Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China

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Abstract: A forest fire can be a real ecological disaster regardless of whether it is caused by natural forces or human activities, it is possible to map forest fire risk zones to minimize the frequency of fires, avert damage, etc. A method integrating remote sensing and GIS was developed and applied to forest fire risk zone mapping for Baihe forestry bureau in this paper. Satellite images were interpreted and classified to generate vegetation type layer and land use layers (roads, settlements and farmlands). Topographic layers (slope, aspect and altitude) were derived from DEM. The thematic and topographic information was analyzed by using ARC/INFO GIS software. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers (vegetation type, slope, aspect, altitude and distance from roads, farmlands and settlements) according to their sensitivity to fire or their fire-inducing capability. Five categories of forest fire risk ranging from very high to very low were derived automatically. The mapping result of the study area was found to be in strong agreement with actual fire-affected sites.

Keywords: Forest fire risk; GIS; Remote sensing; Baihe forestry bureau

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Introduction

Forest fires can cause substantial damage to natural resources and human lives regardless of whether it is caused by natural forces or human activities. To minimize threat from wildfires, fire managers must be able to plan protection strategies that are appropriate for individual local areas. A prerequisite for the planning is the ability to assess and map forest fire risk zones across both broad areas and local sites. Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas (Jaiswal *et al.* 2002).

People studied forest fire risk zones (FFRZ) with a variety of mapping methods. Most of them mapped forest fire risk zones by directly using remote sensing and geographic information systems (GIS) that contain topography, vegetation, land use, population, and settlement information (Chuvieco and Congalton 1989; Chuvieco and Salas 1996; Mariel *et al.* 1996; Jaiswal *et al.* 2002). A common practice was that 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.

Studies on FFRZ in China started as early as the 1950's (Tang and Zhang 1996). And studies on FFRZ for broad area such as countrywide or a province were developed well (Wang 1985; Zheng and Yao 1993; Hu 2003). However these studies cannot be applied successfully at forestry bureau level since lack of details such as topography, social environment, etc.. Only few studies on forestry bureau zones were carried on (Tang and Zhang 1996; Zhang *et al.* 2003).

Remote sensing has opened up opportunities for qualitative analyses of forest and other ecosystems at all geographic and spatial scales. GIS has also developed functions such as analyzing available information and using them as a decision and a support system as well as it compiles the information as a whole and stores it, especially in the operational field needing to make important decisions of a spatial nature (Ilmavirta 1995; Botton and Duquenne 1997; Sauvagnargues *et al.* 1997). GIS technology can serve as a vital technological core for forest fire crisis management (Lymberopoulos 1996; George 1999; Goodrick *et al.* 1999; Keramitsoglou *et al.* 2004). Here, GIS provides a means of overlaying and combining data for analysis.

In this study, an attempt was made to prepare FFRZ maps by integrating satellite images and other ancillary data such as roads, farmlands and settlements from GIS for Baihe Forestry Bureau. Such maps will help forestry department officials prevent or minimize forest fire activities and take proper action when fires break out (Chuvieco and Sales 1996).

Study Area

The study area is Baihe Forestry Bureau locating on the Changbai Mountain Reserve (Fig. 1). With a total area of 190 000 hm^2, the geographical range of Baihe Forestry Bureau is between 127°53′ and 128°34′ E, and 42°01′ and 42°48′N. Within an area of 56 by 89 km, the forestry bureau contains 10 Forest Farms (Fig. 1).

Approximately 89.91% of the study area is covered by vegetation (mainly shrub land and forests) but a dense human settlement has often leaded to a considerable fragmentation of vegetation patches. There are over 1 700 higher plant species, 210 lichen species, and 350 epiphyte species. The dominant forest type

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is broadleaved/Korean pine mixed forest.

The climate of the study area is temperate continental, where winter is cold and summer is cool and moist. The average annual temperature is 2.2℃; frost-free period lasts 110 days; average annual precipitation is 700–1 100 mm depending on the elevation ranging from 500 to 1 400 m above mean sea level. The average elevation is 800 m and the average gradient is about 5 degrees within the forestry bureau.

Extensive forest harvesting did start until the 1970s. Most of naturally regenerated and undisturbed forests were damaged at a variety of degrees within the forestry bureau. Some harvested forests were replaced with plantations (Shao and Zhao 1998; Zhang *et al* 2000). Therefore, there is no clear relationship between forest characteristics with topographic conditions. Forest fires almost occurred every year within the forestry bureau but their damages were not extensive in area partly due to overwalming wildfire suppressing efforts.

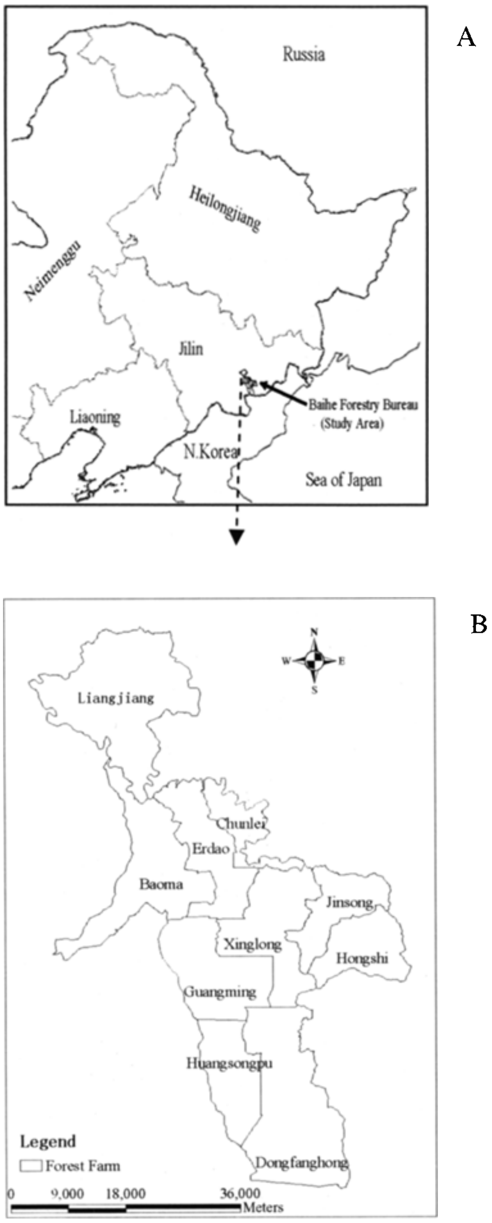

Fig. 1 Geographic location (a) and administrative division (b) of Baihe Forestry Bureau

Material and methods

Data

FFRZ requires integration of natural (fuel and topography) and anthropogenic factors (such as roads, farmlands and settlements). Fuel represents the material available for fire ignition and combustion, and it represents the one factor relating to fire that humans can control (Rothermel 1972; Albini 1976; Salas and Chuvieco 1994). Fuel characteristics include vegetation structure, fuel type and so on (Chuvieco and Salas 1996; Castro and Chuvieco 1998; Keane *et a.l* 1998, 2000). Topography influences occurrence and spread of forest fires through airflow and microclimate. Main topographical factors influencing forest fires are slope, aspect and altitude (Chuvieco and Salas 1996; Castro and Chuvieco 1998). Anthropogenic factors mainly includes: the spatial distribution of certain human infrastructures such as roads, settlements, camping sites, and farmlands that are regarded as areas of higher fire risk (Chou 1992; Vega-García *et al.* 1995; Pew and Larsen 2001) and some socioeconomic variables related to fire occurrence: population density and activity sectors, etc. (Vélez Muñoz 1986, Román-Cuesta *et al* 2003). The data collected for this study area were: vegetation type, slope, aspect, altitude and distance to roads, farmlands and settlements. Satellite images and DEM data were used for obtaining these data.

Methods

Satellite images were processed to produce vegetation map and land use maps. The satellite images were corrected for the influence of atmosphere and topographic relief. And the atmospherically, radiometrically and geometrically corrected/geo-coded images were interpreted and classified by using ERDAS software.

The purpose of digital land cover classification is to link the spectral characteristics of the images to a meaningful information class value, which can be displayed as a map so that resource managers or scientists can evaluate the landscape in an accurate and cost effective manner. In this study, the maximum likelihood supervised classification algorithm was used (Atkinson *et al.* 2000; Shao *et al.* 1996; Hansen *et al.* 1996). The classifications of satellite images were utilized in land cover analysis.

The factors influencing forest fire risk were analyzed in the following order of importance: vegetation type, slope, aspect, altitude and distance from roads, farmlands and settlements. And these factors were classified according to their sensitivity to fire or their fire-inducing capability. First classes represent high-risk places and last classes represent the minor risk place. Each class has different values (Table 1).

The vegetation types were classified according to their flammability that has an influence on ignition and spread of forest fires.

Steep gradient increases the chance of catching fire and the rate of fire spread because of easier loss of water and more efficient convective preheating. Slope classes were created according to this rule. Aspect and altitude were assigned classes too. Since the sunlight is much more reflected on the slopes facing south, fires break out easily and spread fast in the south sides. And fire behavior trends to be less severe at higher elevation due to high rainfall.

Distances from roads, settlements and farmlands have important influences on forest fires. The risk decreases farther from these places. It means that a zone closer to these places was evaluated a higher rating.

Table 1. Variables and their weights in determination of forest fire risk

Variables	Weights	Classes	Values	Fire Risk Relating Classes
Vegetation	7	Very easy	3	High Risk
		Medium	2	Medium Risk
		Very hard	1	Low Risk
Slope	5	>35	5	Very High Risk
		25–35	4	High Risk
		10–25	3	Medium Risk
		5–10	2	Low Risk
		0–5	1	Very Low Risk
Aspect	5	South(136–225°)	4	Very High Risk
		West (226–315°)	3	High Risk
		East(46–135°)	2	Medium Risk
		North(316–45°)	1	Low Risk
Altitude	5	0–600m (except 0)	5	Very High Risk
		600–700m	4	High Risk
		700–850m	3	Medium Risk
		850–1000m	2	Low Risk
		>1000m	1	Very Low Risk
Distance from Roads	3	0–200m	5	Very High Risk
		200–400m	4	High Risk
		400-600m	3	Medium Risk
		600–1000m	2	Low Risk
		>1000m	1	Very Low Risk
Distance from Farm-lands	3	0–100m	5	Very High Risk
		100–400m	4	High Risk
		400–1000m	3	Medium Risk
		1000–2000m	2	Low Risk
		>2000m	1	Very Low Risk
Distance from Settle-ments	3	0–1000m	5	Very High Risk
		1000–2000m	4	High Risk
		2000–3000m	3	Medium Risk
		3000–4000m	2	Low Risk
		>4000m	1	Very Low Risk

In order to obtain effective and more accurate conclusions, mathematical operations in GIS analysis were formed. The equation used in GIS to determine FFRZ was shown in Equation (1).

$$RC = 7*VT + 5*(S+A+E) + 3*(DR+DS+DF) \quad (1)$$

In this equation, RC is the numerical index of FFRZ where VT indicates vegetation type variable with 3 classes, S indicates slope variable with 5 classes, A indicates aspect variable with 4 classes, E indicates altitude variable with 5 classes. DR, DS and DF indicate variables of distance from roads, settlements and farmlands (Table 1). Finally, a FFRZ map was produced based on these analyses by using ARCGIS software.

Results

Image Processing Results

For the indication of FFRZ, land use and vegetation maps were prepared using Landsat ETM+ data acquired in September 2000. The selection of the bands used for classification was made in consideration of the spectral profile analysis. According to the analysis, Landsat TM bands 5, 4 and 3 were selected to make supervised classification. Three categories of fuel type were derived from the images with respect to their vulnerable and combustion properties. The first category includes logged forest and coniferous forest, which are easy to catch fire. The second category includes mixed broadleaf/conifer forest, less vulnerable to catch fire. The third category includes hardwood forest, difficult to catch fire. Roads, settlements and farmlands layers were also derived from the images using the same method. Classification accuracy was determined by using 50 random pixels. The classification accuracy results were 93.7%.

GIS Results

For the production of a FFRZ map, five fire rating classes were used. These classes were formed according to vegetation type, slope, aspect, altitude and distance from roads, farmlands and settlements.

The vegetation-based forest fire risk map was produced according to the vegetation type map. In accordance with the vegetation map, high risk, medium risk and low risk attributes were designated and classified in terms of the flammability of the vegetations (Fig. 2). And the vegetation-based fire risk map was integrated with digital stand map to produce vegetation-based fire risk value of each sub-compartment by using the overlay analysis function of ARCGIS software.

Slope and aspect images were generated from the DEM data. And these images and DEM data were classified to produce the slope-based, aspect-based and altitude-based fire risk images according to Table 1 (Fig. 3, 4 and 5). These images were converted to vector files and integrated with stand map in order to produce slope-based fire risk value, aspect-based fire risk value and altitude-based fire risk value of each sub-compartment by using ARCGIS software.

The land use images derived from satellite images were converted to vector files and integrated with stand map to produce distances from roads, settlements and farmlands of each sub-compartment. And the distances from roads, farmlands and settlements based fire risk maps were produced according to Table 1, and fire risk value of each sub-compartment based on these factors was obtained (Fig. 6, 7 and 8).

Based on Equation (1) and the vegetation-based fire risk value, the topography-based (slope, aspect and altitude) fire risk values and the anthropogenic factors-based (distances from roads, farmlands and settlements) fire risk values, RC was calculated and classified using ARCGIS software with the natural breaks method in order to produce a FFRZ map (Fig. 9).

Forest fires history of Baihe Forestry Bureau from 1974 to 2001 was selected out to check up the utility of this method. Fires mainly occurred in Liangjiang, Baoma, Erdao and Xinglong forest farms during this period (Table 2).

Table 2. Number and percent of forest fires of each forest farm in Baihe Forestry Bureau

Forest farm	Number of forest fires	Percent (%)	Forest farm	Number of forest fires	Percent (%)
Liangjiang	67	34.1837	Jinsong	4	2.0408
Baoma	31	15.8163	Hongshi	4	2.0408
Erdao	26	13.2653	Guangming	4	2.0408
Chunlei	15	7.6531	Huangsongpu	1	0.5102
Xinglong	27	13.7755	Dongfanghong	0	0

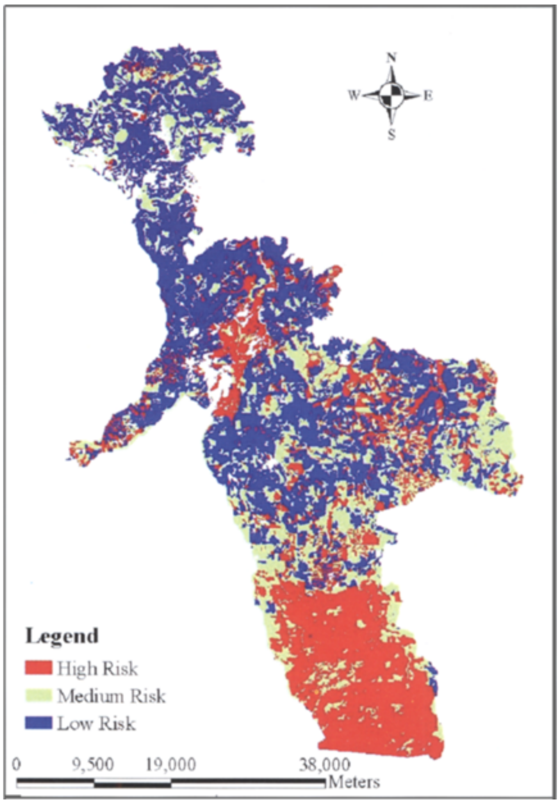

Fig. 2 Stand-based fire risk zone map

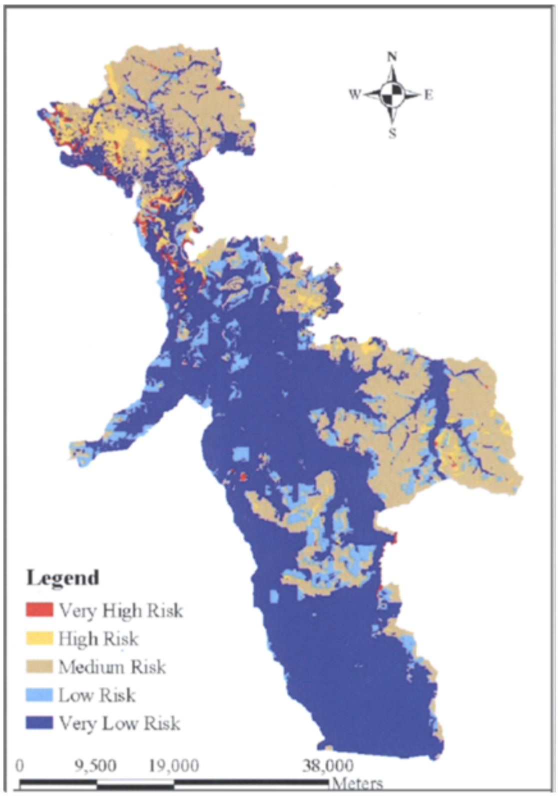

Fig. 3 Slope-based fire risk zone map

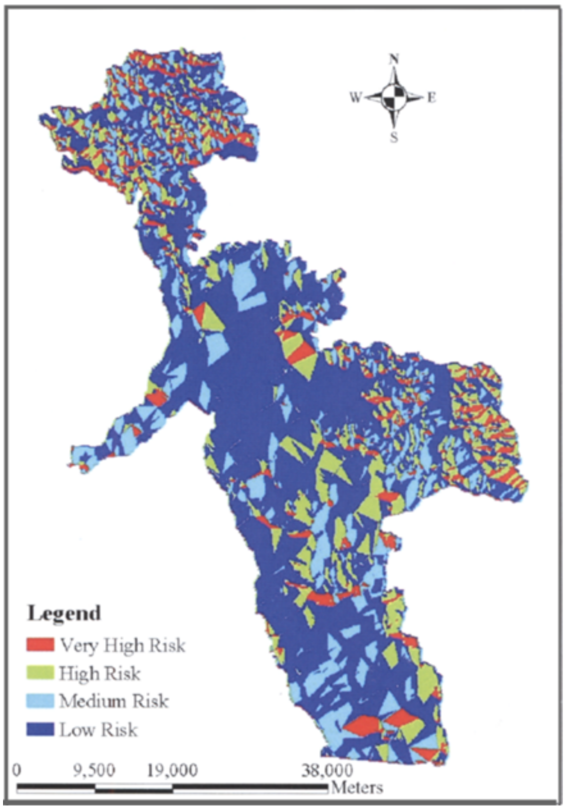

Fig. 4 Aspect-based fire risk zone map

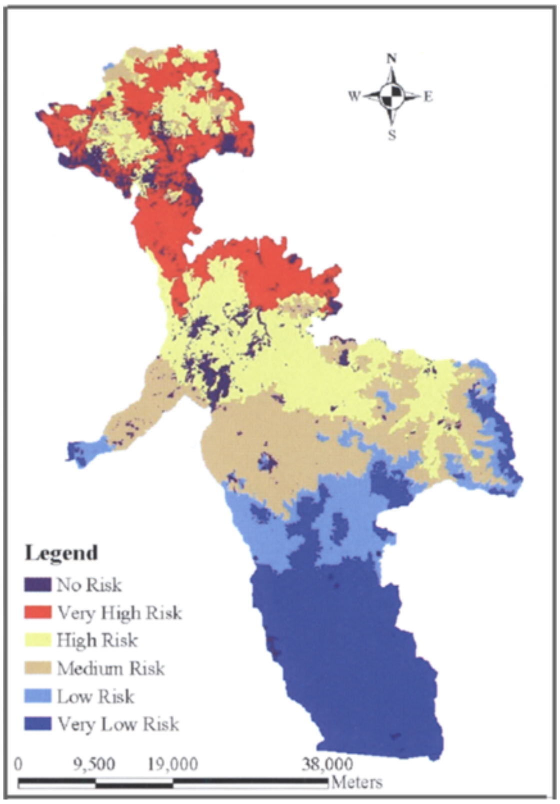

Fig. 5 Elevation-based fire risk zone map

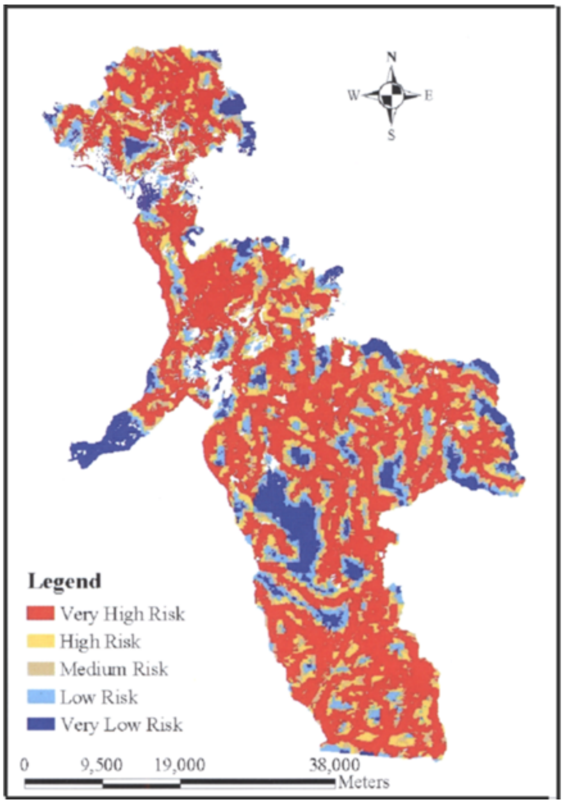

Fig. 6 Road-based fire risk zone map

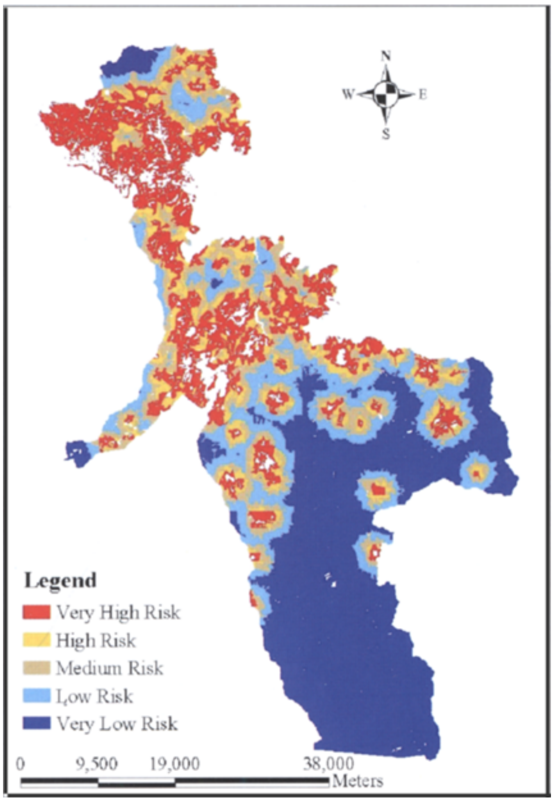

Fig. 7 Farmland-based fire risk zone map

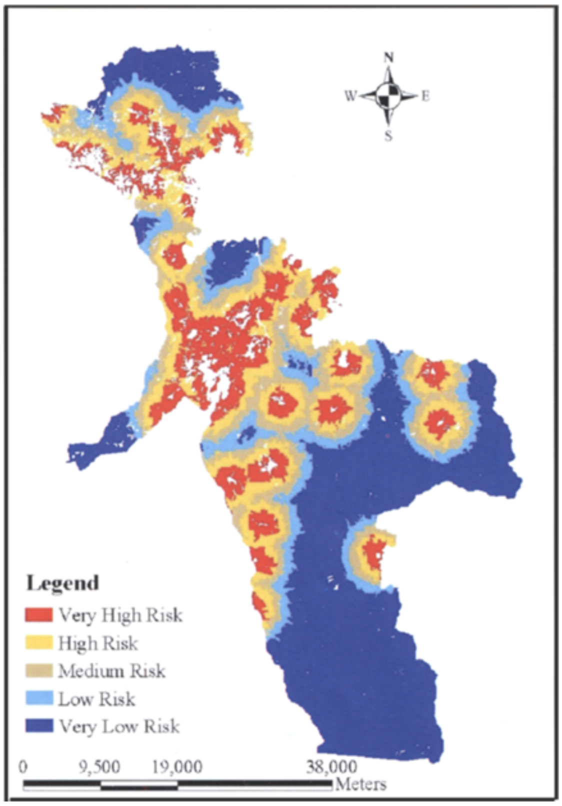

Fig. 8 Settlement-based fire risk zone map

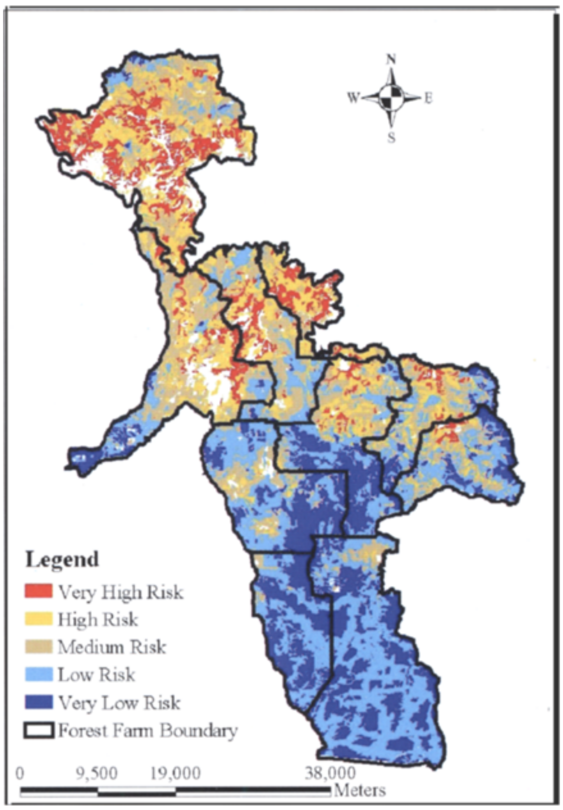

Fig. 9 Synthesized forest fire risk zone

The mapping result showed that medium, high or very high risk zones mainly distribute in Liangjiang, Baoma, Erdao and Xinglong forest farms, and there are almost no high risk zones in Huangsongpu and Dongfanghong forest farms (Fig. 9). This result showed that the method is useful for FFRZ mapping.

Conclusions

Remote sensing and GIS are useful tools for forest fire management. A method integrating remote sensing and GIS is developed in this article. Satellite images and topographic data were analyzed using this method. And the results showed that the method is suitable for FFRZ mapping. It can be applied successfully for managing forest fires for forestry bureau. Forest fire managers can find high-risk places easily and take proper actions to minimize frequency of forest fires and avert damage.

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