The development of forest fire monitoring and warning system for agroforestry areas in Uttaradit Province, Thailand

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Abstract. Forest fire occurs regularly in the northern agroforestry of Thailand started in February to April and it causes economic and environmental losses. This study aimed to develop an automatic spatial data analysis system for monitoring and warning and a system for tracking and warning forest fires in agroforestry areas. Near real-time NDVI in dry season was analyzed to estimate the amount of biomass using a relationship between the NDVI and surveyed dataset. The biomass, hotspot, DEM, slope, aspect and relative humidity data were analyzed by Multi-criteria analysis (MCA) for forest fire risk area. The results are presented on web and mobile platform for forest fire warning. The estimated biomass of March was 7.5 to 9.1 tons/hectare, which corresponded with the results obtained from the field survey. The fire risk factors analysis including hotspot density, relative humidity, and landscape were used to produce the five risk levels. Each risk level area from one to five was 11.84 km², 25.68 km², 42.28 km², 30.85 km² and 20.65 km², respectively. The forest fire monitoring and warning systems were designed and developed in open-source platform, which can be utilized for forest, fire monitor and warning for local administration as well as farmers in the area.

Keywords: Forest fire agroforestry, NDVI, remote sensing, web mapping

1. Introduction
Forest fire occurs annually between February and April in northern agroforestry of Thailand and it causes not only economic but also environmental losses. The forest fire can occur from three important elements composite including heat, oxygen and fuel, which is called "fire triangle". Forest fire can occur from many causes, both naturally occurring and human activities. Agroforestry is an agriculture that uses forest land as a planting area which can be one of forest fire causes.

Uttaradit is largely an agricultural province which best known as durian plantation. It is located in the lower north of Thailand. The area is mostly mountainous and complex terrain in the north and east of the province. In the past, this area has been annually experiencing forest fires, which destroys both durian plantation and agricultural properties.

Several studies have analyzed forest fire risk areas using geographic information systems and remote sensing tools. The related factors to the fire triangle including the land use, topography and meteorology.
of the area are normally added to the analysis with different scores and weights for analyzing forest fire risk area [1, 2]. However the limitation of previous studies were applied a non-real-time dataset [3] which were sometimes not suitable for some dynamic factors. Satellite image can be analyzed for amount of biomass via creating an index and equation for biomass estimation [4]. Normalized Difference Vegetation Index (NDVI) is a widely used index to study the amount of biomass [4]. PyModis is an open source Python based library which is one of a useful tool that allows us to download near real-time satellite data such as MODIS [5]. This study aimed to develop an automatic spatial data analysis system and to develop front-end mobile application for forest fire monitoring in agroforestry areas.

2. Data and methodology

2.1. Data collection and preparation
MODIS dataset between 1 January 2013 and 31 December 2017 with 250 meters spatial resolution from the US Geological Survey (USGS) [6] were downloaded by the maximum 10 % of cloud cover limitation. Then NDVI was applied (equation 1) with value range from -1 to 1. The higher NDVI value can be referred to an area with more density vegetation cover than the lower NDVI.

\[
NDVI = \frac{(NIR - Red)}{(NIR + Red)}
\]  

(1)

where \(NIR\) = Reflection in the near-infrared spectrum  
\(Red\) = Reflection in the red spectrum  
Above ground biomass is estimated from NDVI as equation 2 [4].

\[
AGB = (10,077 \times NDVI) - 2,936.8
\]  

(2)

where \(AGB\) = Above-Ground Biomass (kg)

The data validation was done by field survey method. Three sample plots of trees were sampled and collected by placing the plot of 1 square meter for a total of 10 locations. The data obtained from the sample plots were calculated the AGB and validate with the calculated AGB from the satellite dataset.

2.2. Forest fire risk analysis
Heat, fuel and climate [7] were selected as the fire triangle factors. Hotspots were daily downloaded from NASA’s Fire Information for Resource Management System (FIRMS) [8] were used as a heat factor. The calculated biomass from the equation (2) and relative humidity were represented as the fuel and climate factors, respectively. The topographical factors consisting of attitude at mean sea level, slope and aspect [9] were included in the model. The processing steps were as follows:
1. NodeJS was the tools for downloading 3-hourly hotspot from FIRMS service and also, the daily relative humidity dataset from Thai Meteorological Department. Later the hotspots were analyzed and converted to the hotspot density layer. A spatial interpolation technique was applied for the daily relative humidity layer.
2. PyModis were used as a tool for downloading daily MODIS dataset. The daily MODIS dataset was calculated to AGB.
3. The Digital Elevation Model (DEM) was analyzed and converted to slope and aspect.
4. Above mentioned layers were assigned the risk score for each layer as shown in table 1.
5. All layers including hotspot density, biomass, altitude, slope, and aspect were assigned the risk scores for each layer as shown in table 1 and were applied in Multi-criteria analysis, GIS index model concept. Then the results were grouped into five levels using the equal interval method.
Table 1. Wildfire risk criteria

| Factors          | Derivative data | Valuation methodology                                      | Reference |
|------------------|-----------------|------------------------------------------------------------|-----------|
| Elevation        | DEM             | Very low (1): 93–170 m.; Low (2): 170–230 m.; Moderate (3): 230–290 m.; High (4): 290–350 m.; Very high (5): 350–483 m. | [2, 9]    |
| Slope            | DEM             | Very low (1): 0–5 %; Low (2): 5–15 %; Moderate (3): 15–30 %; High (4): 30–45 %; Very high (5): 45–133 % | [2, 9]    |
| Aspect           | DEM             | Very low (1): N, flat; Low (2): NE, NW; Moderate (3): E, W; High (4): SE, SW; Very high (5): S | [2, 9]    |
| Fuel             | Biomass         | Very low (1):700 kg.; Low (2): 800 kg.; Moderate (3): 900 kg.; High (4): 1,000 kg.; Very high (5): > 1,000 kg. | [2, 9]    |
| Hotspot density  | Hotspot         | Very low (1): 0; Low (2): 1; Moderate (3): 3; High (4): 5; Very high (5): > 5 |           |
| Relative humidity| Relative humidity| Very low (1): < 63.3; Low (2): 63.43; Moderate (3): 63.48; High (4): 63.52; Very high (5): > 63.52 |           |

3. Development of wildfire monitoring system

The steps of a system for forest fire monitoring development as follows:

1. This study inquired the user requirements from farmers in agroforestry area and local administration governors for wildfire monitoring system design.
2. The accuracy assessments of wildfire monitoring system were done from both analysis and results processes.
3. The developed system was tested from farmers and local administration governors.

3. Results and discussion

3.1 Forest fire risk and database

3.1.1. Forest fire database. Sixteen spatial data layers including administration boundaries, village, groundwater, well, contour, road, river, sub watershed, soil type, soil series, geological features, land use in 2007, land use in 2009, land use in 2012, DEM, slope and aspect data were collected. All layers were projected to UTM zone 47 Datum WGS 1984 projection (EPSG: 32647). After that, the attribute data for each layer was added and updated by manual in national standard format. Finally, all layers were imported into GeoServer, a widely used for developing web map services in many applications [10], to create a web map service (figure 1).

3.1.2. Automatically download of satellite images and calculation of biomass. The MODIS data from Terra/Aqua satellites including Surface Reflectance (Band 1) and Surface Reflectance (Band 2) were downloaded from NASA FTP (server ftp://n4ftl01u.ecs.nasa.gov). The data received from NASA FTP was sinusoidal projection and must be converted to UTM zone 47 with a WGS84 datum (EPSG: 32647) using PyModis. Then projected data was calculated the daily NDVI from 2013 to 2016 and as well as the AGB using automatically python script. The result found that the dense vegetation area was distributed in the north side of the study area. The highest NDVI in this area was in December due to the late rainy season and lowest in March due to the dry season (figure 2).
The AGB amount in March was between 7.5 and 9.1 tons/hectare/year. While in December, AGB was higher (between 10.9 to 11.3 tons/hectare/year). Some examples of the AGB volume during the study period are shown in table 2.

The accuracy assessment of AGB was done using dataset in March 2018. The average of AGB from the field survey and from NDVI in the same period were 8.77 tons/hectare and 7.5 to 9.1 tons/hectare, respectively.

3.1.3. Results of the forest fire risk analysis. Seventy-six points of hotspot between 2011 and 2017 (10 points per year) were downloaded from NASA FIRMS and were analyzed for spatial density layer. Hotspots were normally found in the dry season, especially in February to April. In 2016, the hotspots were found more than other study years and mostly found in the forest and agriculture areas. The most density hotspots were established on the north and east of the study area (figure 3).
Table 2. Above ground biomass.

| Date       | ton/hectare |
|------------|-------------|
| 23 Dec 2013 | 11.31       |
| 13 Mar 2014 | 9.07        |
| 26 Dec 2014 | 11.19       |
| 16 Mar 2015 | 7.53        |
| 13 Dec 2015 | 10.95       |
| 18 Mar 2016 | 8.91        |

Figure 3. Multi-criteria analysis methods for analyzing forest fire risk area.

The aspect data can be referred to a level of the fuel moisture that related to the duration of sunlight receivable in the area. The high fire risk area according to the aspect factor was found throughout the study area. The slope factor was affected to the spread of fire. The higher fire spread was found on the higher slopes (more than 45 degrees), and also lower fire spread was found on lower slopes (less than 10 degrees).

Relative humidity (RH) was the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature [11]. The RH in the west area during the dry season was approximately 63% and had more RH value than other areas.

The results of Multi-criteria analysis showed that the area with high forest fire risk score was found in the northeast (figure 3). The area of each risk level from 1 (lowest) to 5 (highest) was 11.84 km², 25.68 km², 42.28 km², 30.85 km² and 20.65 km², respectively.
3.2. The forest fire monitoring and warning system

The user requirements from farmers in agroforestry area and related local administration staffs were collected. Real-time hotspot data and GIS layers that supported forest fire management such as water route, location of resources used to extinguish fires, such as the nearest water source, route etc. were requested from the collected users for showing on the system.

Forest fire monitoring and warning systems were developed using Postgres/PostGIS as database system and were created a web map service using GeoServer. This map service can be accessed from several ways such as GIS desktop software, QGIS or ArcGIS, and web browser. The forest fire monitoring and warning system were produced from NodeJS and Express scripts to build a simple REST API and Angular framework to create frontend web-application. This web-application can be displayed the GIS layers, forest fire areas, and near-real time hotspot data, which can be retrieved from the URL: http://cgi.uru.ac.th/udsafe/ (figure 4).

This system was utilized for the forest fire situation monitoring in March 2018, which could be a tool to identify the location of the hotspot effectively. The finding from the satisfaction evaluation was mentioned that the wildfire monitoring system could reduce the risk of forest fire ($\bar{x} = 4.00$, $SD = 0.79$) and it was very convenient to use as well ($\bar{x} = 3.79$, $SD = 0.79$). The dataset used in the system were accurate ($\bar{x} = 3.83$, $SD = 0.38$) and the system was useful for farmers and government agencies ($\bar{x} = 4.11$, $SD = 0.74$).

4. Conclusion

Forest fire is a natural disaster that affects agroforestry. The study of wildfire hazard area requires the use of the fire triangle concept for the analysis. This study aimed to analyze forest fire risk area and develop the forest fire warning system in agroforestry area. The forest fire risk area was analyzed based on spatial data analysis. The selected data such as heat points, biological quantities, relative humidity are constantly changing and analyzing with statistics. Areas with a high-risk score were found on the northeastern side where several durian plantations are located.
The areas of each fire risk level from 1 (lowest) to 5 (highest) were 11.84 km\(^2\), 25.68 km\(^2\), 42.28 km\(^2\), 30.85 km\(^2\), and 20.65 km\(^2\), respectively. Open source tools could be implemented to develop systems into an online map service. The dynamic data were downloaded from multi-sources which can be used for the forest fire monitoring and warning in agroforestry. The system was designed and developed based on user requirements which could be not only helpful for related sectors on land monitoring and management but also useful as a good practice and guidelines for applying on other areas.

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