Major results according to objectives are here described and discussed include (1) burned area extraction using BAMS, (2) accuracy assessment of burned area mapping, (3) burned area assessment in provincial boundary, (4) burned area assessment in national park, (5) burned area assessment in wildlife sanctuary and (6) burned area in 2014 and forest land use data in 2000.

Burned Area Extraction Using BAMS

Figure 3 shows the appearance of burned area for training area identification by visual interpretation at burned area mapping supervised step under BAMS. Herewith, the color combination with bands 7 (SWIR), 5 (NIR), and 4 (Red) as RGB of Landsat 8 image shows active fire as orange to red, heavy burned area as dark magenta and light burned area as light magenta. In addition, stage of fire development of Landsat image which includes pre-fire, active fire and post-fire scenes are displayed in Figure 4. This

information is applied to select an appropriate scene for burned area extraction as summary in Table 1.

In practice, training areas of burned area from pre-fire and post-fire scenes are applied to extract thresholding values of spectral indices for burned area mapping in two phases. The result of thresholding value for burned area extraction of two main Landsat scenes (130-047, 131-047) in the study area is reported in Table 2. Herein, thresholding values of spectral indices are automatically calculated from first phase to second phase to extract burned area map. Figure 5 shows an example of multi-temporal change of burned area using BAMS from pre-fire and post-fire

scenes while an example of small and large patches of burned area extraction using BAMS are shown in Figure 6. Results of burned area assessment in 2014 of the Upper Northern region, Thailand in February, March and April are summarized in Table 3 while the distribution of burned area is displayed in Figure 7. It was found that the burned area mostly occurred in March with area of 1550.83 km² and followed by April and February with burned area of 509.14 km² and 296.06 km², respectively. The total burned area in the Upper Northern region in 2014 is 2356.03 km² with proportion of 12.57% in February, 65.82% in March and 21.61% in April.

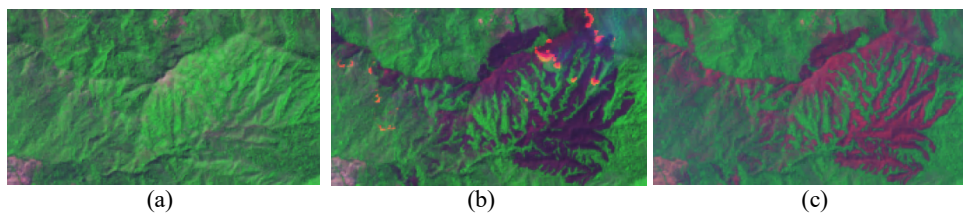


Figure 4. Development of fire: (a) pre-fire: (25 February 2014), (b) active fire: (13 March 2014), and post-fire: (29 March 2014)

Table 2. Threshold values extraction using supervised training area of two-phase algorithm

Scene-Year	First phase	Second phase	Remark
130047-2014	BAIM ≥ 42 and Δ BAIM ≥ -32 and NBR $\leq 2,736$ and Δ NBR ≤ 722 and NDVI $\leq 3,347$ and Δ NDVI ≤ 699 and GEMI ≤ 729 and Δ GEMI ≤ 161 and MIRBI $\geq 15,321$ and Δ MIRBI $\geq -1,725$	BAIM ≥ 47 and Δ BAIM ≥ -17 and NBR $\leq 2,463$ and Δ NBR ≤ 708 and NDVI $\leq 2,779$ and Δ NDVI ≤ 595 and GEMI ≤ 687 and Δ GEMI ≤ 644 and MIRBI $\geq 15,717$ and Δ MIRBI $\geq -1,672$	Pre-fire image: 9 February 2014 Post-fire image: 13 March 2014
131047-2014	BAIM ≥ 36 and Δ BAIM ≥ 35 and NBR $\leq 2,465$ and Δ NBR $\leq 1,801$ and NDVI $\leq 3,862$ and Δ NDVI $\leq 1,795$ and GEMI ≤ 611 and Δ GEMI ≤ 44 and MIRBI $\geq 14,788$ and Δ MIRBI $\geq -2,303$	BAIM ≥ 33 and Δ BAIM ≥ 14 and NBR $\leq 4,583$ and Δ NBR $\leq -2,573$ and NDVI $\leq 4,685$ and Δ NDVI $\leq -2,040$ and GEMI ≤ 810 and Δ GEMI ≤ 301 and MIRBI $\geq 15,173$ and Δ MIRBI ≥ 747	Pre-fire image: 17 February 2014 Post-fire image: 20 March 2014

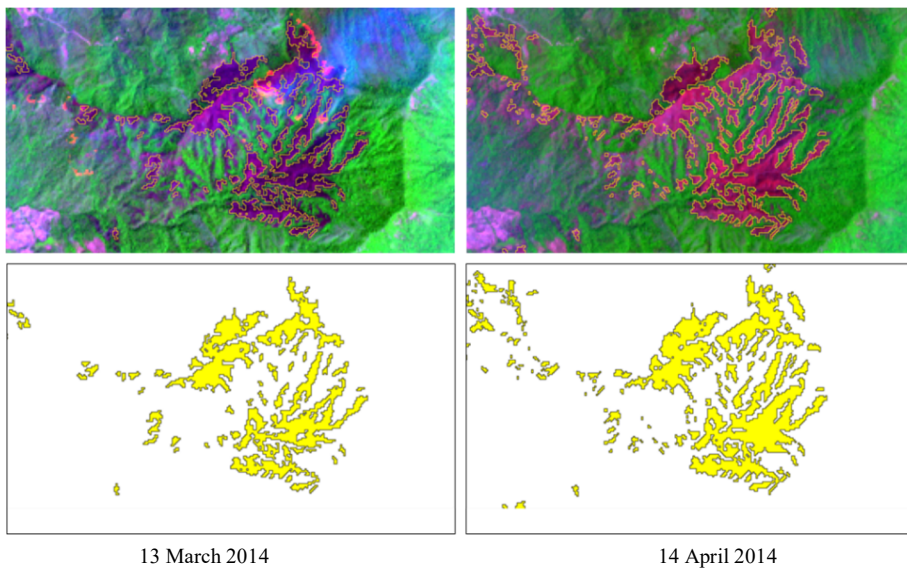


Figure 5. Multi-temporal change of burned area from pre-fire and post-fire scenes

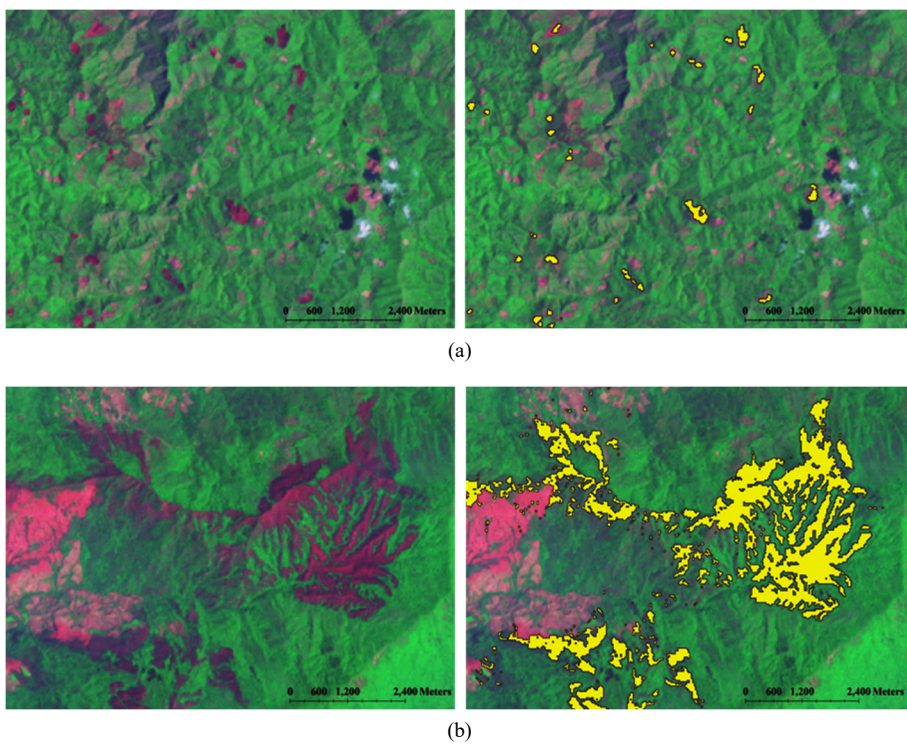


Figure 6. Example of burned area extraction: (a) small and (b) large

Accuracy Assessment of Burned Area Mapping

The accuracy of burned area mapping using BAMS was performed using the DNP ground fire data over two main Landsat scenes 130-047 and 131-047 as result in Table 4. It reveals that 234 points of 251 points from the DNP ground fire record are correctly classified as burned area using BAMS over Landsat scene: 130-047 with overall accuracy of 93.23%. Meanwhile, 176 points of 194 points from the DNP ground fire record are correctly classified as burned area by BAMS over Landsat scene: 131-047 with overall accuracy of 90.72%. Hence, the finding indicates that the accuracy of burned

area extraction using BAMS is acceptable. Additional, the extracted burned area map as Shape file format is ready to use for overlay a nalysis under GIS environment.

Burned Area Assessment in Provincial Boundary

Based on overlay analysis between the classified burned area in 2014 and nine provincial boundary of the Upper Northern region (Figure 7), top three provinces where

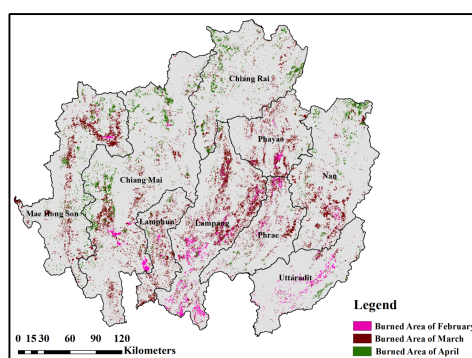


Figure 7. Distribution of burned area in 2014, Upper Northern region, Thailand

Table 3. Monthly burned area in 2014 of the Upper Northern region, Thailand

Month-Year	Area in km ²	Proportion in Percent
February, 2014	296.06	12.57
March, 2014	1,550.83	65.82
April, 2014	509.14	21.61
Total	2,356.03	100.00

Table 4. Accuracy assessment of burned area mapping in 2014 by BAMS with DNP fire ground data

Landsat		Periods	Number of DNP's point	Number of point		Percent	
Scene	Date			Correct	Incorrect	Correct	Incorrect
130-047	13 March 2014	26 February to 13 March 2014	251	234	18	93.23	6.77
131-047	20 March 2014	5-20 March 2014	194	176	18	90.72	9.28

Table 5. Burned area assessment in 2014 by province

No	Province	Area (km ²)	Proportion of region area (%)	Percentage of provincial area (%)	Rank
1	Chiang Mai	511.96	21.73	2.32	1
2	Lampang	466.92	19.82	3.74	2
3	Mae Hong Son	400.28	16.99	3.13	3
4	Nan	262.72	11.15	2.16	4
5	Chiang Rai	205.17	8.71	1.77	5
6	Phayao	149.38	6.34	2.41	6
7	Lamphun	138.88	5.89	3.10	7
8	Phrae	130.56	5.54	2.01	8
9	Uttaradit	90.16	3.83	1.15	9

forest fire occurred in 2014 with high proportion of total burned area are Chiang Mai, Lampang and Mae Hong Son and it covers area of 511.96 km², 466.92 km² and 400.28 km², respectively. In contrast, top three provinces where forest fire occurred in 2014 with low proportion of total burned area are Uttaradit, Phare, and Lamphun and it covers area of 90.16 km², 130.56 km² and 138.88 km², respectively. Details of burned area assessment in 2014 by province are summarized in Table 5. The major finding of burned area assessment in 2014 is consistent with the statistics report of DNP in 2015 who found that top three provinces were Chiang Mai, Mae Hong Son, and Lampang.

Burned Area Assessment in National Park

The result of burned area in 2014 in the declared national parks (NPK) and the prepared national parks (PNPK) is summarized in Table 6, and the distribution of burned area in national parks is displayed in Figure 8. There are 31 of 32 national parks affected by forest fire in 2014, except Si Satchanalai national park. It reveals that top three national parks where have the highest effect by forest fire are Op Luang, Mae Ping, and Mae Yom, with percentage of burned forest area of 5.27%, 3.08%, and 3.04% of forest cover area in 2000, respectively. On contrary, top three national parks where have

Table 6. Burned area in 2014 in national parks of the Upper Northern region, Thailand

No	Name	Status	Area (km ²)	Forest cover area in 2000 (km ²)	Burned forest area (km ²)	Percentage of burned forest area (%)
1	Op Luang	NPK	687.07	614.57	32.40	5.27
2	Mae Ping	NPK	708.93	628.23	19.37	3.08
3	Mae Yom	NPK	497.18	414.50	12.61	3.04
4	Doi Pha Klong	PNPK	1,045.18	968.45	29.30	3.03
5	Mae Wa	NPK	398.53	380.88	11.14	2.92
6	Si Nan	PNPK	866.54	795.62	23.12	2.91
7	Huai Num Dang	NPK	1,248.61	1,082.57	23.39	2.16
8	Chiang Dao	NPK	1,148.45	923.77	17.42	1.89
9	Namtok Mae Surin	NPK	420.09	387.34	6.65	1.72
10	Tham Sa Koen	PNPK	246.17	223.08	3.79	1.70
11	Op Khan	PNPK	547.86	488.43	7.16	1.47
12	Tham Pha Thai	PNPK	1,238.17	1,172.94	16.80	1.43
13	Phusoidao	PNPK	199.49	192.18	2.42	1.26
14	Mae Cha Rim	PNPK	422.02	410.82	4.78	1.16
15	Doi Inthanon	NPK	463.43	400.87	4.50	1.12
16	Mae Ngao	PNPK	322.53	286.90	3.21	1.12
17	Doi Phu Kha	NPK	1,693.29	1,504.43	16.35	1.09
18	Mae Puem	PNPK	350.56	328.90	3.10	0.94
19	Phu Sang	NPK	273.35	242.93	2.00	0.82
20	Doi Luang	NPK	1,214.45	1,018.61	7.91	0.78
21	Si Lanna	NPK	1,477.70	1,314.39	8.89	0.68
22	Doi Wiang Pha	PNPK	449.19	406.84	2.36	0.58
23	Khun Chae	NPK	293.43	273.82	1.35	0.49
24	Lam Nam Nan	NPK	1,058.73	779.22	3.38	0.43
25	Doi Khun Tan	NPK	247.56	230.50	0.91	0.39
26	Salawin	NPK	741.50	721.46	2.08	0.29
27	Khlong Tron	NPK	507.94	487.88	0.76	0.16
28	Mae Fang	NPK	523.74	413.19	0.40	0.10
29	Chae Son	NPK	801.50	749.98	0.70	0.09
30	Doi Suthep-Pui	NPK	281.58	229.25	0.14	0.06
31	Wiang Kosai	NPK	437.35	425.08	0.12	0.03
32	Si Satchanalai	NPK	0.49	0.49	-	-

the lowest effect by forest fire are Wiang Kosai, Doi Suthep Pui, and Chae Son, with percentage of burned forest area of 0.03%, 0.06%, and 3.04% of forest cover area in 2000, respectively.

In addition, the size of the burned forest area in national parks in 2014 varies between 0.12 km² and 32.40 km². Herein, the top three national parks that have the highest burned forest areas are Op Luang, Doi Pha Klong, and Huai Num Dang and they cover area of 32.40 km², 29.30 km², and 23.39 km², respectively. This finding is similar with the previous work of Ongsomwang *et al.* (1999, 2000, and 2001) who found that national parks where highly affected by forest fire were Op Luang and Huai Num Dang. In contrast, the top three national parks that have the lowest burned forest areas are Wiang Kosai, Doi Suthep Pui, and Mae Fang and

they cover area of 0.12 km², 0.14 km², and 0.40 km², respectively. Furthermore, it can be observed that percentage of burned forest area of 10 prepared national parks with 1.82% of forest cover in 2000 is higher than 22 declared national parks with 1.30% of forest cover in 2000. This finding reflects on capacity and efficiency of national parks.

Burned Area Assessment in Wildlife Sanctuary

The result of burned area in 2014 in the declared wildlife sanctuaries (WLS), and the prepared wildlife sanctuaries (PWLS) is summarized in Table 7, and the distribution of burned area in wildlife sanctuaries is displayed in Figure 9. There are 21 of 22 wildlife sanctuaries affected by forest fire in 2014, except Lamnam Nan Fang Khwa wildlife sanctuary. It reveals that the top three

Table 7. Burned area in 2014 in wildlife sanctuaries of the Upper Northern region, Thailand

No.	Name	Status	Area (km ²)	Forest cover area in 2000 (km ²)	Burned forest area (km ²)	Percentage of burned forest area (%)
1	Lumnam Pai	WLS	1199.98	1037.21	65.77	6.34
2	Salawin	WLS	872.67	847.94	25.77	3.04
3	Tham Chao Ram	WLS	98.88	95.86	2.75	2.87
4	Li-Hot	PWLS	406.76	399.88	9.55	2.39
5	Hong Hin	PWLS	30.47	26.39	0.51	1.93
6	Mae Lao-Mae Sae	WLS	499.60	476.02	7.97	1.67
7	Nam Pat	WLS	513.71	488.61	6.25	1.28
8	Mae Tuen	WLS	20.68	19.59	0.24	1.23
9	Khao Lom	PWLS	5.63	5.00	0.06	1.20
10	Doi Pha Mueang	WLS	588.21	556.41	6.50	1.17
11	Wiang Lo	WLS	380.51	341.62	3.78	1.11
12	Mae Cha Rim	WLS	672.56	633.37	6.46	1.02
13	Chiang Dao	WLS	502.21	442.64	4.11	0.93
14	Doi Pha Chang	WLS	583.33	488.41	4.34	0.89
15	San Pan Daeng	WLS	271.09	244.18	1.82	0.75
16	Mae Yuam Fang Khwa	WLS	291.82	277.35	2.03	0.73
17	Mae Lao Fang Sai	PWLS	194.33	164.20	1.11	0.68
18	Mae Sai Kham	PWLS	101.96	100.48	0.56	0.56
19	Samoeng	WLS	243.23	206.97	1.10	0.53
20	Doi Luang	WLS	97.94	97.69	0.47	0.48
21	Omko	WLS	330.03	298.32	1.37	0.46
22	Doi Saeng	PWLS	182.79	148.98	0.64	0.43
23	Doi Wiang La	WLS	467.88	459.76	0.19	0.04
24	Phu Miang-Phu Thong	WLS	74.35	73.81	0.01	0.01
25	Lamnam Nan Fang Khwa	WLS	234.48	228.83	-	-

wildlife sanctuaries which have the highest effect by forest fire are Lumnam Pai, Salawin, and Tham Chao Ram, with percentage of burned forest area of 6.34%, 3.04%, and 2.87% of forest cover area in 2000, respectively.

This finding is similar with the previous work of Ongsomwang *et al.* (1999, 2000, and 2001) who found that wildlife sanctuaries which highly affected by forest fire were Lumnam Pai and Salawin. On contrary, the top three wildlife sanctuaries which have the lowest effect by forest fire are Phumiang-Phu Thong, Doi Wiang La, and Doi Saeng, with percentage of burned forest area of 0.01%, 0.04%, and 0.43% of forest cover area in 2000, respectively.

In addition, the size of the burned forest area in national parks in 2014 varies between 0.12 km² and 32.40 km². Herein, the top three national parks that have the highest burned forest areas are Op Luang, Doi Pha Klong, and Huai Num Dang and they cover area of 32.40 km², 29.30 km², and 23.39 km², respectively. This finding is similar with the previous work of Ongsomwang *et al.* (1999, 2000, and 2001) who found that national parks where highly affected by forest fire were Op Luang and Huai Num Dang. In contrast, the top three national parks that have the lowest burned forest areas are Wiang Kosai, Doi Suthep Pui, and Mae Fang and

they cover area of 0.12 km², 0.14 km², and 0.40 km², respectively.

Furthermore, it can be observed that percentage of burned forest area of 10 prepared national parks with 1.82% of forest cover in 2000 is higher than 22 declared national parks with 1.30% of forest cover in 2000. This finding reflects on capacity and efficiency of national parks.

Burned Area Assessment in Wildlife Sanctuary

The result of burned area in 2014 in the declared wildlife sanctuaries (WLS), and the prepared wildlife sanctuaries (PWLS) is summarized in Table 7, and the distribution of burned area in wildlife sanctuaries is displayed in Figure 9.

There are 21 of 22 wildlife sanctuaries affected by forest fire in 2014, except Lamnam Nan Fang Khwa wildlife sanctuary. It reveals that the top three wildlife sanctuaries which have the highest effect by forest fire are Lumnam Pai, Salawin, and Tham Chao Ram, with percentage of burned forest area of 6.34%, 3.04%, and 2.87% of forest cover area in 2000, respectively. This finding is similar with the previous work of Ongsomwang *et al.* (1999, 2000, and 2001) who found that wildlife sanctuaries which highly affected by forest fire were Lumnam Pai and Salawin. On contrary, the top three

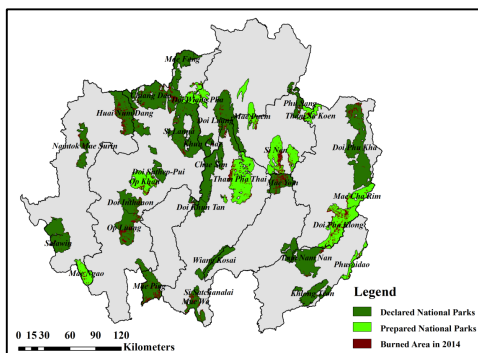


Figure 8. Distribution of burned area in national parks in 2014, Upper Northern region, Thailand

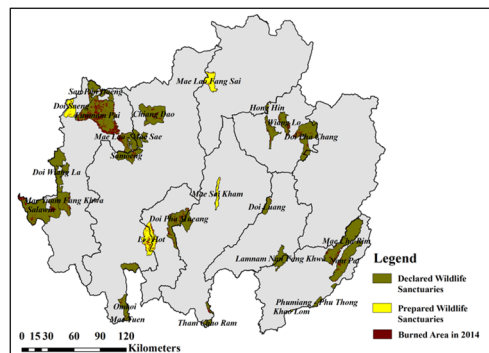


Figure 9. Distribution of burned area in wildlife sanctuaries in 2014, Upper Northern region, Thailand

wildlife sanctuaries which have the lowest effect by forest fire are Phumiang-Phu Thong, Doi Wiang La, and Doi Saeng, with percentage of burned forest area of 0.01%, 0.04%, and 0.43% of forest cover area in 2000, respectively.

In addition, the size of the burned forest area in wildlife sanctuaries in 2014 varies between 0.01 km² and 65.77 km². Herein, top three wildlife sanctuaries that have the highest burned forest areas are Lumnai Pai, Salawin, and Li-Hot and they cover area of 65.77 km², 25.77 km² and 9.55 km², respectively. In contrast, the top three wildlife sanctuaries that have the lowest burned forest areas are Phu Miang-Phu Thong, Khao Lom and Doi Wiang La and they cover area of 0.01 km², 0.06 km², and 0.19 km², respectively.

Furthermore, it can be observed that percentage of burned forest area of 19

declared wildlife sanctuaries with 1.92% of forest cover in 2000 is higher than 6 prepared wildlife sanctuaries with 1.47% of forest cover in 2000. This finding reflects on capacity and efficiency of wildlife sanctuaries.

Burned Area in 2014 and Forest Land use Data in 2000

Based on overlay analysis of burned area with forest land use data and forest types information of the RFD in 2000 (Ongsomwang, 2002), the burned areas inside the forest area are 1569.52 km² or 66.62% of total burned area, and outside the forest area are 786.51 km² or 33.38% of total burned area (Table 8 and Figure 10). This finding infers about effect of human activities on forest fire including gathering of non-timber products, spreading of agricultural debris burning agricultural activities hunting, and carelessness as mentioned by Akaakara (2000).

According to natural forest type classification of the RFD in 2000, forest fire in 2014 mostly occurs in mixed deciduous forest and dry dipterocarp forest and it burned areas about 1020.60 km² and 359.41 km², respectively. Meanwhile, evergreen forest including hill evergreen forest, dry evergreen forest and pine forest is the lowest affect by forest fires with burned area of 68.17 km². The detail of burned area in each forest type is summarized in Table 8. This finding is concordance with the previous studies of Ongsomwang *et al.* (1999, 2000, 2001), who are found that forest fire between 1999 and

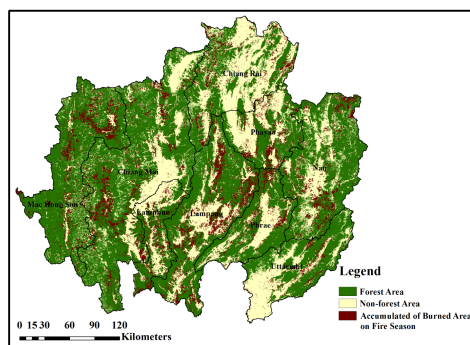


Figure 10. Distribution of burned area in 2014 and forest cover area in 2000, Upper Northern region, Thailand

Table 8. Burned area in 2014 with forest land use data in 2000

Forest and non-forest area	Forest type	Area (km ²)	Percent
	Hill Evergreen Forest	55.36	(3.53)
	Dry Evergreen Forest	11.24	(0.72)
	Pine Forest	1.57	(0.09)
	Mixed Deciduous Forest	1020.60	(65.03)
	Dry Dipterocarp Forest	359.41	(22.90)
	Secondary Growth Forest	41.11	(2.62)
	Forest Plantation	80.22	(5.11)
Forest area		1569.51	66.62
Non-forest area		786.52	33.38

2001 frequently occurred in mixed deciduous forest and dry dipterocarp forest.

Conclusions

Burned area assessment using BAMS with overall accuracy of burned area mapping between 90.72% and 93.23% over two main Landsat images: Path 131 and Row 047 and Path 130 and Row 047, respectively was successfully implemented as a case study of the Upper Northern region of Thailand. In addition, results of burned area assessment in provincial boundaries, protected forest area (national parks and wildlife sanctuaries) and forest types can provide a useful information on forest fire management, especially time and place of burned area.

In conclusion, it can be here concluded that BAMS is suitable for burned area mapping in Thailand. Many advantages of BAMS included (1) it is a freeware; (2) it minimally requires visual delimitation of few burned areas training for supervised burned mapping; (3) it provides reliable information likes visual interpretation and output as a polygon Shape file format; (5) it is easy to operate with free downloaded Landsat data that can save cost and time for burned area mapping; (6) it can reduce the confusion of burned area with other land covers such as cloud, topographic shadows, dark soils, or wetlands; and (7) it allows adjusting threshold or delete/add the selected burned training area for reduce and balance commission and omission errors products. Consequently, it should be here recommended that the DNP and RFD under Ministry of Natural Resources and Environment should apply BAMS as operator tool to obtain annual burned area maps from Landsat data for the country after the end of fire season.

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