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# A Bayesian modeling of wildfire probability in the Zagros Mountains, Iran

Abolfazl Jaafari [a,*], Davood Mafi Gholami [b], Eric K. Zenner [c]

[a] Young Researchers and Elite Club, Karaj Branch, Islamic Azad University, Karaj, Iran
[b] Department of Forest Sciences, Faculty of Natural Resources and Earth Sciences, Shaherkord University, Shaherkord, Iran
[c] Department of Ecosystem Science and Management, The Pennsylvania State University, Forest Resources Building, University Park, PA 16802, USA

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ABSTRACT

The preparation of probability distribution maps is the first important step in risk assessment and wildfire management. Here we employed Weights-of-Evidence (WOE) Bayesian modeling to investigate the spatial relationship between historical fire events in the Chaharmahal-Bakhtiari Province of Iran, using a wide range of binary predictor variables (i.e., presence or absence of a variable characteristic or condition) that represent topography, climate, and human activities. Model results were used to produce distribution maps of wildfire probability. Our modeling approach is based on the assumption that the probabilities reflect the observed proportions of the total landscape area occupied by the corresponding events (i.e., fire incident or no fire) and conditions (i.e., classes) of predictor variables. To assess the effect of each predictor variable on model outputs, we excluded each variable in turn during calculations. The results were validated and compared by the receiver operating characteristic (ROC) using both success rate and prediction rate curves. Seventy percent of fire events were used for the former, while the remainder was used for the latter. The validation results showed that the area under the curves (AUC) for success and prediction rates of the model that included all thirteen predictor variables that represent topography, climate, and human influences were 84.6 and 80.4%, respectively. The highest AUC for success and prediction rates (86.8 and 84.6%) were achieved when the altitude variable was excluded from the analysis. We found slightly decreased AUC values when the slope-aspect and proximity to settlements variables were excluded. These findings clearly demonstrate that the probability of a fire is strongly dependent upon the topographic characteristics of landscapes and, perhaps more importantly, human infrastructure and associated human activities. The results from this study may be useful for land use planning, decision-making for wildfire management, and the allocation of fire resources prior to the start of the main fire season.



## 1. Introduction

Wildfires are a major environmental concern for vegetation ecosystems (Renard et al., 2012) that destroy millions of hectares annually (FAO, 2007, 2010). At global and local scales, fires have adverse effects, such as soil erosion, forest degradation, air pollution, loss of lives and biodiversity, and damage to infrastructures (Adab et al., 2015; Chuvieco et al., 2010; Eskandari and Chuvieco, 2015; Omi, 2005). Over the last years there has been a global increase in number and severity of these fires (Williams et al., 2014). In this context, the lack of efficient tools and models that support wildfire monitoring and prediction has been identified as a critical information gap that needs to be addressed for successful fire management.

In Iran, wildfire is seen as a significant threat to forests and pastures. Some estimates suggest that an average of 400 fire events occur per year that burn over 60 km$^2$ of land (Adab et al., 2013; Ardakani et al., 2011; Jahdi et al., 2015). This trend is expected to continue and may even increase in the future due to ongoing climate and land use changes, as well as increasing human activities (Eskandari and Chuvieco, 2015). Although these increasing numbers of fire ignitions constitute a problem for fire detection and suppression planning, very few studies have been conducted to delineate vulnerable areas and better understand the influential factors that drive fire ignitions. Wildfire probability modeling provides an analytical framework to investigate and characterize fire spread and behavior in diverse and complex ecosystems (Jahdi et al., 2015) and may thus offer insights into response strategies to ongoing climate change effects expected in the near future.

Wildfires do not occur at random, but tend to follow certain spatial and temporal patterns (Chen et al., 2015). The start of a fire and its spread stem from the joint combination of ignition agents, weather and climate, vegetation, topography and/or human influences (Carmo et al., 2011; Oliveira et al., 2012; Pourtaghi et al., 2016). Therefore, the probability that a fire occurs can be estimated considering historical fire locations and a set of factors such as topography, climate and the presence of human infrastructures that characterize the environment and are not expected to change significantly over a short time period

* Corresponding author at: Young Researchers and Elite Club, Islamic Azad University, P.O. Box: 31485-313, Karaj, Alborz, Iran.
*E-mail addresses:* ajaafari@gmail.com, a.jaafari@modares.ac.ir (A. Jaafari).

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of time (Oliveira et al., 2014). Starting with the knowledge of where the most fire-prone areas have been located in the past enables the development of spatially explicit hazard mitigation plans.

A number of methods that have taken advantage of Remote Sensing (RS) and Geographical Information System (GIS) techniques have recently been developed for fire probability modeling. These methods generally assume that conditions that have led to the occurrence of a fire in the recent and more distant past are likely to continue causing fires in the future as well. Thus, the spatial location of historical fire events as well as various factors associated with burn areas are typically the most important input variables for these methods. The most common methods used in fire probability modeling are multicriteria decision analysis (Majlingová, 2015; Pourghasemi et al., 2014), logistic regression (e.g., Oliveira et al., 2012; Pourghasemi, 2016; Syphard et al., 2008), maximum entropy (Arpaci et al., 2014; Chen et al., 2015; Parisien et al., 2012; West et al., 2015), random forest (Arpaci et al., 2014; Oliveira et al., 2012; Pourtaghi et al., 2016), fuzzy systems (Pourghasemi et al., 2014; Semeraro et al., 2016), Bayesian modeling (Dickson et al., 2006; Dilts et al., 2009; Romero-Calcerrada et al., 2008; Silva et al., 2015), and classification and regression tree models (Amatulli et al., 2006; Lozano et al., 2008; McKenzie et al., 2000). However, despite great strides forward to identify fire-prone areas with these models, none of the above approaches have thus far been identified as the best strategy that should be employed.

The main objective of this paper was to evaluate the predictive ability of a statistical/probabilistic method based on Bayesian probability modeling, referred to as Weights-of-Evidence (WOE; Bonham-Carter et al., 1989). Our approach was to link fire events to a set of predictor variables that characterize the environmental features within our study area, such as topography and climate as well as several measures of human activities. In addition, we examined the model sensitivity to different input variables and to the exclusion of one predictor variable from the analysis at a time to produce the most accurate estimate of wildfire probability. We illustrate the proposed scheme via a case study from a part of the Zagros Mountains in southwestern Iran.

The remainder of the paper is structured as follows: First, a general description of the study area is presented in Section 2. Then, the construction of a spatial database, the theory of the WOE Bayesian method, and the validation method are explained in Section 3. Section 4 provides the modeling results and discussion. In Section 5, we close the paper with the presentation of conclusions and suggestions for future research.

## 2. Study area

Our study area is the Chaharmahal-Bakhtiari Province in southwestern Iran. This province covers approximately 16,532 km$^2$ and is located between 31°9′ N to 32°48′ N latitude and 49° 28′ E to 51° 25′ E longitude (Fig. 1). The area is characterized by a variable and rough topography, with slope gradients between 0° (flat) and >80° and altitudes between 783 and 4178 m. The annual rainfall amounts vary between 1400 mm in the northwestern and 250 mm in the eastern and southeastern portion of the province, with a provincial average of 560 mm. Most of the rainfall occurs during winter and spring; droughts of 2–3 months duration occur in the summer. The mean annual temperature ranges from 5 °C in the central parts to 16 °C in the western parts, with an average of 10 °C. The terrain strongly affects the local climate as temperature decreases and precipitation increases markedly with elevation. Wind regimes are complex and show considerable spatial variation. During

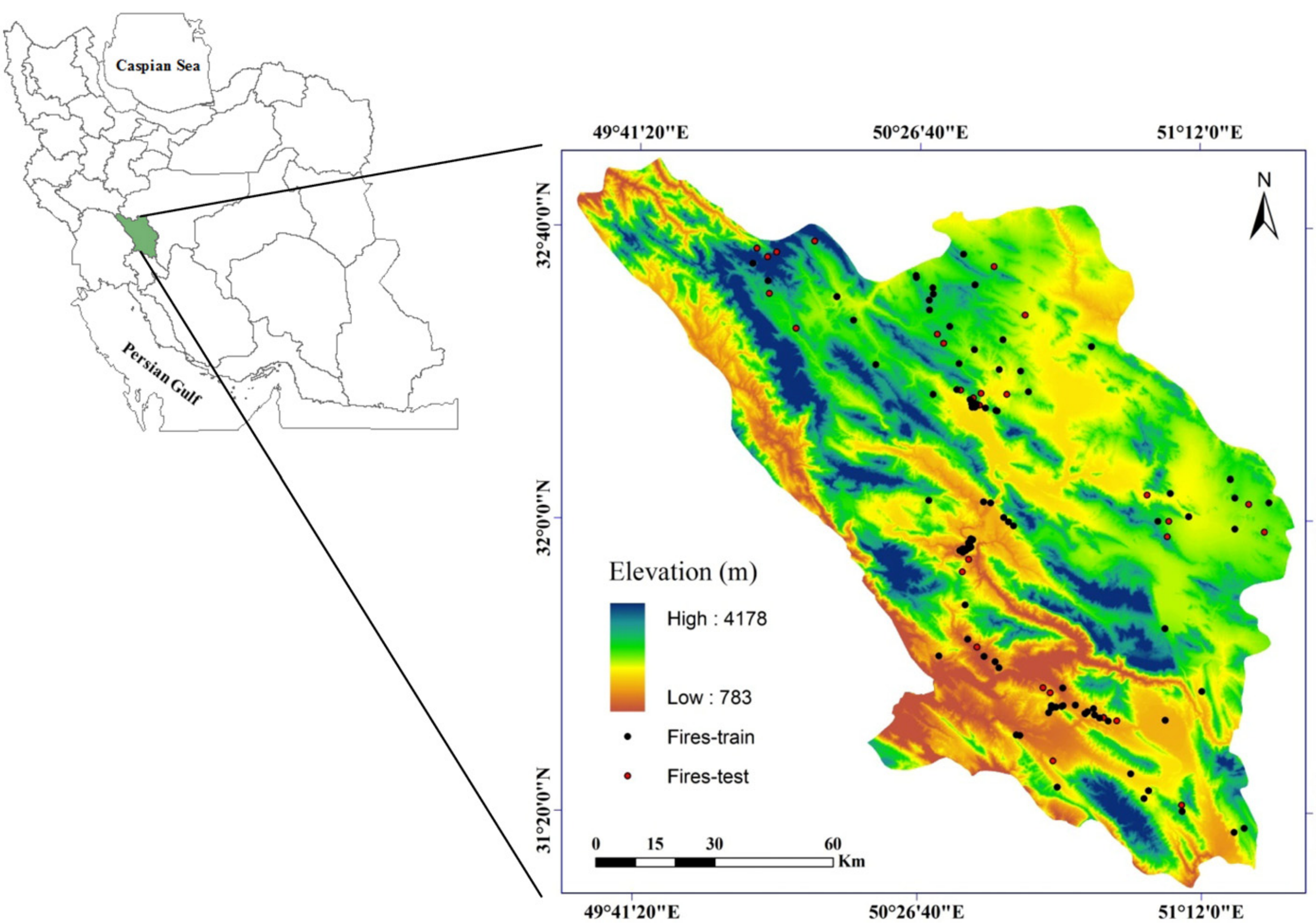


Fig. 1. Location of study area with fire event locations.