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Forests and rangelands' wildfire risk zoning using GIS and AHP techniques

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ABSTRACT

Wildfire in forests and rangelands, apart from its initiating causes, is considered as an ecological disaster. Zoning natural areas according to their susceptibility to fire helps to put off operations and reduces catastrophic losses caused through a wise management plan. In this study, the zoning map of wildfire risk in forest and rangeland areas has been produced using GIS, Analytical Hierarchical Processing (AHP) and remote sensing techniques. The study area is about 196000 ha of Ilam Township, located in western Iran. The influencing factors in wildfire occurrence include current land use/cover, roads and rivers, as well as physiographic, climatic and anthropogenic themes. The locations of the wildfires have been registered by using a GPS from 2007 to 2009, to map wildfire occurring pattern in the study area. Then, using AHP techniques the influencing factors in occurrence and extension of the fires were compared in pairs and weighed. According to the weight calculated for each factor and its corresponding classes, the weighed maps of the factors were produced and employed to produce the final map of wildfire risk zoning. Finally, the zoning map of wildfire risk was produced including five classes of the risk from high to very low. Comparing the map of the wildfire risk potential to the actual fires that happened, it was found that 50 and 40 percents of the fires initiate form the areas, marked as high risk and risky zones on the map, respectively. The results indicate a high compliance of the map of wildfire risk zoning and the location of the fires in the study area. As so it predicts more than 90 percent of occurring forest and rangelands wildfires and would be helpful data for arranging a better wildfire fighting annual plan in national and regional forests and rangeland management headquarters. The model could turn to a more sophisticated one by adding extra influencing factors like, wind speed and its directions. The present model is a static one and to solve such a problem it should be promoted to a dynamic model.

Keywords: *Wildfire, Risk zoning, GIS, AHP, Iran.*

INTRODUCTION

Forests and rangelands are natural resources with important roles in maintaining environmental balance, and their health is a good indicator of the ecological conditions prevailing in the region. Forests and rangeland wildfire is one of the most effective factors on wild animals and natural vegetations. It is a potential risk factor, affecting physical, ecological, biological and environmental properties of forest stands (Rajeev Kumar *et al*., 2002). In some cases, wildfire, as a natural phenomenon, is considered a part of the carbon cycle that also helps forest and rangeland health. So preventing this type of fires could be considered as an intervention in natural cycles. Sometimes, a planned forest fire program is a strategy foresters employ to prevent disastrous forest fires. This type of forest fires, called forest wildfire, is a kind of disaster and crisis (Husseinali, & Rajabi, 2006). Generally, wildfires can be considered as ecological disasters, regardless of whether they occurred naturally or by human factors. Controlling natural wildfires is actually impossible, however it is possible to prevent frequent forest and rangeland fires and to reduce the catastrophic losses caused by them by mapping and managing the areas susceptible to these fires (Rajeev Kumar *et al*., 2002; Dong, *et al*., 2005). Despite the efforts made by natural resource managers to prevent wildfires, an average of 5400 ha of forest and rangeland are destroyed due to the fires annually, which cause vast economic, social and environmental consequences in the study area. According to FAO reports, about 4830 ha of Iran's forest and rangeland has been destroyed from 2003 to 2007, annually (Mohammadi, 2009). So, having an up-to-date map of wildfire risk zoning is of great of importance for conserving forest and rangelands in western Iran and even more for protecting the civilians in these areas from the fires. Analyzing these fires is based on works of mapping potential risk of forest fire ignitions, wildfire detection, wildfire control and mapping severity of the fire risk. This information is helpful for foresters, fire brigades and also researchers interested in the subject (Klaver, *et al.*, 1997). Several studies have been done on the subject of forest wildfire worldwide, but not many in Iran. Trying to define ecological characteristics and phyto-sociology of the areas, affected by forests and rangelands wildfires, are some other kinds (Zare-Mayvan & Memaryani, 2001). Mapping the wildfires risk zoning, and presenting classes of potential risk for the fires, is one of the most regular kinds of studies (Mohammadi, 2009). Nowadays, GIS, Remote Sensing and mathematical techniques have provided many new opportunities for analyzing and managing the wildfires, quantitatively. Using these technologies, provide an effective instrument to predict the area at risk of forest and rangeland wildfires through modeling procedures (Pradhan, *et al.*, 2005). Remotely-sensed products e.g. vegetation indices and topographic derivatives e.g. Digital Elevation Model (DEM), Slope and Aspect that have been integrated into wildfire risk zoning models have also been employed to delineate high risk area of forests and rangelands (Akbari-Nia, *et al.* 2008). Ancillary data such as forest and rangeland species, land/use cover, stand age and the neighborhoods like crop field, and residential area have also been used to create risk indicators and influence factors with the imageries (Bülent, *et al.* 2008, Rajeev Kumar, *et al.*, 2002). These empirical models describe, estimate and predict wildfire dynamics by providing risk indicators. Fire Potential Index (FPI) also has been defined based on surface flammable materials in forest and status of their moisture (Huesca, *et al.* 2008). This study aims at determining the role of the most important influencing factors on potentials of forest and rangeland wildfire risk and preparing the map of risk zoning for Ilam Township, Iran.

The study area with a surface area of about 196000 ha, is located in Northwest Ilam province, Iran, within 33°21'35" to 33°51'36" N Latitude and 45°40'34" to 46°51'12" E Longitude.

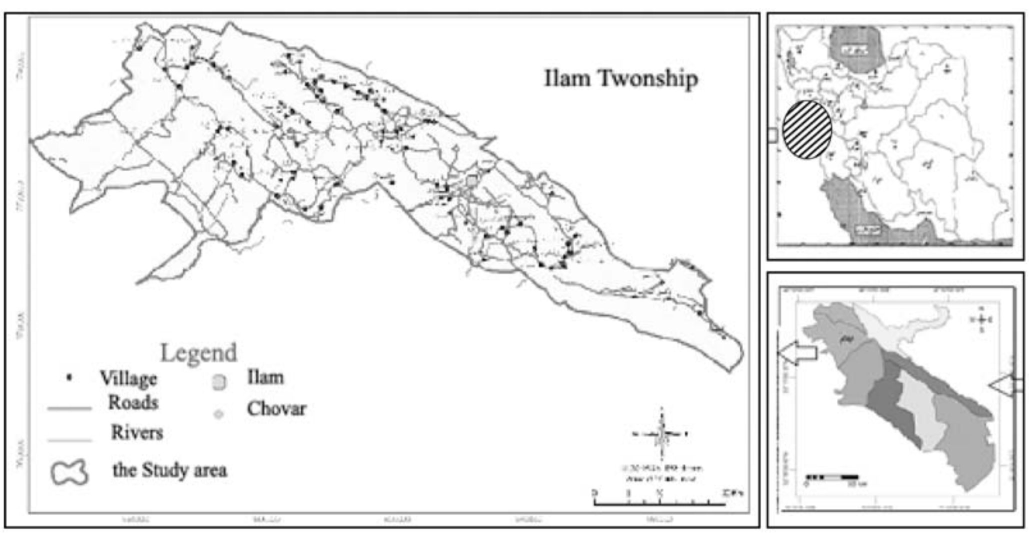

Fig 1. Location of the study area in Ilam Province,Iran

Fig.1 indicates the location of the study area in Iran, in Ilam Province. The province database on forest and rangeland wildfires indicates that 95 wildfire cases have happened in forests and rangelands of Ilam province in 2008, burning 1514 ha of the natural resources of the province.

MATERIALS and METHODS

Study area

Forest and rangeland wildfire statistics were collected for the period 2007 to 2010. The fire zones were also registered using handset GPS by the Natural Resources Management Office, Ilam, Iran (Headquarter of Natural Resource and Watershed Management, Ilam Province, 2010). Fig.2 also indicates locations of the occurrence of fire in the study area for the period. Then the natural and physical characteristics of the fire locations were determined according to the frequency of wildfire occurrence in the study area.

Digital Elevation Model (DEM) of the study area was produced using digital topographic map of the region, by an interpolation technique in a raster environment. Then, aspect and slope layers of the region were produced by using the DEM. The layers of distance from roads and rivers were produced using buffering application in ArcGIS software. Population density layer was obtained by establishing a population database for point map of villages in the study area. Then, the population density was calculated by using the villages' territorial area and the population number in each area. Temperature and precipitation layers were produced by establishing regression models between temperature and precipitation measures in the location of local weather stations and their corresponding elevation from the DEM.

Land cover layer was derived from satellite image interpretation, using both digital image classification methods and visual interpretation techniques. The existing land use/cover map of the region was employed as ancillary data. IRS-1c LISS-IV imagery, dated 20 June 2007, resized to a spatial resolution of 5.8m, was the main remotely-sensed data source in this research. Then, all thematic layers including elevation, slope and aspect, distance from rivers and roads, population density, temperature and precipitation layers, considered as influencing factors on forest and rangeland wildfire risk, were entered in ArcGIS software for further analysis. The occurrence of fires is involved with a wide range of different influencing factors.

To determine how much a certain factor influences forest and rangeland wildfire occurrence, an AHP procedure has been employed in Expert Choice software. It has also been repeated for weighing the influence of the classes within a certain factor. In this research, AHP procedure type was of the weighing participating factors. The process was started by scoring, first the factors and then the classes within the factor layers. In a compensational manner, each factor or each class, included in a factor layer could compensate the lack of the other influencing factors and could be alternated by the others. For instance, a higher class of land cover could compensate the lower class of air temperature to prepare the site for a forest and rangeland wildfire. The scoring process was based on understanding the importance of a certain factor and its corresponding classes in occurring forest and rangeland wildfires. In this manner, the factors and the classes could be compared in a pair wise procedure. Comments of experts on the influencing factors on forest and rangeland wildfire occurrence were analyzed; however, it indicated a high rate of variation in answers. Besides, weight of a certain class within an influencing factor was estimated by calculating ratio of occurred wildfire area located in the class to the total area of the fires in the region. Then, the scores were scaled on a range of 0 to 100 (Mohammadi, 2010; Shadfar, *et al,* 2008). To estimate the ratio for the classes, the forest and rangeland wildfire occurrence layer was overlaid on the influencing factors, separately.

After the scoring classes within a factor layer, the highest score of including classes was assigned to the factor layer itself. The logic is based on the fact that the influence of a factor layer equals the maximum score of the classes, included in the layer. By assigning the scores to the factor layers and their corresponding classes, in Expert Choice software, the corresponding weights were calculated. All the weights were scaled into a range of 100 points (Shadfar, *et al*. 2008; Garaei, *et al*. 2009, Carmel, *et al*, 2009). The closer score to 100 means the more susceptibility and risk of forest and rangeland wildfire occurrence and vise versa. To calculate the final weight, the weight of the including classes in a layer were multiplied by the weight of the layer. The model, shown in Eq.1, was commonly used to determine potential risk of occurring forest and rangeland wildfires. By entering the layers into the model, the map of forest and rangeland wildfires risk zoning was produced and classified into categories of the risk zones.

$$FFRZ = W_{Ri}(a_1RiI + a_2RiII + a_3RiIII + a_4RiIV) + W_{Ty}(b_1TyI + b_2TyII + b_3TyIII + b_4TyIV) + W_{Al}(c_1AlI + c_2AlII + c_3AlII + c_4AlIV) + W_{As}(d_1AsI + d_2AsII + d_3AsIII + d_4AsIV) + W_s(e_1SI + e_2SII + e_3SIII + e_4SIV) + W_{Ra}(f_1RaI + f_2RaII + f_3RaIII + f_4RaIV) + W_{Te}(g_1TeI + g_2TeII + g_3TeIII + g_4TeIV) + W_p(h_1PI + h_1PII + h_3PIII + h_4PIV) + W_{Ro}(i_1RoI + i_2RoII + i_3RoIII + i_4RoIV)$$

(Eq.1)

Where, *FFRZ* is Forest Fire Risk Zone, *Ri*; Distance from the river, a_1, a_2, a_3, a_4: the corresponding weight of its classes, *Ty*; Land Cover, b_1, b_2, b_3, b_4 the corresponding weights of its classes, *Al*; Elevation, c_1, c_2, c_3, c_4 the corresponding weights of its classes, *As*; Aspect, d_1, d_2, d_3, d_4 the corresponding weights of its classes, *S*; Slope, e_1, e_2, e_3, e_4 the corresponding weights of its classes, *Ra*; Precipitation, f_1, f_2, f_3, f_4 the corresponding weights of its classes, *Te*; Temperature, g_1, g_2, g_3, g_4 the corresponding weights of its classes, *P*; Population density, h_1, h_2, h_3, h_4 the corresponding weights of its classes, *Ro*; Distance from roads, i_1, i_2, i_3, i_4 the corresponding weights of its classes of I, II, III & IV, finally, W_{Ri}, W_{Ty}, W_{Al}, W_{As}, W_S, W_{Ra}, W_{Te}, W_P & W_{Ro} are the weights of the influencing factors of forest and rangeland wildfire risk.

To estimate validity of the results, gained through using the model, potential risk of forest and rangeland wildfires occurrence were compared to the wildfires occurred in the study area. Table 8 indicates the percentage of synchronization between these two.

RESULTS

Through intensive fieldwork, map of previous forest wildfires was produced. GIS layers of surface elevation, aspect, slope and its corresponding classes were obtained from a fine DEM of the study area. Satellite imagery, topographic layer, distance from roads, distance from rivers and layer of population density were obtained from local databases. Land use/cover layer, already produced through intensive field work, was also digitized and entered in the process. Gradient of temperature and annual precipitation were modeled in GIS employing the DEM, average annual temperature and rainfall measurements, were recorded in local weather stations, using statistical regression modeling. After preparing the influencing factor layers of forest and rangeland wildfire occurrence, the layers were classified (Table 2). Then, ratio of fire area in a certain class of a factor layer to the total area of the wildfire zone in the whole study area was calculated (Table 3). The hierarchical structure employed in this study is also illustrated (Table 4).

Table 2. Classes defined within the influencing factors

Code	Land Cover	Dist. Rivers	Temp. (D)	Precip. (mm)	Dist. Road(m)	Pop. Density	Aspect (+flat)	Slope (%)	Elev. (m)
1	Bare land -low cover	25	25-30	250-450	200	200>	N	0-10	0-750
2	Poor range –agri.	50	20-25	450-570	400	200-500	S	10-20	750-1500
3	Thin forest – ave.	100	15-20	570-700	600	500-3000	E	20-50	1500-2250
4	Dense forest – good range	100<	10-15	700-850	>600	3000<	W	> 50	2250-3000

Table 3. The score of the classes within the influencing factors, in the study area

Code	Land cover	Dist. River	Precip.	Temp.	Dist. Road	Pop. Density	Aspect	Slope	Elev.
1	0	6	71	0	30	87	7	28	71
2	9	6	27	7	21	0	54	53	17
3	74	11	2	22	17	3	32	15	12
4	17	77	0	71	32	10	7	4	0

Table 4. The hierarchy of the influencing factors and their corresponding classes

The Criteria (The Factors)	The Sub-Criteria	The alternatives
Topography	Elevation (m)	0-750
		750-1500
		1500-2250
		2250-3000
	Slope (%)	0-10
		10-20
		20-50
		>50
	Aspect	North
		South
		East
		West
		Flat
Climate	Precipitation(mm)	250-450
		450-570
		570-700
		700-850
	Temperature	10-15
		15-20
		20-25
		25-30
Land cover		Bare lands & low cover
		Agriculture & rangeland (3)
		Low forest & rangeland (2)
		Dense forest & rangeland (1)
	Distance from Rivers	25
		50
		100
		>100
	Distance from Roads	200
		400
		600
		>600
Human Factors	Population Density	200>
		200-500
		500-3000
		>3000

Table 5. The Scores, gained by the Criteria (the factor layers) out of 100

Criteria	Score	Sub-Criteria	Score
		Altitude	71
Topography	71	Slope	53
		Aspect	54
Human factor	87	Pop. density	87
		Dist. road	32
Climate	71	Temperature	71
		Precipitation	71
Dist. River	77		
Land cover	74		

The scores, in tables 3 and 5 were entered into Expert Choice software weighing program, directly. Tables 6 and 7 indicate the resulting weights.

Table 6. The weights of the classes in the factor layers, calculated using AHP

Code	Land Cover	Dist. River(m)	Precip.	Temp.	Dist Road(m)	Pop. Density	Aspect	Slope (%)	Elev. (m)
1	0.00	0.016	0.093	0	0.058	0.167	0.007	0.029	0.075
2	0.04	0.016	0.039	0.009	0.04	0.00	0.057	0.056	0.018
3	0.195	0.029	0.008	0.029	0.033	0.006	0.034	0.016	0.013
4	0.059	0.203	0	0.093	0.062	0.019	0.007	0.004	0

Table 7. The weights of the Criteria (the factor Layers) and the Sub-Criteria (the corresponding classes)

Criteria	Weight	Sub-Criteria	Weight
		Altitude	0.075
Topography	0.187	Slope	0.056
		Aspect	0.057
Human factor	0.229	Pop. density	0.167
		Dist. road	0.062
Climate	0.187	Temperature	0.093
		Precipitation	0.093
Dist. river	0.203		
Land cover	0.195		

The weights, calculated for various classes were entered in a scaling system based on a range of 100 points. The scaled weights are presented in table 8.

Table 8. The Scaled weights of the classes included in the factors' layers

Code	Land Cover	Dist. River(m)	Precep.	Temp.	Dist. Road(m)	Pop. Density	Aspect (+flat)	Slope (%)	Elev. (m)
1	0	7.88	100	0	53.22	100	12.28	51.78	100
2	20.51	7.88	41.93	9.67	64.51	0	100	100	24
3	100	14.28	8.6	31.18	93.54	3.5	59.64	28.57	17.33
4	30.25	100	0	100	100	11.37	12.28	7.14	0

To get the final weights, the weights calculated for each certain class, shown in table 8, were multiplied by the corresponding weight of the influencing factor layer. This was done for all of the factors. Then, the factors were integrated in GIS using the model, Eq. (1) to map the wildfire susceptibility zoning in the study area. The factors' hierarchy is shown in table 2. Descriptions of the wildfire risk classes have been presented in table 9.

Table 9. Site description of wildfire risk zone, risk classes, susceptibility and actual wildfires occurrences

	Site Descriptions of Wildfire Risk Zone	Fire Risk Class	Fire Suscept. (%)	Actual Fire (%)
a)	Semi-dense forest, Good rangelands in understory, Elev.; ranges750-2000m, Slope; 20 -50%, Aspect; Southern, Pop. Density; 500-3000 and more, Temp.; 20 – 25d, Precipitation; 450-700mm	High	50.3	19
b)	Thin forest, average and poor rangelands in understory, Elev.; <1500m, Slope; <20%, Aspect; Western, Pop. Density; <500, Temp.; 20 – 25d, Precipitation; 450-700mm	Risky	40	33
c)	Very thin forest, Average and Poor rangelands, Elev.; <1500m, Slope; < 10%, Aspect; Western, Pop. Density; <200, Temp.; >20d, Precipitation; <570mm	Average	6.9	32
d)	Agricultural lands, Poor rangelands, Elev.; ranges1500-1700m, Slope; <10%, Aspect; all aspects, Adjacent to roads, Temp.; 15-20d, Precipitation; 570-700mm	Low risk	2.8	15
e)	Bare Lands, No vegetation Cover, river beds	No-Risk	0	1

The final map of the wildfire risk zones (Fig.2), was compared to the actual wildfire locations, to assess its accuracy. Coincidence of high risk areas with the actual fire occurrence in the study area was an important test for the success of this approach (Table 8).

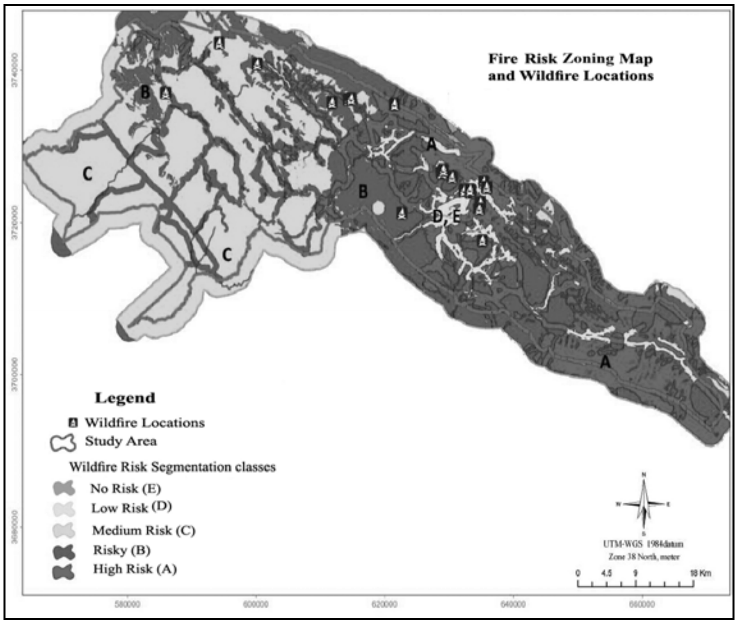

Fig 2. Wildfire risk zoning map and the location of the wildfires.

DISCUSSION

In this study, the forest and rangeland fire susceptibility zoning map was produced by combining GIS and AHP capabilities. The results indicate that GIS and AHP are useful instruments to map forest and rangeland wildfires and to understand the key factors to manage fires in the study area. However, AHP technique is of that logic with a compensational behavior. So the factors with interactions which may be the cause of intermediate situations would be ignored. The results indicate that the highest risk of the wildfire belongs to the second class of elevation (1000-2000m) in the mountainous areas. Similar results also reported by Dong, *et al.*, (2005) and Mohammadi (2010) present effects of surface elevation and topography on the susceptibility of forests and rangelands to wildfires. The most susceptible areas to fires are the 3rd (20-50%) and the 4th classes of slope, with probabilities of 20-50% and more than 50%, respectively. Research, accomplished by Rajeev Kumar *et al.* (2002), Dong *et al,* (2005) and Keane *et al,* (2009) conform with these results. The highest potential of wildfire risk is expected for southern aspects. Majority of the wildfires have occurred in Persian oak forest (*Querqus persica* L.), however, this class is the dominant land cover class of the study area. Reaching of enough light to the bottom floor of the forest stands and soil surface, because of sparse forest canopy, causes a good herbaceous ground cover, providing sufficient fuel and surface materials for the fires in dry climate conditions. The highest wildfire risk occurs in the classes of low precipitation and high temperatures, which is quite reasonable according to the climate factors. It also occurred in the area with high population density, which is why the highest forest wildfire risk was placed around the main city of the region, Ilam. In terms of distance from roads and rivers, in both cases, the majority of the fires occurred far from the entities. According to Erten *et al.* (2002) and Rajeev Kumar *et al,* (2002), the fires are expected to occur near roads and rivers. It seems that these two factors are not the main influencing fire susceptibility factors in the study area, as shown in tables 6 and 7. Roads facilitate access to the entire region, so the more intensive monitoring over forest and rangelands, the less probability of occurring wildfires. However, orchards and farms are supervised by their owners to prevent fire initiations in their properties; they will increase probability of extending unwanted fires, used for agricultural activities, towards forests and rangelands in their neighborhood. This is the reason why the majority of wildfires happen far from riversides, because orchards and farms, owned by local communities are located there. About 50 percent of wildfires occurred in high risk areas and 40 percent are located in risky areas (Table 9). So, it seems the map of forest and rangeland wildfire susceptibility zones, produced in this research, predicts more than 90 percent of occurring forest and rangeland wildfires in the study area and would be helpful data for arranging a better wildfire fighting annual plan in national and regional forest and rangeland management headquarters. All wildfires were considered to have originated from existing natural potentials for ignitions and not from fires extended to the region. However, the model, proposed in this research, could turn to a more sophisticated one by adding extra influencing factors like, wind speed and its directions. The current model is a static one and to solve such a problem it should be promoted to a dynamic model, using dynamic factors like winds.

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پهنه‌بندی خطر آتش‌سوزی جنگل‌ها و مراتع با استفاده از تحلیل سلسله مراتبی و سامانه اطلاعات جغرافیائی

ع. مهدوی، س. ر. فلاح شمسی، ر. نظری

چکیده

آتش سوزی در جنگل ها و مراتع، صرفنظر از عوامل مسبب آن، بلیه اکولوژیکی مهمی محسوب می‌شود. پهنه بندی نواحی طبیعی با توجه به حساسیت آنها به آتش سوزی، به برنامه‌های اطفاء حریق کمک می‌کند و خسارت‌های ناشی از این عامل مخرب را در خلال یک برنامه مدیریت هوشمندانه کاهش می‌دهد. در این تحقیق نقشه پهنه‌بندی خطر آتش‌سوزی در عرصه‌های جنگلی و مرتعی با استفاده از فنون سامانه اطلاعات جغرافیائی، تحلیل سلسله مراتبی و سنجش از دور تولید شده است. منطقه مورد مطالعه حدود 196000 هکتار از محدوده شهرستان ایلام در غرب ایران واقع شده است. عوامل موثر بر وقوع آتش‌سوزی شامل پوشش/کاربری فعلی، راه‌ها و رودخانه‌ها، فیزیوگرافی، اقلیم و عوامل انسانی مورد توجه قرار گرفته است. موقعیت آتش سوزی‌ها با استفاده از یک دستگاه موقعیت یاب جهانی بین سالهای 1386 تا 1389 ثبت شده تا نقشه ای از الگوی وقوع آتش سوزی در منطقه مورد مطالعه تهیه شود. سپس با استفاده از فنون تحلیل سلسله مراتبی، عوامل موثر در وقوع آتش‌سوزی و توسعه آتش به صورت دو به دو مقایسه شده و وزن داده شده اند. با توجه به وزنی که برای هر عامل محاسبه شده و طبقه‌ای که به آن تعلق می‌گیرد، نقشه‌های وزنی عوامل تولید شده و برای تولید نقشه نهائی پهنه‌بندی خطر آتش‌سوزی مورد استفاده قرار گرفته است. سرانجام؛ نقشه پهنه‌بندی خطر آتش‌سوزی شامل 5 طبقه خطر آتش‌سوزی از زیاد به کم تولید شد. نتیجه مقایسه نقشه خطر بالقوه آتش‌سوزی با آتش‌سوزی‌های واقع شده در منطقه نشان می‌دهد که به ترتیب 40 و 50 درصد آتش‌سوزی‌های نشات گرفته در منطقه، به ترتیب در پهنه هائی قرار گرفته اند که بر نقشه خطر به عنوان طبقه بسیار پرخطر و خطرناک قرار گرفته اند. نتایج تحقیق نشان دهنده انطباق بالای نقشه پهنه‌بندی خطر آتش‌سوزی با موقعیت آتش‌سوزی‌های رخ داده در منطقه مورد مطالعه است. بنابراین نقشه مورد نظر حدود 90 درصد وقوع آتش سوزی های جنگل ها و مراتع را پیش بینی می کند و داده‌ای مفید برای سازمان‌دهی برنامه اطفاء حریق در سطح ملی و منطقه‌ای و در سازمان جنگل‌ها، مراتع و آبخیزداری محسوب می‌شود.