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Fire danger assessment in Iran based on geospatial information

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ABSTRACT

Fire danger assessment is a vital issue to alleviate the impacts of wildland fires. In this study, a fire danger assessment system is proposed, which extensively uses geographical databases to characterize the spatial variations of fire danger conditions in Iran. This assessment requires three steps: (i) generation of the required input variables, (ii) methods to integrate those variables for creating synthetic indices and (iii) validation of those indices versus fire occurrence data. This fire danger model is based on previous works but adapted to Iranian conditions. It includes an estimation of the fire ignition potential (both considering human and climatic factors) and fire propagation potential. The former was generated from a logistic regression approach based on a wide range of input variables. The fire propagation probability was estimated from the Flammap fire behavior model. A first stage for validation of our fire danger system was based on comparing the estimated danger values to actual fire occurrence, based on satellite detected active fires and burned areas. The logistic regression model for fire ignition probability estimated 72.7% of true ignitions. Detected hotspots occurred more frequently in areas with higher fire ignition probability (average value: 0.65) than non hotspots (average value: 0.4). Propagation probability showed higher values for areas with higher proportion of burned area ($r = 0.68$, $p < 0.001$).

1. Introduction

Forest fires are considered a major disturbance in forest ecosystems. At global scale, they account for a significant share in global CO_2 emissions (25–40% of those produced by fossil fuel combustion: Bowman et al., 2009). At regional and local scale, fires also have important socioeconomic implications, affecting both lives and structures. Fire risk assessment is very relevant to reduce the most negative impacts of fire, by improving the level of preparedness of fire managers and the rural areas more potentially affected by fires. Following recent papers (Chuvieco et al., 2014; Chuvieco et al., 2010; Thompson et al., 2011), fire risk can be considered a combination of physical probability that a fire occurs, and the potential damage it may cause. The former is commonly named fire danger, while the latter fire vulnerability. This paper deals with developing a fire danger product for Iran, which is the largest country of the Middle East, and has important areas affected by wildland fires.

The assessment of fire danger conditions should be related to both fire ignition and propagation. The former depend on fuel amount and moisture conditions on one hand, and on the presence of external causes (both anthropogenic and natural) leading to fire starts, on the other. Fire propagation is favored by weather conditions (particularly wind speed), terrain roughness and fuel horizontal and vertical continuity (Merril and Alexander, 1987; Taylor and Alexander, 2006). Since human activities have a great impact on fire ignition and suppression (Hantson et al., 2015; Thompson, 2014), societal conditions should also be considered to generate comprehensive fire danger assessment products.

Several recent papers have presented models to generate fire danger products at different spatial and temporal scales (Chuvieco et al., 2014; Chuvieco et al., 2010; Loboda 2009; Padilla and Vega-Garcia, 2011; Paz et al., 2011; Prasad et al., 2008; Romero-Ruiz et al., 2010). Most commonly the integration schemes of those studies are difficult to generalize, as they depend on environmental conditions and available information. However, a few studies have tried to establish scale-independent fire danger integration

Abbreviations: NWCG, national Wildfire Coordinating Group; RS, remote Sensing; GIS, geographic Information Systems; MODIS, moderate Resolution Imaging Spectroradiometer; AHP, analytic Hierarchy Process; HFI, hybrid Fire Index; ROC, receiver Operating Characteristic; MCDM, multi Criteria Decision Making; HII, human Influence Index; CIESIN, center for International Earth Science Information Network; IGHP, interrupted Goode Homolosine Projection; FMC, fuel Moisture Content; FI, fireline Intensity; PP, propagation Probability; IP, ignition Probability; MNRA, mazandaran Natural Resources Administration; GNRA, golestan Natural Resources Administration; IMGO, iranian Military Geographical Organization.

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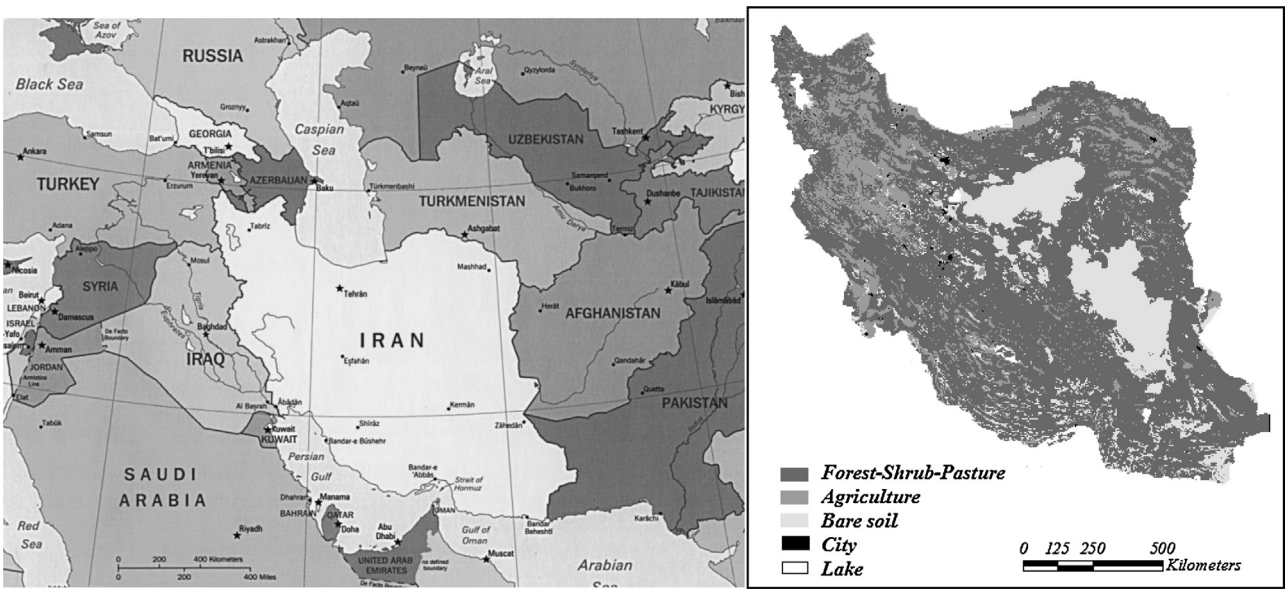

Fig. 1. Location of Islamic Republic of Iran and land cover map (Source: Iranian Military Geographical Organization (IMGO).

systems that could be applicable in a more generalized way. This was the approach that Chuvieco et al. (2010) followed to develop a fire risk assessment system for several Spanish regions, using an extensive use of remote sensing (RS) and Geographic Information Systems (GIS). Later these authors extended their study to cover the whole Spanish territory using a grid of 1 sq km and deriving most input data from RS or GIS analysis (Chuvieco et al., 2014). This integration scheme has been the basis for this paper, which aims to generate a fire danger product that could serve the wildland fire management strategic decisions of Iran.

Different studies have been done to evaluate fire danger in forest regions of Iran. Some researchers have used Analytical Hierarchy Process (AHP) to assess fire danger at regional scales (Mohammadi et al., 2010; Salamati et al., 2011; Mahdavi et al., 2012; Zarekar et al., 2013). Other authors have used different methods to model fire danger in local scales. Adab et al. (2013) used different indices for fire risk evaluation in Northeastern Iran. Hotspots data derived from MODIS satellite sensor were used to validate the indices. Assessment of these indices with receiver operating characteristic (ROC) curves found 76.7% agreement rates. Eskandari et al. (2013) assessed fire danger in District three of Neka-Zalemroud forests-Iran. A fire risk model obtained from fuzzy AHP and MCDM method in a GIS framework, was used to map the forest fire risk in the study area. The used factors included four major criteria (topographic, biologic, climate and human factors) and seventeen sub-criteria. The actual fire data in study area was used for cross checking. Results showed that the high-risk regions accordance with the actual fires.

These fire danger studies previously carried out in Iran used different methods, study areas and spatial scales. National scale products have never been generated in Iran, and therefore a global vision of fire conditions is still lacking. Therefore, the main goal of this paper is to generate a fire danger assessment product for Iran, based on the national conditions and data limitations of the country. Our product is based on the Chuvieco et al.'s ((2014)) fire danger scheme, as it is scale-independent and modular. We have focused in this paper in the fire danger component, and more precisely in those factors that are more stable on time (named constant danger in the last edition of the Glossary of Wildland Fire Terminology: NWCG, 2014). The paper first introduces the methods to generate the required input variables as geographical data layers. Then it addresses the integration of the different input variables into synthetic fire danger indices. Estimation of danger includes the consideration of fuel characteristics, human and natural causes, average wind speed, wind direction and slope gradients. Finally, the paper presents comparisons of fire danger values with actual fire occurrence, as detected by MODIS hotspots. The system was developed to cover the whole Iranian territory (1800,000 km^2), with grid cells of 1 km^2.

2. Material and Methods

2.1. Study area

The Islamic Republic of Iran is located in the Southwest of Asia spreading from 24 to 40 degrees N and 44 to 64 degrees E and it covers 1.6 million sq km. It borders the Persian and Oman Gulf in the South and the Caspian Sea in the North (Fig. 1). The climate is mostly characterized by very arid, arid or semi-arid regions, but some subtropical areas are found along the Caspian coast. Altitude ranges from −28 m (Caspian Sea) to 5671 m (Damavand Peak). Forests are mainly located in the North and Western regions, and have uneven-aged and mixture structure. The most common tree species are *Fagus orientalis* Lipsky, *Carpinus betulus L., Quercus castaneifolia* C.A.Mey., *Alnus subcordata* C.A.Mey., *Parrotia persica* (DC.) C.A.Mey., *Zelcova carpinifolia* (Pall.) Dipp., *Acer sp.*, etc., while shrub common species are *Buxus hyrcanus* Pojark., *Mespilus germanica L., Crataegus pentagyna* Wldast. & Kit. Ex Willd, *Prunus caspica*, etc.; Herb species are more diverse (*Asperula odorata L., Ruscus hyrcanus* Woron., *Carex sp., Siclaman sp., Rubus sp.*, etc.). Shrub and herb species have more flammability than tree species. Among tree species, *Fagus orientalis* Lipsky, *Carpinus betulus L. and Parrotia persica* (DC.) C.A.Mey. have more flammability than others (Adeli and Yakhkashi, 1975).

Even though Iranian fire statistics are still not very reliable, some estimations account for an average yearly burned area exceeding 5000 ha (Adab et al., 2013). The most affected regions in the country are the North, West, Northwestern and Northeastern regions, which include also the most burnable forest and pasture regions. Forest fires are considered as a frequent hazard in the Golestan Province (Northeast of country), in the Mazandaran Province (North of country) (MNRA, 2011; Eskandari et al., 2013), in the Pave-Kermanshah Province (Mohammadi et al., 2010) and