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**[Research]**

# Forest fire vulnerability map using remote sensing data, GIS and AHP analysis (Case study: Zarivar Lake surrounding area)

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## ABSTRACT

Fire has an important role in destruction and negative side effects on forest ecosystem. The main aim of this study was to determine the main factors influencing the fire on set in Zarivar Lake forest area using remote sensing data, Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) analysis. Vegetation density map derived from SPOT-HRG image data with 71.38% accuracy and 0.695 Kappa coefficients. The results of AHP analysis on destructive fire factors indicated that temperature and human-made factors had maximum influence on fire occurrence in the study area. Based on AHP analysis, final vulnerability map of study area was produced in Arc Map environment with 5 vulnerability areas. The results indicated that 78.03% of burned areas in 2009 and 2010 occurred in very high, high and moderate vulnerability area of final fire vulnerability map. So, this map can be used in forest management of Zarivar Lake area in dry season.

**Key words:** AHP, Forest fire, GIS, Vulnerability map, Zarivar Lake.

## INTRODUCTION

Forest is a dynamic and complex ecosystem that is in equilibrium normally. When forest is affected by a natural or a synthetic destructive, its self-regulatory mechanism becomes weak or disappears (Barnes *et al*. 1998; Banjshafiei *et al*. 2008). The fire is one of the destructive factors in forest ecosystem. It is an ecological factor that has an important role in destruction, shaping and reconstruction of forest stands (Certini 2005). The forest fire also directly causes a reduction in biodiversity, deforestation and climate change (Hai-wei *et al*. 2004). Nowadays, fire - in natural ecosystems is the most destructive agent after human activities such as farming and development of cities (Hai-wei *et al*. 2004).

The significance of the damage caused by fire varies in different regions and countries since its intensity depends on local climatic conditions (Jazireie 2005). In some cases, fire is considered as a natural phenomenon and a part of the nitrogen cycle through which it helps to sustain the forest health (Jazireie 2005). The devastating fires, so called wildfires are considered as a kind of incident. The planned fire is a solution to prevent catastrophic fire in forest stands. The forest fires and disaster such as floods and earthquakes are differing since the approximate time and location of forest fire occurrences can be estimated. Usually, forest fires develop gradually. consequently, it is possible to reduce damages and casualties during their occurrences (Hosainali & Rajabi 2005).

Risk of fire depends on several factors such as density and structure of forest plants, topography, human activities and climate pattern. These factors do not change on a daily basis and do not alter in a time, at least at the season of fire (Chuvieco *et al*. 1997). The fire-cycle analysis can be defined as: preparing a potential map of fire ignition, defining fire, controlling the overall fire progression and preparing a fire vulnerability map. These data or informations are useful for forest management, protective forces and researchers who are interested in the topic of natural fires (Klaver & Fosinight 1997). The spatial information is also required to support the modern forest management. Providing managerial guidelines and predicting the effects of these guidelines on land use, reveals an urgent need to produce an accurate and meaningful data and information. Therefore, the utilization of remote sensing data and GIS technique in natural resource and forest management can be very useful (Adab *et al.* 2008).

Burned area (charcoal) residue and the vegetation scar produce longer lasting spectral signals (spectral reflection) that allow the estimation of the area affected by fire. The burned area signal is, therefore, more adequate to assess ecological and economic damages (compared with non-fire zones), and to estimate atmospheric emissions. Remotely sensed data is one of the suitable one in the forest fire researches, because reflection of fire burned area is totally different (Fig. 1).

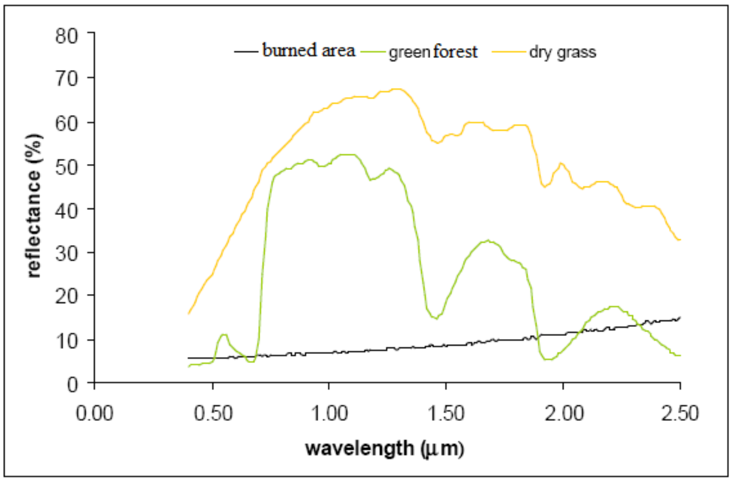


**Fig. 1.** Spectral signatures of burned area, green forest and dry grass (Curran 1985).

The fire phenomena happen in natural and planted forest stands of Iran each year. The fire is an ecological factor that has an important role in destruction of forest stands and this phenomenon has large negative side effects on forest ecosystem in Iran. The fire has reduced about 160000 hectares (Kazemi 2005) of natural and planted forests in Iran during 28 years (1968 to 1996). According to the Food and Agriculture Organization of the United Nations, 0.06% of Iranian forests are destroyed by fire each year (FAO 2001).

In this study we investigated destructive factors of forestsfire and the consequence of injuries on forest stands in the Zarivar Lake area, West Iran. In detail, the aims of this study were: i) to determine the main factors influencing the fire; ii) to identify areas with the greatest fire vulnerability; iii) to assess a fire vulnerability map of study area using SPOT 5 image data, AHP and GIS techniques.

## MATERIAL AND METHODS

### Study area

The study area (Fig. 2) is located in the Zarivar Lake region of Marivan county, West Iran, with a latitude range from 46° 3' 5″ to 46° 10' 8″ N and a longitude range from 35° 30' 3″ to 35° 37' 7″E. The whole area has homogenous environmental and climatic characteristics: average annual precipitation = 800 mm; average minimum winter temperature = 7.7°C; average maximum summer temperature = 33.2°C, mean annual temperature = 13.7°C.

The study area was 8236.5 ha, where 860.25 ha was covered by the lake, 1123 ha was swamp, while 6253.25 ha was covered by forest, grassland and agricultural cultivations.

Elevation in the study area ranged from 1300 to 1880m a.s.l. The soil type was forest brown and texture varied between sandy clay loams to clay loam. The main vegetation of this area was an uneven-aged mixed forest dominated by *Quercus brantii var. percica*. These forests were mainly coppice and used to soil and water protection.

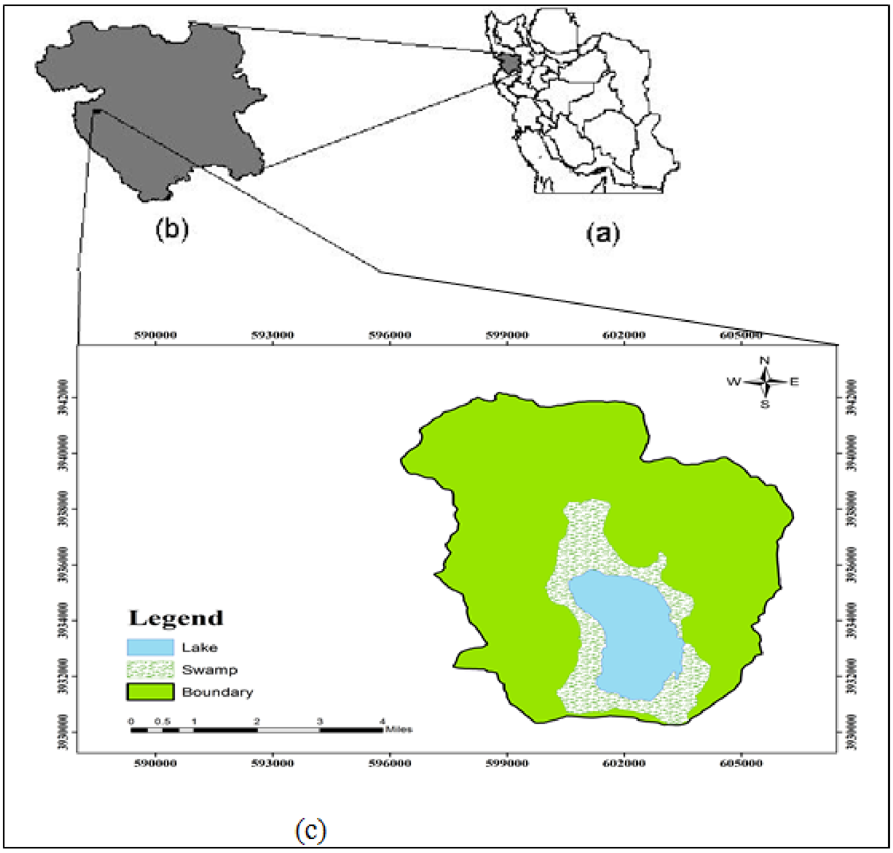


**Fig. 2.** Study area (c), its location in Iran (a) and in Kurdistan Province (b).

**Data collection and analysis**

The fire vulnerability occurrence in the forested area depends on several factors. Firstly, we determine the most important factors since it is, in fact, the most important goal of this study. The forest-fire vulnerability is related to vegetation density, distance from roads, residential areas, streams and lake, physiographic features (slope and aspect), and climatic variables (temperature and amount of precipitation) (Mohammadi *et al*. 2010, 2013; Amalina *et al.* 2016).

These data layers were obtained from digital topographic-thematic maps (on a scale of 1:25,000), weather data and interpretation of SPOT 5 satellite image. SPOT-HRG data (Table 1), with fine spatial resolution (10 m) recorded on 9 July 2005 was used to extract vegetation density. So that, a supervised classification, i.e. maximum likelihood approach was applied on the SPOT-HRG data. A Digital Elevation Model (DEM) was produced using digital topographic maps in a scale of 1:25000. Then slope and aspect maps were produced from DEM. Maps of distance from residential areas, roads, streams and the lake were also extracted from digital thematic-topographic map. Regional temperature and rainfall studies were conducted employing the information obtained from the weather stations around the Zarivar lake area. The fires occurred during 2009 and 2010 were used to validate the model. As most of the fires happen in July, consequently, the average temperature and annual rainfall in July during these two years were employed to the temperature and rainfall maps. The AHP technique was applied to determine the importance of coefficients influencing the forest-fire occurrence. In order to obtain the sample size, Cochran method was used as

$$n = \frac{\mathrm{N}t^2\mathrm{pq}}{(\mathrm{N}-1)d^2 + \mathrm{t}^2\mathrm{pq}}$$

Where:

n = number of samples required, N = population size, t = student-t test at 95% confidence level, d = desired level of precision = 5%, p= favorable probability of occurrence = 0.5 and q =l-p = (0.5) (Vakilifard & Nazari 2011). Finally, weight of each factor was calculated using AHP and the forest-fire vulnerability map was generated.

**Table 1.** Characteristics of SPOT-HRG image data.

| Satellite | Sensor | Band | Wavelength (μm) | Spatial Resolution (m) | Date |
|---|---|---|---|---|---|
| SPOT | HRG | green | 0.50-0.59 | 10 | 9 July 2005 |
| | | red | 0.61-0.68 | 10 | |
| | | Near infrared | 0.78-0.89 | 10 | |
| | | SWIR | 1.58-1.75 | 20 | |

**Model Validation**

According to the data obtained from the Office of Natural Resources in Marivan City, Kurdistan Province, Iran concerning to the fires occurred in 2009 and 2010 in the study area, the burned regions with the largest area were defined and surveyed by GPS devices. Once the quantitative amounts of weights for each factor obtained by AHP, the model was produced, following by producing the forest fire vulnerability map in Zarivar region by ArcGIS software. Finally by the overlap of the map produced and burned areas, the model was validated.

**RESULTS**

Several maps including vegetation density, distance from residential areas, roads, streams and the lake, physiographic features (slope and aspect), and climatic variables (temperature and amount of precipitation) were generated in this study. Because the area studied was small so, temperature and rainfall maps have been prepared in one class and were generated using the interpolated in Arc Map environment. Also, the vegetation density map was prepared based on SPOT-HRG image data as aforementioned. Ground truth data were produced and used in parameter supervised MLC algorithm. In overall, 7 classes including lake, swamp, agricultural areas, residential area and forest area with 3 densities (5-25%, 25-50%, and > 50%) were produced. The overall accuracy and Kappa Coefficient of this classification were 71.38% and 0.695, respectively. Low pass filter with 5×5 pixels was used to remove single pixels of the classified map. For further analysis, raster format of the classified map convert to vector format. So that, the vegetation density map derived from MLC classification after filtering entered into the ArcGIS software environment and transform to vector format. The AHP method was used to determine the weight and importance of coefficients influencing the forest-fire occurrence. To weigh each one of the nine criteria, a 9*9 matrix was defined.Then, based on the expert opinion and a comparison between the mutual elements in the matrix, the weight of each criterion was obtained. Thus, the number of population- that is the number of professors and experts in natural resources, fire and the AHP was considered as 25 (N = 25) and the required sample calculated by Cochran formula is 22 patients (S = 22). 22 experts completed the questionnaire forms and for each of the forms the inconsistency ratio (IR) was calculated. From the total 22 forms, the error percentage was above 0.1 in 2 forms, consequently omitting them. Saaty (1990) has suggested that the geometric mean is the best method for integrating judgments in a group hierarchy process. Therefore, the final form of the AHP was developed based on the geometric mean of the remaining 20 forms. Then, the weight for each factor - that is the effect of each factor on fire - was calculated in EC Software. The results indicated that obtained inconsistency ratio (IR) was less than 0.1 (about 0.08) and paired comparisons in AHP matrix were at an acceptable level (Fig. 3). The results of AHP analysis on destructive fire factors showed that temperature and distance from residential area had maximum impact on fire occurrence, while distance from river and lake had minimum influence in Zarivar Lake forest area. In order to weigh inner layers, each factor was assigned a code from 1 to 5. The code number 5 refers to the highest impact on fire, while the code 1 indicates the lowest impact on the occurrence and also the spread of fire in the study area (Table 2).

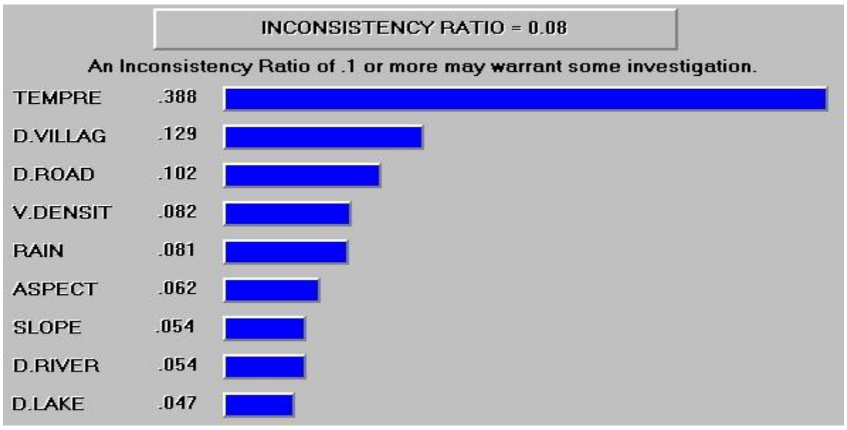


**Fig. 3**. Final weight of effective factors on influencing the forest-fire occurrence.

**Table 2.** Weighing within the layer.

| code | Aspect | Slope (%) | Distance from residential area (m) | Distance from roads (m) | Distance from rivers (m) | Distance from lake (m) | Temperature (°C) | Rainfall (mm) | Vegetation density (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Flat | 0-10 | 2000< | 800< | 0-50 | 0-500 | | | - |
| 2 | Northern | 10-20 | 1500-2000 | 600-800 | 50-100 | 500-1000 | | | No forest |
| 3 | Eastern | 20-30 | 1000-1500 | 400-600 | 100-150 | 1000-1500 | 23.34-25.52 | 712-758 | 5-25 |
| 4 | Western | 30-50 | 500-1000 | 200-400 | 150-200 | 1500-2000 | | | 25-50 |
| 5 | Southern | 50< | 0-500 | 0-200 | 200< | 2000< | | | 50< |

All vector layer maps, based on the weights obtained from EC software, were integrated in Arc Map environment and the final vulnerability map was generated. The results of this study indicated that destructive fire factors in Zarivar Lake forest region had 5 vulnerability areas: very low, low, moderate, high and very high vulnerability (Fig. 4), because each factor divided into 5 classes (Dong *et al.* 2005; Mohammadi *et al*. 2010). The results fire vulnerability areas in hectare and percentage were shown in Table 3.

Polygons of burned areas occurred in 2009 and 2010 in Zarivar Lake forest region were surveyed and used to evaluate the final vulnerability map. The results indicated that 3.86%, 25.71%, 48.46% and 21.97% of burned areas happened in very high, high, moderate and low vulnerable area of final vulnerability map respectively (Table 4).

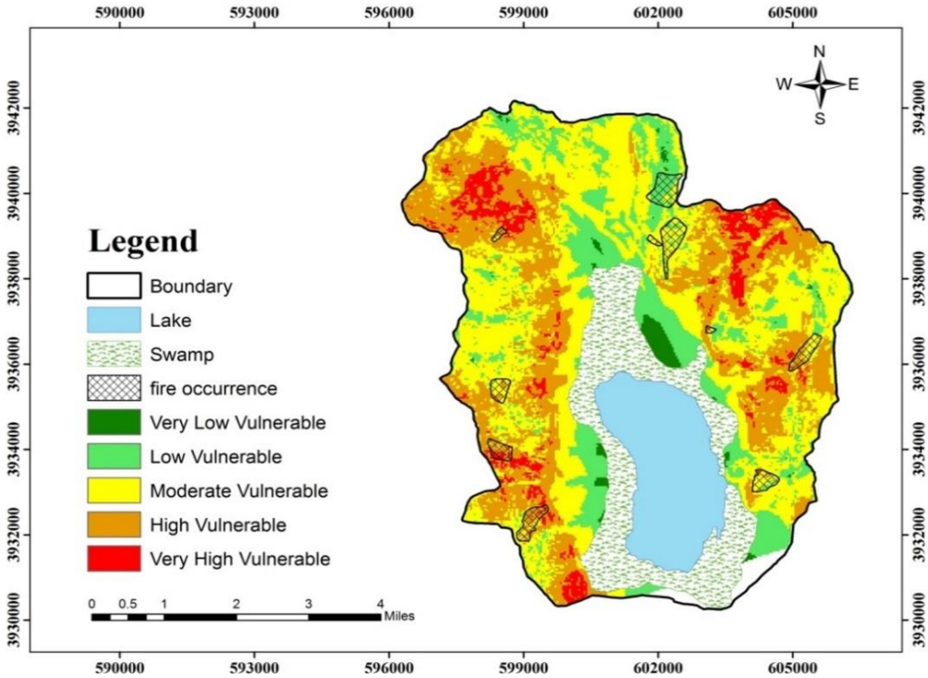


**Fig. 4**. Forest fire vulnerability map in Zarivar region.

**Table 3.** Fire vulnerability areas in hectare and percentage of study area derived from final map.

| Area of classes | Very high | High | Moderate | Low | Very low |
|---|---|---|---|---|---|
| Hectare | 303 | 1800 | 2901 | 1058 | 186 |
| Percentage (%) | 4.89 | 28.79 | 46.4 | 16.93 | 2.99 |

**Table 4.** Percentage of fire-occurrences based on vulnerability categories on zoning map.

| Classes | Very high | High | Moderate | Low | Very low |
|---|---|---|---|---|---|
| Areas of fire vulnerable categories (%) | 3.86 | 25.71 | 48.46 | 21.97 | 0 |

## DISCUSSION

The study area represents a considerable proportion of the western part of Iran, while little fire research has been conducted until very recently. Zarivar Lake is a touristic area. This paper was trying partly to fill this gap in knowledge. The study was focused on the determination of three main different methodological approaches, remote sensing, GIS and AHP analysis. Based on the results of AHP analysis on destructive fire factors, the temperature had maximum influence on fire occurrence. The levels of temperature and humidity played the most significant role in determining the vulnerability of forest fires. Our findings were in line with other researcher's findings (Hosainali & Rajabi 2005; Mohammadi *et al*. 2010, 2013; Amalina *et al.* 2016). In the Zarivar Lake forest area, dry seasons encompassed five months of the year (June to October) and 90% of fires occurred in these seasons during 2009 and 2010. Although human activity is one of the most important factors in the creation of fire, we can say that human being plays a dual role in occurrence and spread of fire. The distance from the residential areas and roads (anthropogenic factors) received the second greatest weight. Since the human activity was higher in the proximity of residential areas and roads, and humans were the most important cause of fire, thus by increasing in the distance from these areas, the incident of fire will be lower. Our findings were in line with those of other researchers (Jaiswal *et al.* 2002; Erten *et al.* 2004; Dong *et al.* 2005; Gigolo *et al.* 2006; Mahdavi *et al.* 2012; Amalina *et al.* 2016). In the present study, the vegetation cover density was identified to be one of the most important factors. Since vegetation density determines the amount of fire fuel, it can be one of the most important factors leading to fire. Evidently, by increasing in vegetation density, the probability of fire occurrence and its spread were higher. Amelia *et al.* (2016) came to the same conclusion. The vegetation density and biomass data were not available for the Zarivar Lake forest region. Therefore, the vegetation density map was derived from SPOT- HRG data using MLC algorithm. In the study area, weight and importance of coefficients influencing the forest-fire occurrence were produced by EC software. These layer maps including vegetation density, geographical aspects, slopes, distance from water sources (streams and lake), distance from roads and residential area, rainfall transform to vector format in the ArcGIS software environment. The weights and importance of coefficients influencing these factors were different. Our findings were in accordance with those of other researchers (Erten *et al.* 2004; Dong *et al.* 2005; Pandey & Barik 2006; Rahimi & Esmaili 2010; Mahdavi *et al.* 2012). Of the total area studied, 4.89% and 28.79% had very high and high fire performance respectively. Average, low and very low fire performance were encompassed 46.4%, 16.93% and 2.99% of the total area respectively (Table 3).

Considering that 80% of the area has a moderate to very high fire risk performance, it is necessary to adopt preventive approaches to fire in these forests. Polygons of burned areas of the Zarivar Lake forests occurred in 2009 and 2010 overlaid on the final vulnerability map in Arc Map environment (Fig. 4). About 3.86% of burned areas happened in very high vulnerability, 25.71% in high, 48.46% in moderate and 21.97% in low out of final vulnerability map. These findings are consistent with those of Chuvieco & Conglaton (1989) who showed that 22% of the pixels located in high-risk areas, had been actually burned in the past years. We suggest that he role of wind factor, including wind speed and direction, would be considered in further studies. Besides, if the height difference in the area is high, the height criterion can be investigated as an effective factor in the fire. Considering these factors, Forest Fire Service of Iran can be used the fire vulnerability map for fire management in the Zarivar Lake forest area during dry seasons.

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# تهیه نقشه مناطق آسیب‌پذیر نسبت به آتش‌سوزی با استفاده از داده‌های سنجش از دور، GIS و AHP، (منطقه مورد مطالعه: مناطق اطراف دریاچه زریوار)

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## چکیده

آتش‌سوزی نقش مهمی در تخریب و نابودی و ایجاد تاثیر منفی در اکوسیستم‌های جنگلی دارد. هدف اصلی این مطالعه تعیین فاکتورهای اساسی تاثیرگذار در ایجاد آتش‌سوزی در جنگل‌های منطقه دریاچه زریوار با استفاده از داده‌های سنجش از دور، سیستم اطلاعات جغرافیایی، و روش تحلیل سلسله مراتبی است. نقشه تراکم پوشش گیاهی با استفاده از داده‌های تصویر ماهواره‌ای SPOT-HRG با صحت کلی ۷۱/۳۸% و ضریب کاپای ۰/۶۹۵ تهیه شد. نتایج حاصل از روش AHP بر روی فاکتورهای مخرب در ایجاد آتش‌سوزی نشان داد که درجه حرارت و فاکتورهای انسانی بیشترین تاثیر را در ایجاد آتش‌سوزی در منطقه مورد مطالعه دارند. بر اساس روش AHP، نقشه نهایی مناطق آسیب‌پذیر در منطقه مورد مطالعه در محیط Arc MAP با پنج طبقه آسیب‌پذیری تهیه شد. نتایج نشان می‌دهد که ۷۸/۰۳% از مناطق سوخته شده در سالهای ۲۰۰۹ و ۲۰۱۰ در طبقات با آسیب‌پذیری بسیار زیاد، زیاد و متوسط رخ داده است. مراکز کنترل آتش‌سوزی جنگل‌های ایران می‌تواند از نقشه مناطق آسیب‌پذیر برای مدیریت آتش‌سوزی در جنگل‌های دریاچه زریوار در فصل خشک استفاده کند.

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