Pol. J. Environ. Stud. Vol. 24, No. 5 (2015), 2309-2314

Short Communication

Prediction of Future Forest Fires Using the MCDM Method

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Received: December 4, 2012
Accepted: October 10, 2013

Abstract

This research was done to predict future forest fires using the multi-criteria decision-making (MCDM) method in District Three of Neka-Zalemroud Forests. We used a fire risk model integrated with the MCDM method in a GIS framework to map the forest fire risk in the study area. Factors included four major criteria (topographic, biologic, climatic, and human factors) and 17 sub-criteria. Data of these parameters were collected and organized in the GIS framework to provide the factor maps. Then the major criteria maps (using weighted overlay of sub-criteria maps of each criterion) and the fire risk map (using weighted overlay of four major criteria maps) were provided using the fire risk model. The actual fire data in the study area was used for cross checking. Results of this study showed the high-risk regions in fire risk map accordance with the actual fires. It can prove the high accuracy of the MCDM method and the used model to predict future fires in Hyrcanian Forests of Iran.

Keywords: fire, Hyrcanian Forests, MCDM, GIS

Introduction

Fire with natural or anthropogenic origins has destructive impacts on the environment, forests, and humans [1, 2]. Forest fires are one of the most important sources of land degradation that lead to deforestation processes [3]. Fire threatens thousands of hectares of forests around the world annually, as the average of annual fires in forests of the world is about 6-14 million hectares [4]. Thus prediction of high-risk fire areas using a proper model and method is very important because knowing where the fire risk is highest will help to reduce threats to minimize threats to forests, natural resources, humans, and property by fire [5]. Thus construction of a fire risk map has great importance for conserving forests and rangelands, and even more for protecting the residents in these areas from fires [6]. Therefore, finding the best method and model to predict future fires in forest areas is very important regarding the destructive effects of fires on forests.

A great range of techniques has been used to model fire risk, from pure "crisp" mathematical models (usually based on Rothermel [7] equations), to cellular automata and computational intelligence techniques [8]. The more complex fire models require spatial information that is furnished by remote sensing and geographic information systems (GIS) [9].

Various studies have applied GIS to map fire-risk areas in forests. Some of these studies have been done using a

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defined formula for forest fire-risk [10, 11]. Some of them have modified the old fire-risk formulas to effective factors on forest fires on a regional scale [12]. Others have been performed using the fire risk model [5, 13-16]. Some of these studies have also applied the AHP method integrated with GIS to predict fire risk locations [6, 17-20].

However, no studies have been done to evaluate fire risk potential using the MCDM method to predict future fires in high-risk areas in the temperate deciduous forests of northern Iran, despite the fact that large areas of these forests have been burned by wildfires in recent years [21]. Therefore, in this study we evaluate the fire risk potential in District Three of Neka-Zalemroud Forests using a multi-criteria model and MCDM method, and we verify the validation of this multi-criteria model to predict the future fires in these forests. It is predicted that this method has good efficiency to predict the future fires in the northern Hyrcanian Forests of Iran.

Material and Methods

Study Area

District Three of Neka-Zalemroud Forests is located between 36º 30’ to 36º 40’ N latitude and 53º 15’ to 53º 26’ E longitude south of Neka and Behshahr counties of Mazandaran Province in Iran (Fig. 1). It covers an area of 153.07 km^2. The study area is bound by Neka-Behshahr Road in the north, Chakhani and Souterabad in the east, Zarandin Khoramchamaz in the south, and Ablou in the west. Minimum and maximum altitudes from sea level are 90 and 820 m, respectively. Soil texture mainly is loam to sandy in the study area. In addition, District Three has a calcareous structure in terms of geology. Annual temperature mean is 17.16ºC and annual precipitation mean is 602-621 mm in the study area. Forests of the study area have uneven-aged and mixed structure. Plant species include trees (*Fagus orientalis, Carpinus betulus, Quercus castaneifolia, Alnus subcordata, Acer* sp., *Parrotia persica, Zelcova carpinifolia,* etc.), shrubs (*Buxus hyrcanus, Mespilus germanica, Crataegus pentagyna, Prunus caspica,* etc.) and herbs (*Asperula odorata, Carex* sp., *Ruscus hyrcanus, Siclaman* sp., *Rubus* sp., etc.). Wide areas of these forests have been burned by wildfires in recent years [21].

Research Methods

In this study our methodology consisted of four different components [22]:

1) determination of fire risk major criteria and sub-criteria and preparation of the maps,
2) assignment of in-layer and out-layer weights to sub-criteria in a GIS environment,
3) combination of sub-criteria and major criteria maps and construction of fire risk potential map, and 4) validation of the fire risk potential map.

Determination of Fire Risk Major Criteria and Sub-Criteria and Preparation of the Maps

In this study, the data used included the maps of four major criteria and their 17 sub-criteria. These major criteria and sub-criteria are shown in Fig. 2. The topographic factor maps were obtained from DEM of ASTER sensor (with 25-m pixel size). The biological and human factor maps were provided by the Mazandaran Natural Resources Administration (MNRA), and ground samplings were made using GPS. The climatic factor maps were obtained from the Mazandaran Meteorological Administration. The actual fires map in the study area also was provided by MNRA. These data have been organized in a GIS framework to provide the digital maps of factors and further analysis.

Assignment of In-Layer and Out-Layer Weights to Sub-Criteria in a GIS Environment

First, maps of each sub-criterion were converted to raster format. After classification of sub-criteria maps, the values (classes) in each map were normalized to values between zero and one in the GIS environment. Value zero was assigned to the very low-risk class while

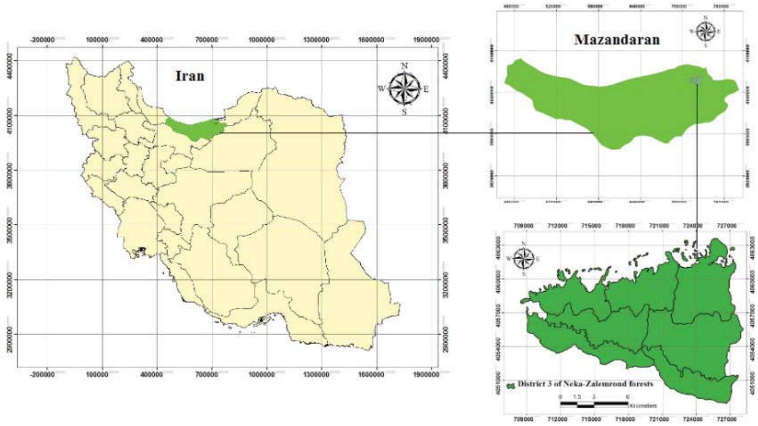


Fig. 1. Study area map.

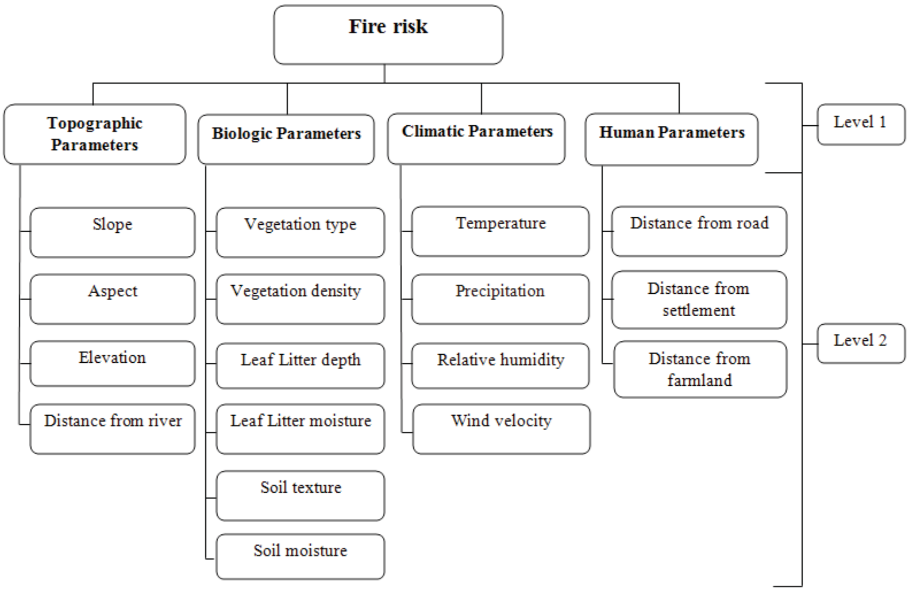


Fig. 2. Fire risk criteria and sub-criteria in the study area.

value one was assigned to the very high-risk class in each sub-criterion map. Values between zero and one were assigned to the low-, medium-, and high-risk classes in each sub-criterion map. These values were considered as in-layer weights of each sub-criterion. This process was performed for all sub-criteria maps. Out-layer weights of sub-criteria have also been obtained from coefficients in the fire risk multi-criteria model [22] in this study (equations 1 to 5). The major criteria models and the fire risk model were presented based on obtained weights.

$$\textbf{\textit{Topographical criterion index}} = w\,(slope) + w(aspect) + w(elevation) + w(distance\ from\ river) \tag{1}$$

$$\textbf{\textit{Biological criterion index}} = w(vegetation\ type) + w(vegetation\ density) + w(leaf\ litter\ depth) + w(leaf\ litter\ moisture) + w(soil\ texture) + w(soil\ moisture) \tag{2}$$

$$\textbf{\textit{Climatic criterion index}} = w(temperature) + w(precipitation) + w(relative\ humidity) + w(wind\ velocity) \tag{3}$$

$$\textbf{\textit{Human criterion index}} = w(distance\ from\ road) + w(distance\ from\ settlement) + w(distance\ from\ farmland) \tag{4}$$

$$\textbf{\textit{Fire risk index}} = w(Topographic\ index) + w(Biologic\ index) + w(Climatic\ index) + w(Human\ index) \tag{5}$$

…where *w* (coefficients in each equation) indicates the out-layer weight of each sub-criteria and criteria [22].

Combination of Sub-Criteria and Major Criteria Maps and Construction of Fire Risk Potential Map

Once sub-criteria maps are created, they are multiplied by weights. Maps of each major critera (topographic, biologic, climatic, and human) were obtained by weighing overlays of the sub-criteria maps of each criterion (Fig. 3). Finally, the fire risk map was obtained by weighing the overlay of the major criteria maps. These processes were performed through GIS spatial analysis using the raster calculator option in GIS.

Validation of the Fire Risk Potential Map

In this study, the actual fires map has been overlaid on the fire risk potential map to check the validation of the fire risk potential map and to assess the accuracy of the used model based on MCDM in District Three of Neka-Zalemroud Forests.

Results

Weight of Sub-Criteria and Major Criteria and Modeling of Forest Fire Risk Using Fuzzy AHP

Regarding the weights of sub-criteria and major criteria, the major criteria models and the fire risk model have been presented as the following equations:

$$\textbf{\textit{Topographic criterion index}}\ 0.2517(slope) + 0.3056(aspect) + 0.2177(elevation) + 0.225(distance\ from\ river) \tag{6}$$

Biological criterion index

$$0.1839(\textit{vegetation type}) + 0.1762(\textit{vegetation density}) + 0.1839(\textit{leaf litter depth}) + 0.1839(\textit{leaf litter moisture}) + 0.1306(\textit{soil texture}) + 0.1415(\textit{soil moisture}) \quad (7)$$

Climatic criterion index

$$0.2652(\textit{temperature}) + 0.2257(\textit{precipitation}) + 0.2381(\textit{relative humidity}) + 0.271(\textit{wind velocity}) \quad (8)$$

Human criterion index

$$0.3736(\textit{distance from road}) + 0.3227(\textit{distance from settlement}) + 0.3037(\textit{distance from farmland}) \quad (9)$$

Fire risk index

$$0.208(\textit{Topographic index}) + 0.2595(\textit{Biologic index}) + 0.2315(\textit{Climatic index}) + 0.301(\textit{Human index}) \quad (10)$$

Combination of Major Criteria Maps and Construction of Fire Risk Potential Map

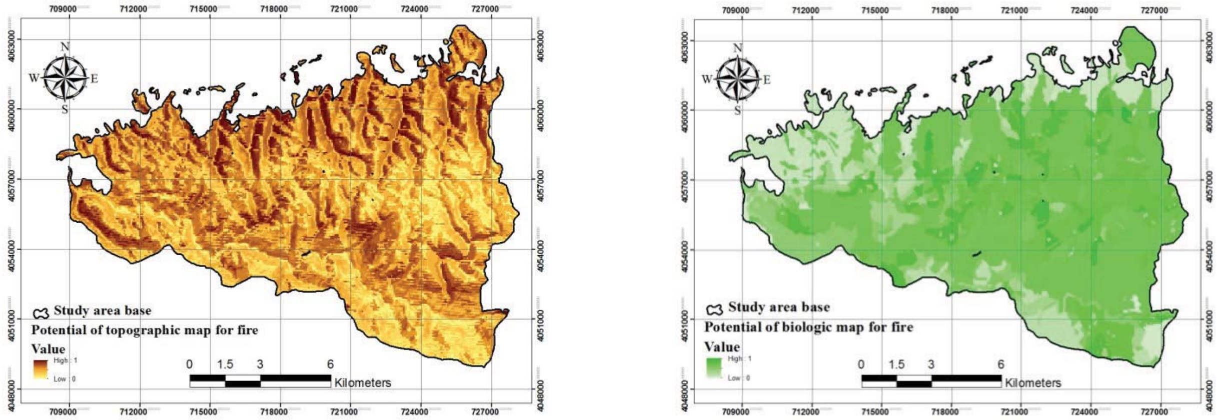
The fire risk map was obtained by weighing overlay of the major criteria maps and was classified into five classes (Fig. 4). In the fire risk potential map, the individual cells have been ranked from very low to very high based on their predicted risk to fire.

Validation of the Fire Risk Potential Map

In this study, the accuracy of the fire risk potential map was tested using the actual forest fires map. The actual fires map in the study area is shown in Fig. 5. The qualitative validation results of fire risk potential map are shown in Fig. 4. The quantitative validation of fire risk potential map is in Table 1.

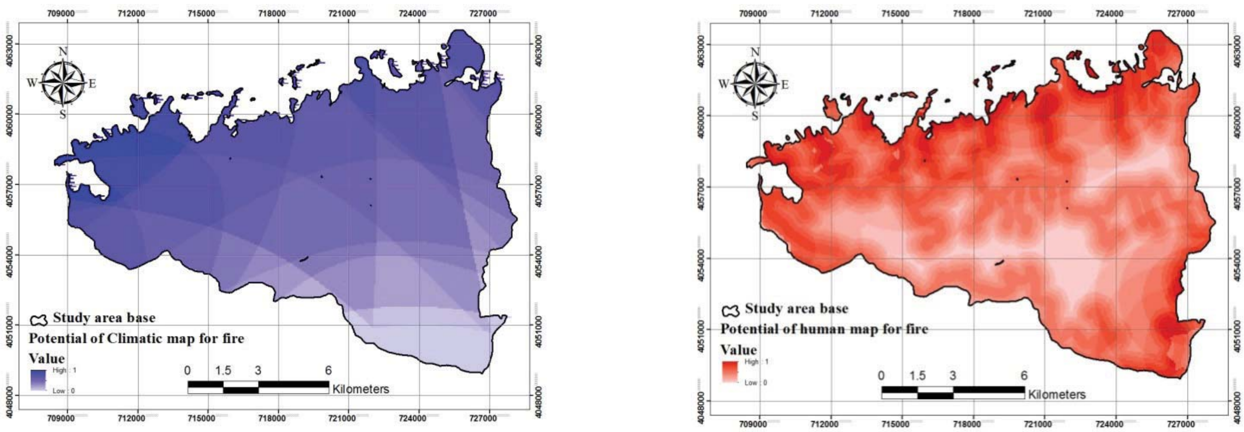
Discussion

Over the past few decades, fires in Hyrcanian Forests of Iran have received increasing attention because of the wide range of ecological, economic, and social impacts.



a) Topographic potential map for fire.

b) Biological potential map for fire.



c) Climatic potential map for fire.

d) Human potential map for fire.

Fig. 3. Major criteria fuzzy maps.

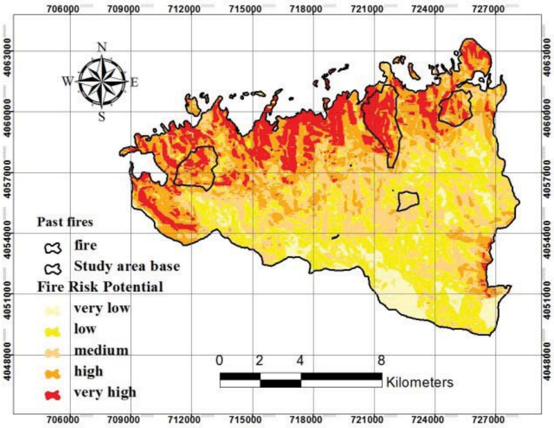


Fig. 4. The fire risk potential map and validation of it.

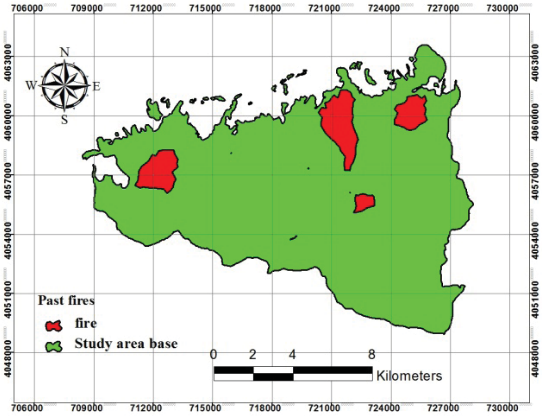


Fig. 5. The actual fires map.

Table 1. Quantitative validation of fire risk potential map using actual fires.

Actual fire	Area (ha)	Area of very high and high risk classes inside actual fire	Correlation
1	313.79	254.46	0.81
2	443.69	409.09	0.92
3	212.14	170.28	0.80
4	69.87	0.0084	0.0001
Total	1,039.50	833.85	0.80

This study was done to detect the areas with high-risk potential for fire and to predict the future fires in District Three of Neka-Zalemroud Forests using the multi-criteria model and MCDM. Results of analysis of the fire risk potential map show that 14.45% (2,204 hectares) of the study area has very high potential, and 24.29% (3,706 hectares) of the study area has high potential for forest fires. In addition, the medium, low, and very low potential for fire in the study area is 28.85% (4,403 hectares), 23.6% (3,601 hectares), and 8.81% (1,345 hectares), respectively. Thus most of the study area has high and very high potential for forest fire. Therefore, these forests will be exposed to future fires. Thus the preventive activities of fire occurrence in District Three is essential. The monitoring and management planning for fire control and prevention (building of fire breaks or establishing lookout towers) should be done in the most high-risk areas.

Results of overlays of the actual fires map on the fire risk potential map in current research show that the actual fire patterns largely follow the fire risk patterns. So the burned regions in the study area have high accordance with the very high-risk and high-risk regions in the forest fire risk potential map. As expected, 80% of the burned regions have been located in the very high-risk and high-risk regions. In addition, 17% the burned areas have been located in the medium-risk regions. The areas of low- and very low-risk in the burned area is limited (3%).

Thus the used multi-criteria model based on MCDM has good efficiency to predict the future fires in high-risk areas of Neka-Zalemroud Forests in northern Iran.

Conclusions

Considering the high accuracy of the proposed method for forest fire risk in this study, the prediction of future fires occurring in District Three of Neka-Zalemroud Forests is possible using the fire risk potential map. Actual forest fires have occurred in the high-risk areas; then it is expected that future fires will also occur in the high-risk areas. Therefore, the local forest fire management system should consider the actions according to predicting, preventing and controling fires in the high-risk areas.

Finally, it is suggested that the used model will be modified with attention to all the effective factors on forest fires in each forest region, so that the accordance of the fire risk model with the actual fires will increase.

References

1. PODUR J., MARTELL D.L., KNIGHT K., Statistical quality control analysis of forest fire activity in Canada. Canadian Journal Forest Research. **32**, 195, **2002**.
2. KAZEMI S.M., Fire and forest ecosystems. Cultivation and Industry Journal. 79, **2005**.
3. HERNANDEZ-LEAL P.A., ARBELO M., GONZALEZ-CALVO A., Fire risk assessment using satellite data. Adv. in Space Res. **37**, 741, **2006**.
4. ENCINAS L.H., WHITE S.H., DEL REY A.M., SANCHEZ G.R., Simulation of forest fire fronts using cellular automata. Advances in Engineering Software. **38**, 372, **2007**.
5. ADAB H., KANNIAH K.D., SOLAIMANI K., Modeling forest fire risk in the northeast of Iran usingremote sensing and GIS techniques. Nat Hazards. **65**, 1723, **2013**.
6. MAHDAVI A., FALLAH SHAMSI S. R., NAZARI R., Forests and rangelands' wildfire risk zoning using GIS and AHP techniques. Caspian Journal of Environmental Sciences. **10** (1), 43, **2012**.
7. ROTHERMEL R.C., How to predict the spread and intensity of forest and Range fires, USDA Forest Service,

Intermountain Forest and Range Experiment Station, 143, **1983**.

8. ALLGOWER B., CARLSON J.D., WAGTENDONK J.W.V., Introduction to fire danger rating and remote sensing-will remote sensing enhance wild land fire danger rating? In: Wild land fire danger estimation and mapping, the role of remote sensing data. (Eds Chuvieco E.), World Scientific publishing: New Jersey, **2003**.
9. BONAZOUNTAS M., KALLIDROMITOU D., KASSOMENOS P.A., PASSAS N., Fire risk analysis. Hum. Ecol. Risk Assess. **1**, 617, **2005.**
10. CHUVIECO E., CONGALTON R.G., Application of remote sensing and geographic information systems to forest fire hazard mapping. Remote Sens. Environ. **29**, 147, **1989**.
11. DONG X.U., LI-MIN D., GUO-FAN SH., LEI T., HUI W., Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China. Journal of Forestry Research. **16** (3), 169, **2005**.
12. ESKANDARI S., OLADI J., JALAIVAND H., Efficiency Evaluation of Dong Model for Determination of Fire Risk Potential in Zarrin Abad Forests of Neka- Mazandaran Province. Iranian Journal of Forest and Poplar Research, **21** (2), 31, **2013**.
13. JAISWAL R.K., MUKHERJEE S., RAJU D.K., SAXENA R., Forest fire risk zone mapping from satellite imagery and GIS. International Journal of Applied Earth Observation and Geoinformation. **4**, 1-10, **2002**.
14. KEANEA R.E., DRURYA S.A., KARAUA E.C., HESSBURGB P.F., REYNOLDSC K.M., A method for mapping fire hazard and risk across multiple scales and its application in fire management. Ecol. Model. **221**, 2, **2010**.
15. PAZ SH., CARMEL Y., JAHSHAN F., SHOSHANY M. Post-fire analysis of pre-fire mapping of fire-risk: A recent case study from Mt. Carmel (Israel). Forest Ecol. Manag. **262**, 1184, **2011**.
16. JANBAZ GHOBADI GH., GHOLIZADEH B., MAJIDI DASHLIBURUN O., Forest Fire Risk Zone Mapping From Geographic Information System in Northern Forests of Iran (Case study, Golestan province). International Journal of Agriculture and Crop Sciences. **4** (12), 818, **2012**.
17. MOHAMMADI F., SHABANIYAN N., POURHASHEMI M., FATEHI P., Forest fire hazard mapping using AHP and GIS. Iranian Forest and Poplar Researches Journal. **18** (4), 569, **2010**.
18. SOWMYA S.V., SOMASHEKAR R.K., Application of remote sensing and geographical information system in mapping forest fire risk zone at Bhadra wildlife sanctuary, India. J. Environ. Biol. **31** (6), 969, **2010.**
19. SALAMATI H., MOSTAFALOU H., MASTOORI A., HONARDOOST F., Evaluation and provision of forest fire risk map using GIS in Golestan forests. Proceeding of the first international conferences on fire in natural resources, Iran. 10, **2011**.
20. MAHDAVI A., FALLAHSHAMSI R., NAZARI R., HEIDARI M., Provision of fire risk map in forest and pasture lands in Ilam city using AHP. Proceeding of the first international conferences on fire in natural resources, Iran. 13, **2011**.
21. Mazandaran Natural Resources Administration (MNRA). Forestry plan of District three of Neka-Zalemroud forests, Iran's Forests, Rangeland and Watershed organization Publishing: Mazandaran, **2010**.
22. ESKANDARI S., OLADI GHADIKOLAEI J., JALILVAND H., SARADJIAN M.R., Forest Fire Risk Modeling and Prediction in District Three of Neka-Zalemroud Forest using Geographical Information System. Iranian Journal of Forest and Poplar Research. **21** (2), 203, **2013**.