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Rangeland Fire Risk Zonation using Remote Sensing and Geographical Information System Technologies in Boroujerd Rangelands, Lorestan Province, Iran

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ABSTRACT Conflagration of forests and rangelands is one of the most frequent events in Iran. It is regarded as one of the most important parts of land degradation that occurred due to range destruction and desertification. This study was conducted in Boroujerd, Lorestan Province in west of Iran in 2013 to determine the fire risk model. The data prepared for the study area involved the vegetation types, land use, elevation, slope, aspect, standard topographic map and mean annual climatic data (evaporation, rainfall and temperature). Landsat ETM+ data were used for the image analysis. Analytical Hierarchical Process (AHP) model was applied to weigh and generate the fire risk map. Results showed that the highest weight of factors has been given to the land use because land use contribute to the maximum extent due to inflammability factor. The second highest weight was related to rainfall since it caused the biomass growth (fuel factor). Land use and rain played important roles in the modeling of fire risk zonation. The third one was attributed to the evaporation because of fuel drying and highly inflammability. The other variables comparatively had less impact on fire risk. Based on the statistics achieved for different weight classes, the map was reclassified into five classes as very low, low, moderate, high and very high in order to generate fire risk area map. Also, final map showed that most of the fires which occurred in the last year (5 fire control points about 4812.323 ha) might be put in the firing class of very high risk. Finally, about 42353.36 ha of the total area fell in the class of very high fire risk. The results indicated that 90% of burned areas were located in high risk class.

Key words: *Analytical Hierarchical Process, Conflagration, Risk zonation, Satellite Images*

1 INTRODUCTION

Conflagration of forests and rangelands in Iran is one of the most frequent events. Based on the reports delivered by Iranian Forests, Rangelands and Watershed Organization, natural resources of Iran including forest, rangeland, desert, grove and shrub cover 83.48% of the country area (Shariat Nezhad, 2008). Also, the forests and rangelands constitute 61.82% (Shariat Nezhad, 2008). Mostly, the desired conflagration happened in this area (Ardakani, 2009). Conflagration is considered as a serious problem distressing many terrestrial ecosystems in the earth system and causing the economic damages for people such as missing income relative to the land uses,

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destruction and lost property, agricultural damages and loss of biodiversity (Butry, 2001; Bruke, 1997; Pettenella, 2009). Topography and human influential actions play important roles in the occurrence of wild fires since antiquity (De Vliegher, and Basigos, 1995). The term "risk" is used to describe the probability that a fire might start as it can be affected by the nature and incidence of causative agents (Keane, 2010). Kamyab and Mahiny (2013) determined that one of the most important uses of the models is their capability of predicting future based on the past. Kailidis and Pantelis (1988), Karteris and Kritikos (1992) and Vazquez and Moreno (1993) determined the relationships between fires and the climatic conditions using statistical fire data. Kuntz (1995) investigated the fire risk modeling based on satellite Remote Sensing (RS) and Geographical Information System (GIS) and demonstrated that simple fire risk assessment was possible using the resultant thematic class. A precise evaluation of rangeland fire problems and decisions on the solutions can be satisfactory when a fire risk zone mapping is available (Jaiswal, 2002). The GIS-based model seems to be a reasonably good approach (Jain, 1996; Roy and Porwal, 2005) with respect to the conditions in Iran where a major part of the rangeland is encroached upon by the population. Antoninetti *et al.* (1993) integrated topographical and satellite data for the identification of fire hazard areas. The combination of a spatial basic data (elevation, slope, aspect, precipitation, plant community types and fuel models) with remote sensing technique appeared to be a working tool for the management in North Cascades National Park (USA) (Root *et al.,* 1985). Mohammadi *et al.*, (2010) created risk map of forest fire by using GIS and (AHP) in some part of Paveh county that were derived five categories of forest fire risk, automatically. Mansouri *et al.* (2012) explained that to management program of forest fire crisis by GIS and RS technology in conflagration. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability (Dong *et al.,* 2005; Erten *et al.*, 2005). Hazard mapping and risk assessment are essential to understanding and addressing risks that can interfere with a community's ability to achieve that vision (Noson, 2004; Vakalis *et al.,* 2004). The recourse to GIS-supported modeling tested as an integrated, dynamic and operational tool for spatial diagnosis, display and recommendation as regards to risk management (Gltie, 2008). Future fuel mapping needs are also discussed which include better field data and fuel models, accurate GIS reference layers, improved satellite imagery, and comprehensive ecosystem models (Keane *et al.,* 2001). Rangeland susceptibility to wildfire may be estimated using (NDVI) and (fPAR) change analysis. (fPAR) change data may be included as an input source for early fire warming models, and may increase the accuracy and efficiency of fire and fuel load management in semiarid rangelands (Chen *et al.,* 2011). Williams *et al.* (2014) suggested that post-fire risk assessment of potential hydrologic hazards should adopt a probability-based approach that considers varying site susceptibility in conjunction with a range of potential storms and that determines the hydrologic response magnitudes likely to affect values-at-risk. The results of the discriminate analysis showed the important factors, including presence of hunters and shepherds, distance from roads, average temperature, distance from the springs, and rainfall during the growing season and slope (Faramarzi *et al.,* 2015). The results of analyses demonstrated that Classification Tree Analysis (CTA) is equally adept at classifying areas of low severity as well as those with high severity with reliable accuracy (66-100%) (Weber *et al.*, 2010). Mahdavi *et al.* (2012) have been used GIS, AHP and RS techniques for zoning map of wildfire risk in forest and rangeland areas. 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. A considerable investment in post-fire research over the past

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decade has improved our understanding of wildfire effects of soil, hydrology, erosion and erosion-mitigation treatmens effectiveness (Robichaud *et al.*, 2012). In the present study, an attempt is made to prepare a rangeland fire risk zone map by integrating a satellite image, a topographical one and other ancillary data in a GIS framework for Boroujerd rangelands which is the most important part of Lorestan Province according to the animal husbandry role.

2 MATERIALS AND METHODS

2.1 Study area

The study area (Boroujerd rangelands) is situated between 48° 30′ to 49° 00′ eastern longitude to 33° 33′ to 34° 04′ northern latitude and covers an area about 197000 ha. The area is located in the neighborhood of northern Markazi and north-western Hamedan Provinces. The area has an uneven topography (69% mountains and hills) with the elevation ranging from 1580 to 3510 m and mean elevation about 2500 m a.s.l (Figure 1). The area is covered with different land uses such as residential area, village, garden, farm and natural cover of shrub-land along with grasses and forbs. There are a lot of fires in the rangelands of the studied area. In the north of catchment, there are Sardareh and Sequzan peaks with the height of 2546 m and 2310 m a.s.l respectively. Garin, Mishparvar, Shahneshin, Chaleh khob and Baghe Abrisahm peaks exist with the heights of 3510, 3378, 2944, 2634 and 2425 m a.s.l in the south of catchment, respectively. There are two regions and two cities named Boroujerd and Oshtorinan in the Silakhor basin. Also, there are seven rural districts, 189 villages with 21888 families and 89017 persons. Farmlands, forests and rangelands occupy 51543, 1040 and 77510 ha, respectively.

2.2 Data collection

The data used in this paper are gathered by Landsat ETM+ (spatial resolution 30 m) with the scale of 1:50,000 and contour interval of 20 meters, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 30 m and Garmin 72 GPS for defining and identifying the burned areas and estimating the vegetation losses. The data prepared for this study area were as follows: rangeland types map, vegetation map, elevation, slope, aspect, standard topographic maps and climate data (evaporation, rainfall, and temperature).

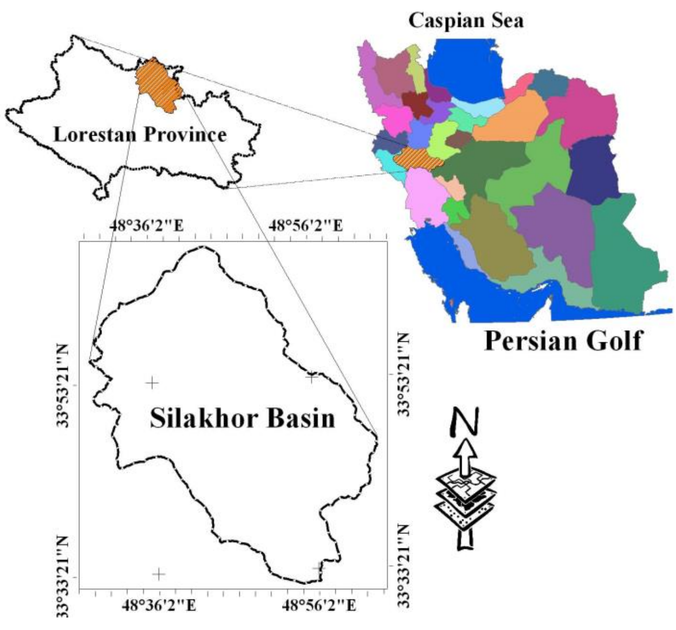

Figure 1 Location of study area, Province and region in Iran

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2.3 Methods

Landsat ETM+ data were used for analyzing the images. ASTER data were used to generate Digital Elevation Model (DEM) for the study area. The topographical factors involving the altitude, slope and aspect layers were derived from DEM. The satellite images were corrected for the effects of atmosphere and topographic relief. These data were geo-coded with the help of rectified topo-sheets according to geographic (lat./long.) projection system with WGS 1984 datum using ERDAS imagine software. Boundary of Boroujerd rangelands was digitized from topo-sheets in the form of vectors with the help of ERDAS 9.1 using vector tools; on the other hand, an area of interest boundary generated by the means of vector files helped to get the subset image of Silakhor basin with regard to the satellite data. Complete road network was digitized using topo-sheets and a buffer was created for the distances of 200 m, 400 m, 600 m and more than 600 m from the center of the road. The flowchart of methodology is shown in Figure 2. Settlement areas were digitized in the form of point vectors and then checked with the satellite images. As the settlement area was outside the rangeland of Boroujerd, the settlement buffer was created for the distances of 200 m, 400 m, 600 and more than 600 m. The Landsat ETM+ images were used in the study. The images were rectified with top sheet using the nearest first order neighborhood rules. Totally, 13 ground points were used to register the images with the rectification error using ERDAS.

2.4 Generation of thematic layers

For entering the spatial data in GIS, it is necessary to convert the resource information to the maps; hence, the mapping of thematic layers is one of the primary requirements. Remote sensing coupled with the limited ground checks is the most appropriate way for generating the resource maps. Standard topographic map was used for DEM generation.

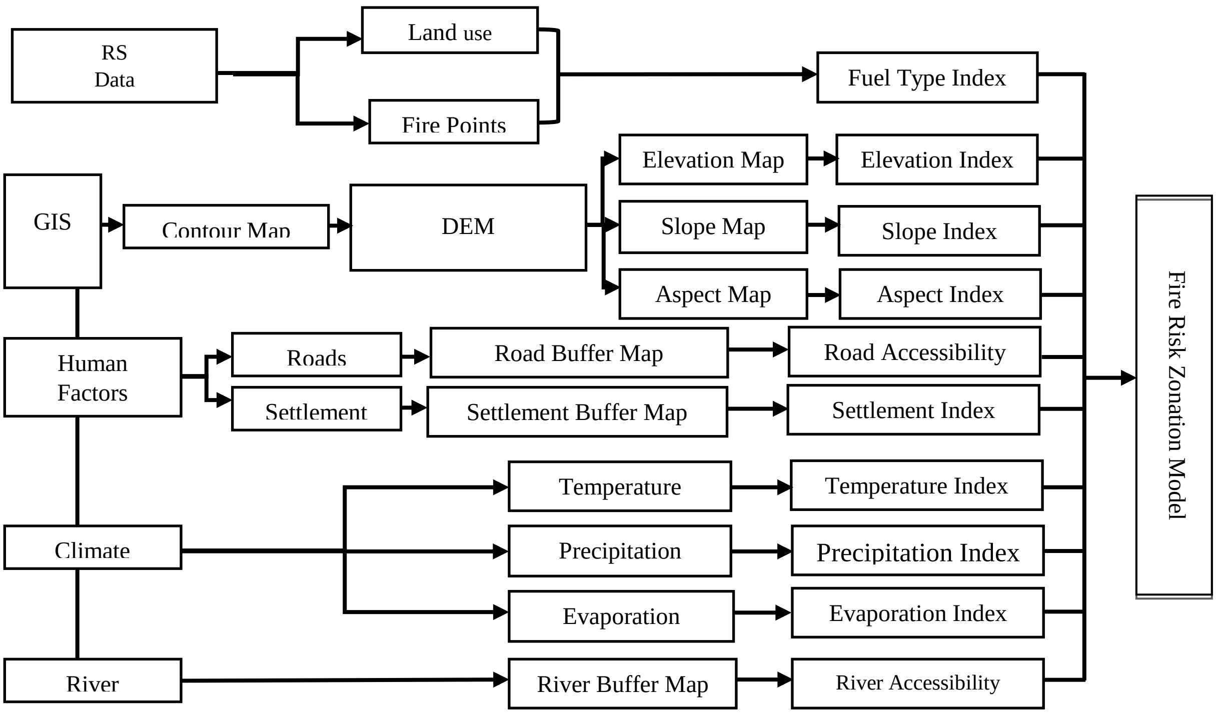

Figure 2 Methodology flowchart applied in this study

2.5 Generation of topographic (slope and aspect), climatic (rainfall, temperature and evaporation) and human factors (road, settlement and river buffering)

A subset of ASTER 30 m DEM of study area was clipped using a boundary vector layer. Elevation, aspect and slope were generated from ASTER 30 m DEM using ERDAS EMAGINE 9.1 and topographic analysis tool of ArcGIS (Figures 3 to 5). To create climatic maps such as rainfall, temperature and evaporation, contour lines of climatic factors were applied by the means of mean annual data which have been reported by Boroujerd climatology station during 10 years (Figures 6 to 8). Accessibility to the rangeland having an important role in fire risk zonation with the roads and settlement causes fire in the rangeland. Also, rangelands surrounding the rivers have low potentials to fire (Figures 9 to 11).

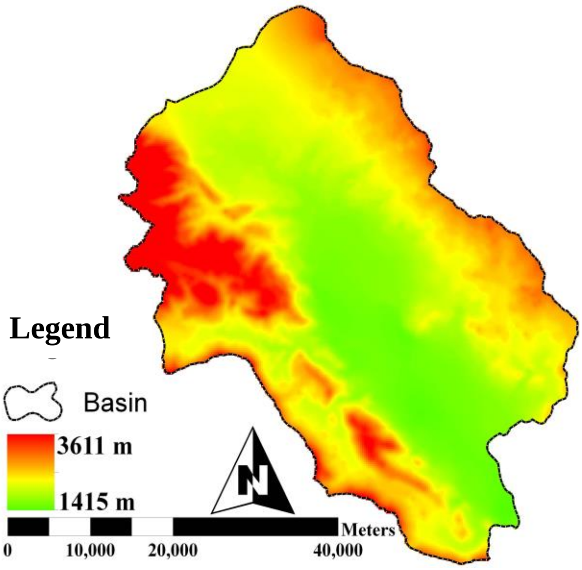

Figure 3 Digital Elevation Model map of the area

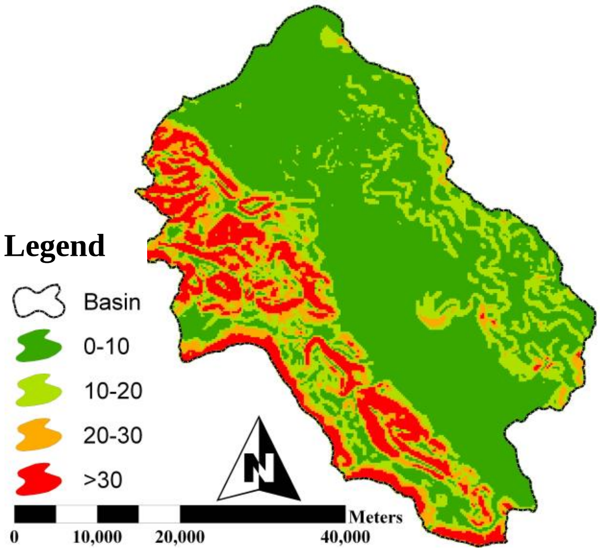

Figure 4 Slope map with categories

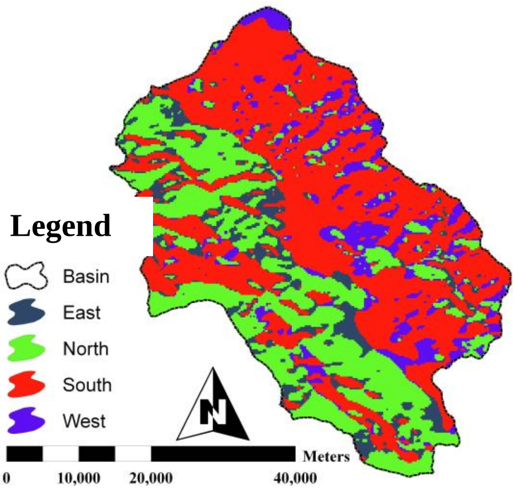

Figure 5 Aspect map of the area in four section

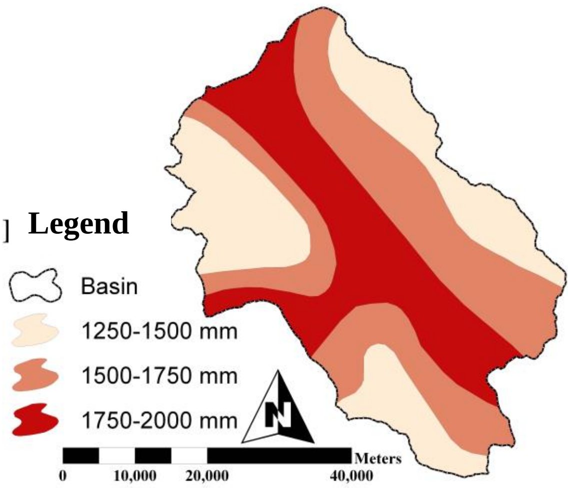

Figure 6 Evaporation map of the area fall in three categories

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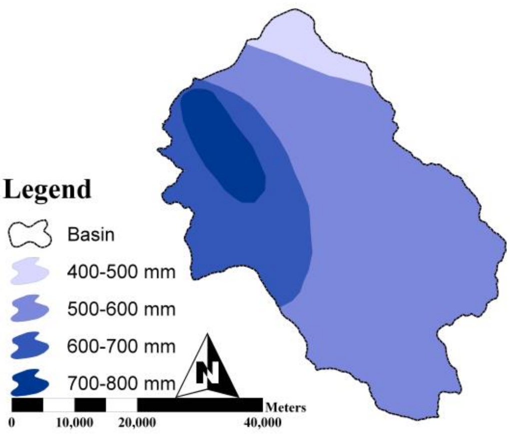

Figure 7 Rainfall map (Data source: Boroujerd Climatology Station, 2014)

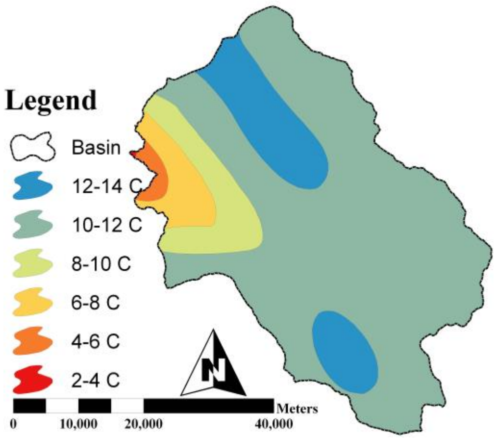

Figure 8 Temperature map (Data source: Boroujerd Climatology Station, 2014)

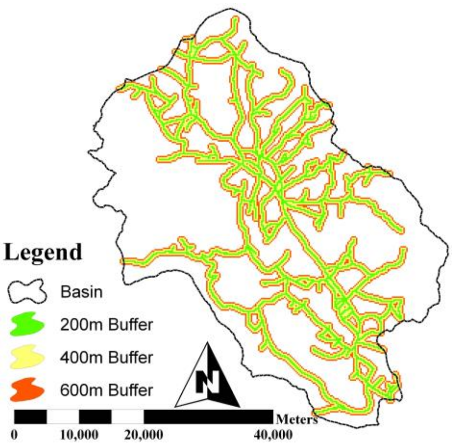

Figure 9 Road buffer map of the area

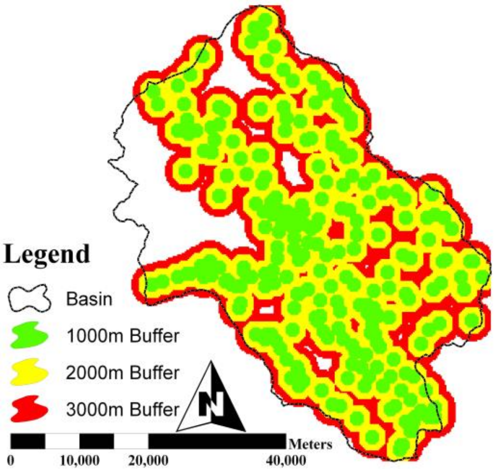

Figure 10 Village buffer map of the area

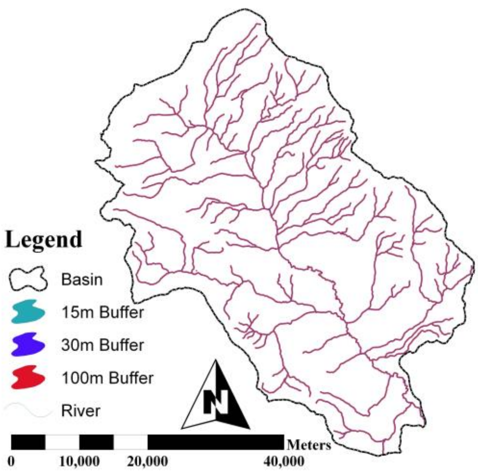

Figure 11 River buffer map of the area

Results of this study have been analyzed by AHP method (EC: Expert Choice 2000 software) and then, a model of sustainable utility has been created in the marginal lands. AHP method based on human brain hierarchy and fuzzy theory's complex problems were recommended by Saaty (2002). Such processes as judgment complex, decision making and personal to value with a logic method were utilized. This technique is related to the personal imagination and experiences in order to logically solve and understand the problems step by step for making the final decision. Other preference of AHP is the creation of group cooperation and unit structure for making decisions and solving problems. This method creates a balance between the factors according to their importance and enables the researchers to select the best case with respect to the desired goals. In this method, several factors like cluster trees are created and compared to present valuable parameters (Zebardast, 2002).

3 RESULTS

3.1 Generating index value maps, fire risk zonation index/fire risk modeling

In the present study, the map layers were generated. AHP model was used for weighing the factors and making the priorities and then, maps were reclassified for assigning the weights. Weights were given to each factor according to their influence on fire behavior by having the experiences and opinions of experts in the field. In this study, spatial modeling has been done to obtain the combined effects of land use index, elevation index, slope index, aspect index, road index and settlement index. Different weights have been assigned with regard to the importance of specific variables related to the studied area. Among nine factors, the highest weight has been given to the land use because land use contributes to the maximum extent due to the inflammability factor. The second highest weight has been given to the rain because it results in the biomass growth (fuel factor). Therefore, land use and rain had played important roles in fire risk zonation modeling. The third one is the evaporation because of the drier fuel and high inflammability. The other variables comparatively have less impact on the estimation of fire risk zonation. Different weights were examined for different variables and the weights given in the AHP model were used to generate a fire risk zonation map. Based on the statistics of different weight classes, the map was reclassified into five classes as very low, low, moderate, high and very high to generate the fire risk area map (Figures 12 and 13 and Tables 1 and 2).

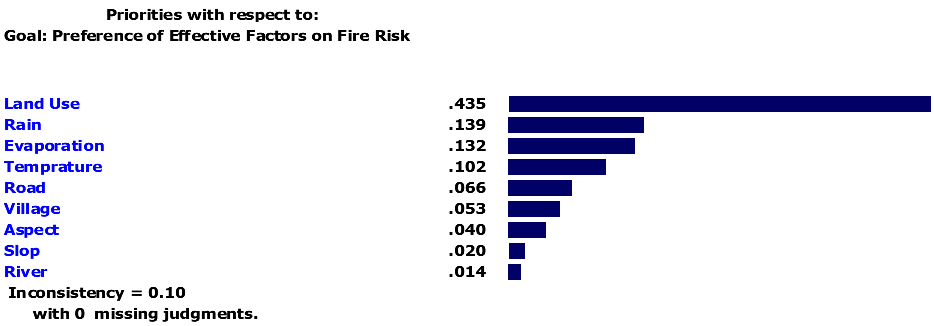

Figure 12 Factors affected fire risk model and weights

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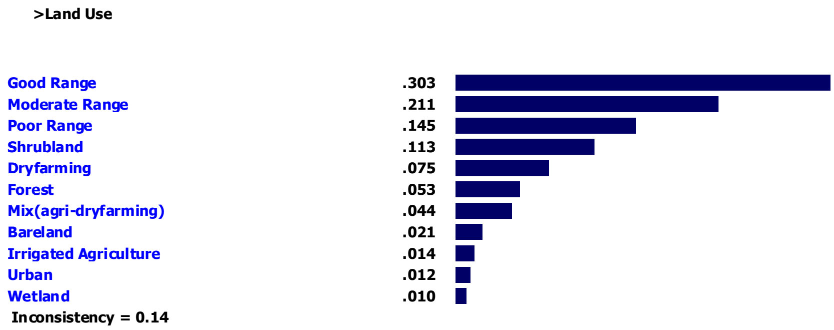

Figure 13 Land use classes and weights

Table 1 Climatic factors classes and weights

Rain fall (mm)	Weight	Evaporation (mm)	Weight	Temperature (°C)	Weight
700-800	0.751	1750-2000	0.672	12-14	0.404
600-700	0.279	1500-1750	0.265	10-12	0.274
500-600	0.111			8-10	0.140
				6-8	0.108
400-500	0.039	1250-1500	0.063	4-6	0.051
				2-4	0.023
Inconsistency	0.09	Inconsistency	0.03	Inconsistency	0.09

Table 2 Topographies and field factors classes and weights

Roads buffers (m)	Weight	Settlement buffer (m)	Weight	Aspect	Weights	Slope (%)	Weight	River buffers (m)	Weight
200	0.554	1000	0.615	North	0.663	0-10	0.657	15	0.595
400	0.310	2000	0.319	East	0.162	10-20	0.203	30	0.249
600	0.097	3000	0.066	West	0.133	20-50	0.094	100	0.107
600<	0.039			South	0.042	50<	0.046	100<	0.049
Inconsistency	0.06	Inconsistency	0.001	Inconsistency	0.07	Inconsistency	0.06	Inconsistency	0.03

3.3 Fire risk zonation map

A further study of risk zonation map with the accessibility to the rangeland and land use map showed that high fuel contents were falling in very high and high risk areas whereas (fuel to fire) the others were falling in low and very low fire risk areas in spite of good rangelands because of high biomass. Very high and high fire risk areas were mostly lying in the parts around the roads and villages having people and ecotourism whereas the areas with high elevation in spite of good fuel were falling in low and very low fire risk areas because they are far from the settlement and recreation roads. This may be attributed to the fact that high risk of fire can be created by people. Thus, fire could certainly be averted by taking precautionary measures. Hence, despite the fact that no fire prone areas can be demarcated where fire occurs due to natural or intentional human causes, it is advantageous to have a fire risk map to avert possible disasters caused by fire due to human activities. It can be helpful to Natural Resources Office of Boroujerd as this

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type of fire risk zone map will enable the office to set up an appropriate fire-fighting infrastructure for the areas which are more prone to fire damages. Such a map will help to plan the main roads, subsidiary roads and inspection paths and may lead to a reliable communication and transport system to efficiently fight small and large rangeland fires (Figure 14).

3.4 Validation of range fire risk model

The final range fire risk map was validated with the data of past fire incidences collected from field visits and fire points taken from Natural Resources Office of Boroujerd. The area with different fire risk zones and fire points is summarized in Table 3.

The results of the study showed that 100% fire incidences, 50% incidences had occurred in very high and high risk areas.

Results also showed that most of the fire control points are matched with the fire risk map except in very high and very low areas. This subject is an important document that fire points considerably occur in very high risk areas in last year; consequently, fire risk map is suitable for the area. Also, in very low risk areas, there are few fire points; so, this is another witness to the accuracy of model.

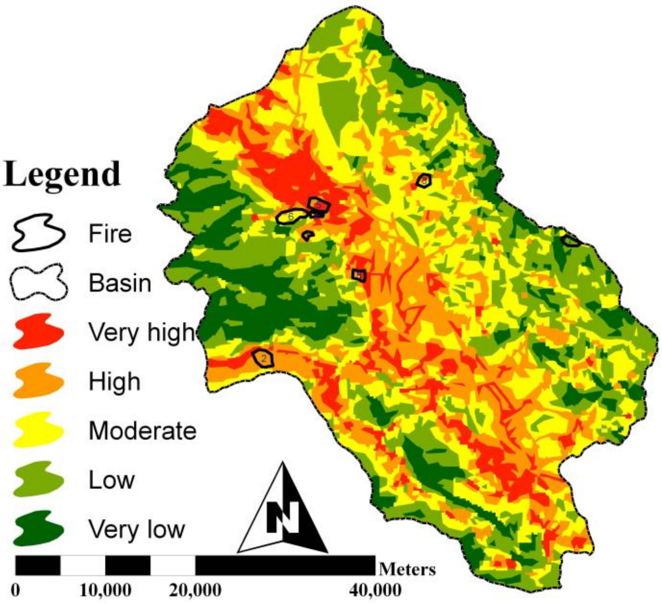

Figure 14 Rangeland of Boroujerd Fire Risk Zonation Map and Control Points

Table 3 Fire risk categories compare with fire control points to create map

Fire Risk	Fire control points (%)	Fire risk map (%)	Fire control points (ha)	Fire risk map (%)
Very high	18.63	21.49	4812.323	42353.36
High	22.00	26.74	5682.258	52693.23
Moderate	28.25	27.41	7297.725	54022.07
Low	29.34	10.28	7579.081	20260.79
Very low	1.78	14.08	460.6931	27744.19
Total	100.00	100.00	25832.08	197073.6

4 DISCUSSION

Hazard mapping is essential to understanding and addressing risks that can interfere with a community's ability to achieve that vision in which the study showed and adapted with Noson (2004), and this study.

The integration of satellite data into GIS can be very useful to determine risky places and to plan range management after fire that this result coincide with study of Erten *et al.* (2005) as it mentioned in the study.

Mahdavi *et al.* (2012) have been used AHP technique for zoning map of wildfire risk in forest and rangeland areas and referred that it is useful to define priority of affecting factors of fire, so this study used AHP also because it is fast and simple to using.

Five categories of rangeland fire risk, including very high to very low, confirm results of Xu Dong *et al.* (2005) and Mohammadi *et al.* (2010). The mapping result of the study area was found to be in strong agreement with actual fire-affected sites. The results indicate that the 90% of burned areas are located in high risk class that also is alike with Mohammadi *et al.* (2010) results. The study showed that same result of Chen *et al.* (2011) and Williams *et al.* (2014) recognition of rangeland susceptibility to wildfire is very important and need to input source for early fire warming models, increase the accuracy and efficiency of fire and fuel load management in rangelands.

The results of Faramarzi *et al.* (2015) showed the important factors, including presence of hunters and shepherds, distance from roads, average temperature, distance from the springs, and rainfall during the growing season and slope and the present study in addition to confirm them also priority factors as most of the important factors were land use and rain. Mohammadi *et al.* (2014) used logistic regression to study the forest fire risk and identify the most influential factors in the occurrence of forest fires. The estimated coefficients for the independent variables indicated that the probability of occurrence of fire is negatively related to land slope, site elevation and distance from farmlands, but is positively related to amount of annual precipitation. This result confirms the study but first affective factor in our study was land use and rain second because existence of fuel is more important than rain. This study showed that physical factors such as topography are important after extracting the reasons of fire which depend on the aspect and speed of wind as well as slope is important to increase or decrease of fire. Also slope which can increase or decrease the fire.

Fire spreading speed in the uneven grounds is irregular and unpredictable. Western and southern aspects are sensitive to fire because sun facing aspects receive direct Sun rays and make the fuel drier and highly inflammable; higher slopes contribute to the convectional preheating and easy ignition and spreading of fire. Besides steep slopes, the dry biomass is more close to fire flames causing the fire to spread more speedily which is approved by Tahir *et al.* (2013).

Fire risk map resulted in developing the fire risk assessment of study area using multi criteria analysis while integrating different layers. Fire risk index map can be used to prioritize the rangeland fire prevention initiatives at the management level. Rangeland types, land use maps and other parameters can be helpful in the installation of suitable watch towers for the prevention of fire. Layer generation for the slope, altitude and land use can be used for calculating the response time for the regarded disaster. Digital elevation model can be effectively applied for studying the terrain characteristics and generating a viewshed. The precision of map can be increased by adding more number of variables in the analysis such as wind speed in different months. According to human activities fire risk

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map, can be useful for Natural Resources Office of Boroujerd as this type of fire risk zone map will enable the department to set up an appropriate fire-fighting infrastructure for the areas more prone to fire damages. Providing this map will help to plan the main roads and may lead to a reliable communication and transport system in order to efficiently fight small and large rangeland fires.

5 ACKNOWLEDGMENT

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پهنه‌بندی خطر آتش‌سوزی مراتع با استفاده از سنجش از دور و تکنولوژی سامانه اطلاعات جغرافیایی در مراتع بروجرد، استان لرستان، ایران

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چکیده آتش‌سوزی در جنگل‌ها و مراتع ایران یکی از حوادثی است که بسیار اتفاق می‌افتد و از جمله عوامل بسیار مهم تخریب مراتع می‌باشد. این مطالعه در مراتع شهرستان بروجرد واقع در استان لرستان در غرب ایران و در سال ۱۳۹۲ برای تهیه مدل خطر آتش‌سوزی صورت گرفت. اطلاعات مورد استفاده در این مطالعه شامل نقشه‌های تیپ گیاهی، کاربری اراضی، ارتفاع، شیب، جهت و داده‌های متوسط سالانه هواشناسی (تبخیر، بارندگی و درجه حرارت) می‌باشند. برای آنالیز تصویر از داده‌های ETM^+ ماهواره لندست استفاده شد. روش آنالیز تحلیل سلسله مراتبی برای وزن‌دهی به عوامل موثر در آتش‌سوزی برای تهیه نقشه خطر به کار رفت. نتایج نشان داد که بیش‌ترین وزن به عامل کاربری اراضی اختصاص یافت برای این‌که مواد سوختی متفاوتی در اراضی مختلف به‌دلیل پوشش گیاهی مختلف وجود داشت. دومین عامل که بیش‌ترین اثر بر آتش‌سوزی داشت میزان بارندگی سالانه بود چرا که این عامل باعث افزایش رشد گیاهان و به تبع آن افزایش پوشش گیاهی شد که عامل مهم در فراهم شدن ماده سوختی است. در نتیجه کاربری اراضی و میزان بارندگی سالانه منطقه بیش‌ترین اثر در تهیه مدل خطر آتش‌سوزی داشت. سومین عامل تبخیر بود که باعث شد. مواد سوختنی قابلیت اشتعال بالایی داشته باشند. متغیرهای دیگر وزن کم‌تری جهت تهیه نقشه خطر نسبت به کاربری اراضی و میزان بارندگی داشتند. نقشه خطر آتش‌سوزی به ۵ طبقه با خطر خیلی کم، کم، متوسط، زیاد و خیلی زیاد تقسیم شد. هم‌چنین نقشه نهایی نشان داد که بیش‌تر آتش‌سوزی‌های رخ داده در ۵ سال گذشته (۵ فقره آتش‌سوزی در حدود ۴۸۱۲/۳۲۳ هکتار بیش از ۹۰ درصد) در منطقه با خطر بالای آتش‌سوزی قرار داشتند. سرانجام می‌توان گفت که حدود ۴۲۳۵۳/۳۶ هکتار از کل منطقه در بخش با خطر بالای آتش‌سوزی قرار گرفتند.

کلمات کلیدی: آتش‌سوزی وسیع، آنالیز تحلیل سلسله مراتبی، پهنه‌بندی خطر، تصاویر ماهواره‌ای

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