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CASE REPORT

Predicting fire hazard areas using vegetation indexes, case study: Forests of Golestan Province, Iran

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ABSTRACT

Every year, hundreds of fires occur in the forests and rangelands across the world and damage thousands hectare of trees, shrubs, and plants which cause environmental and economic damages. This study aims to establish a real time forest fire alert system for better forest management and monitoring in Golestan Province. In this study, in order to prepare fire hazard maps, the required layers were produced based on fire data in Golestan forests and MODIS sensor data. At first, the natural fire data was divided into two categories of training and test samples randomly. Then, the vegetation moisture stresses and greenness were considered using six indexes of NDVI, MSI, WDVI, OSAVI, GVMI and NDWI in natural fire area of training category on the day before fire occurrence and a long period of 15 years, and the risk threshold of the parameters was considered in addition to selecting the best spectral index of vegetation. Finally, the model output was validated for fire occurrences of the test category. The results showed the possibility of prediction of fire site before occurrence of fire with more than 80 percent accuracy.

Keywords: Time Series; MODIS Sensor; Threshold; NDWI

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1. Introduction

Since natural resources are among the most important and valuable national capital of every country, and according to the main role of these resources on economic and social life of human being, their conservation and expansion should be one of the most essential plans in every country. Many factors cause quantitative and qualitative changes on natural ecosystems such as natural extinction, natural disasters such as fire, flood, population density, pests and plant diseases[1]. Among these destructive factors, fire is one of the main causes of natural ecosystem destruction, which leads to significant damages on these areas[2]. Iran has forests and rangelands with different climates and vegetations. According to Forest, Rangelands, and Watershed Management Organization (FRWO) report, natural areas of the country include: forest, rangeland, desert, and shrubbery, which are 83.48 percent of total area of the country[3]. In addition, according to FRWO report, forest and rangelands are 61.82 percent of total area of the country. Investigations show that most of fire occurred in these areas[4]. In Iran, about

160000 hectares of forests have been destroyed by fire during 28 years (1969-1997), After Iranian revolution (from 1979 to 1996), about 87000 hectares of forest destroyed by fire[5].

Determining susceptible areas to fire is one of the first measures for forest and rangeland conservation and protection against fire. Forest fire hazard map can be used as a useful guide for natural fire management and an important prevention strategy. These maps will help the natural resources bureau officers to be aware of fire hazard in natural environment, or do the best thing during fire. Remote sensing can provide useful information about environment, before, during, and after fire, especially monitoring active fire[6,7]. So far, various researches have been carried out on zoning areas with high fire potential[8-11]. Mosavari *et al*. and Shorfi *et al*. categorized fire hazard areas into low to high potential areas using overlaying climate layers and common assessment methodologies, and mentioned that large area of these classes will lead to difficult management efforts[12,13]. In almost all studies related to identification of fire hazard area, quick management will be practically impossible due to zoning and large hazard area. Therefore, in this study, in order to dynamic and long-term consideration of effective factors on fire occurrence to achieve fire hazard threshold and integrate them into a decision tree, a system is trying to be produced for active and dynamic prediction on different times to achieve the least fire potential area for best management of fire occurrence.

2. Materials and methods

2.1 Study area

Golestan Province is located in the southeastern part of Caspian Sea. The area of this province is 20387 square kilometers. This province is located 36° 30' to 38° 08' northern latitude and 53° 51' and 56° 22' eastern longitude. The southern parts of this province are mountainous and northern parts of it are desert area. The area of forests in this province is 451705 hectares that is 22 percent of province total area. Due to lower annual precipitation and proximity to arid regions in the eastern part of the country, Golestan Province forests are more vulnerable to fire[14]. Geographical location of the study area is shown in **Figure 1**.

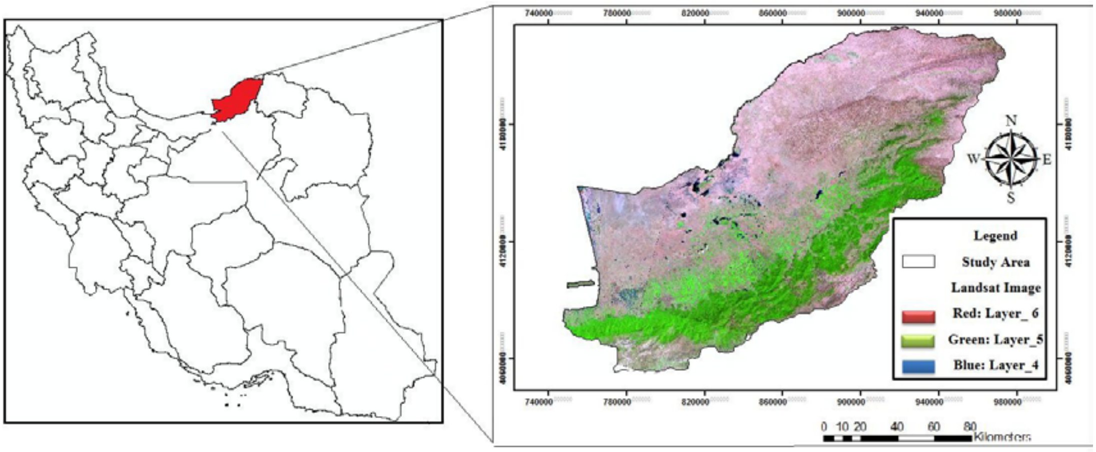

Figure 1. The geographical location of study area within Iran, Golestan Province**.**

2.2 Methodology

In order to develop a fire alerting system, studying of fire reports showed 75 natural fire occurrences between 2011 and 2015. About 60 percent of these points were used for developing the alerting system and 40 percent of them were used for accuracy assessment. The required data for this study were prepared using satellite imageries. These data were prepared on three steps. At first, natural fire's points were determined and the map of forest type prepared (**Figure 2**). The second step was preparing vegetation's moisture stress map by global vegetation moisture and greenness indexes such as NDVI, MSI, WDVI, OSAVI, GVMI and NDWI, using satellite imageries of MODIS sensor. These factors were considered in a time series of 15 years, a little before fire occurrence. Finally, the best indexes were selected and the threshold was calculated for each of them through comparing factors before fire occurrence and long-term 15 years' normal values. Then accuracy assessment was done to determine the precision of the model predicted areas for 40% of the points. **Figure 3** shows steps 2 and 3 of determining the threshold and producing system.

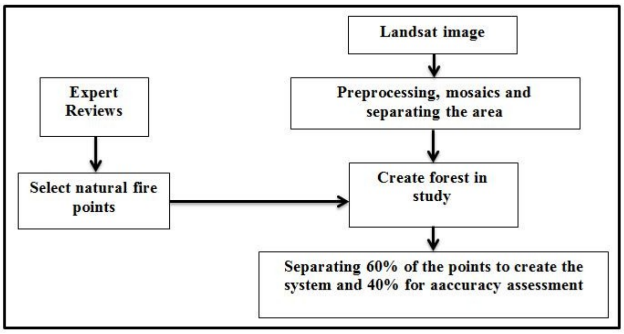

Figure 2. The first step is to provide forest map and fire points.

One of the main functions than we can do by satellite imageries is preparing forest vegetation map[15]. In this study, OLI sensor images on Landsat satellite were used to prepare forest map. These images were suitable as there was no cloud coverage. The steps of pre-processing, geometric corrections and image alignment, radiometric correction, image mosaicing, and finally image clipping were done based on the boundary of the study area on satellite images. Then the natural fire points were put on forest map, which 40% of these points were randomly used to evaluate the accuracy and 60% of them were used to produce the system.

The remote sensing data including satellite imageries of MOD13Q1, MODIS sensor from 2000 to 2015 were used in this study. These images were suitable as there was no cloud coverage. Image clipping was done based on the boundary of the study area on satellite images. Then, according to the previous studies, 4 following indexes were selected from existing indexes (**Table 1**)[16,17]. These indexes were analyzed as before fire occurrence and long-term 15 years in median, mean, minimum and maximum statistics.

Table 1. Remotly sensed Indexes use in study

Source	**Formula**	**Explanation**	**Index**
Hunt and Rock[18]	MSI = MIR/NIR	Moisture Stress Index	MSI
Rouse *et al.*[19]	NDVI = (NIR - RED)/(NIR + RED)	Normalized Difference Vegetation Index	NDVI
Clevers[20]	WDVI = NIR - αRED	Weighted Difference Vegetation Index	WDVI
Rondeaux *et al.*[21]	OSAVI = 1.16 NIR - RED / NIR + RED + 0.16	Optimized Soil Adjusted Vegetation Index	OSAVI
Gao[22]	NDWI = NIR - SWIR/NIR + SWIR	Normalized Difference Water Index	NDWI
Ceccato *et al.*[23]	$\mathrm{GVMI} = \frac{(\mathrm{P2}+0.1)-(\mathrm{p6}+0.02)}{(\mathrm{P2}+0.1)+(\mathrm{P6}+0.02)}$	Global Vegetation Moisture Index	GVMI

2.3 Calculating the threshold and quantify moisture stress indexes

Global indexes of moisture stress and greenness such NDVI, MSI, WDVI, OSAVI, GVMI and NDWI were applied on satellite imageries of MODIS sensor and vegetation moisture stresses map was produced.

By calculating the arithmetic average of factors in each long-term event, the threshold of each factor was calculated. In each factor, the threshold that has the greatest difference with long-term normal values was selected due to early alerting.

2.4 Results

Analyzing time series and number of days before fire occurrence shows the threshold of each index for considering probability of fire occurrence (See **Table 2**).

Table 2. Threshold of indexes for probability of fire occurrence

The threshold is based on the median value	**The threshold is based on the minimum value**	**The threshold is based on the maximum value**	**The threshold is based on the mean value**	**Threshold of index**
0.82	1.54	1.65	1.55	MSI
0.065	0.11	0.165	0.153	NDVI
0.19	0.245	0.345	0.218	WDVI
0.10	0.18	0.129	0.102	OSAVI
1.175	1.66	1.72	1.58	GVMI
1.42	0.83	1.78	1.593	NDWI

2.5 Selecting the best vegetation index and threshold

For each index, the threshold that describes the fire occurrence better was used, so that the selected threshold had the highest difference from the normal values obtained from images time series.

Considering these thresholds and comparing remote sensing indexes showed that the NDWI is able to predict fire occurrence better since it has the highest threshold value based on the maximum difference (1.78 is different value from long-term normal value) and then the index GVMI with the threshold of 1.72 is ranked second. In order to continue the study, this index was used to produce fire hazard maps and accuracy assessment.

Therefore, the hazard amount of NDWI and GVMI index was calculated based on the thresholds for accuracy assessment of 40% of fire occurrences (See **Figure 2** and **Figure 3**). And the precision of each index calculated separately. For an example, the hazard map of NDMI is presented for fire occurrence in 2015/1/7.

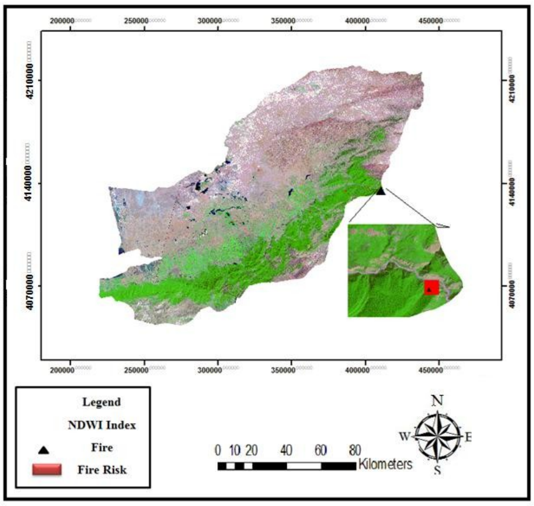

Figure 2. Fire risk is based on the NDWI index.

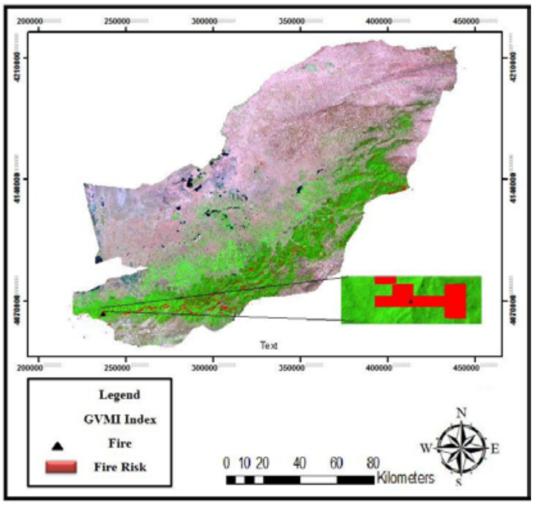

Figure 3. Fire risk is based on the GVMI index.

The Kappa coefficient was calculated for each index as presented in **Table 3**. Among the studied factors, Normalized Difference Moisture Index (NDWI & GVMI) has the highest accuracy of 85.00%.

Table 3. Evaluation of forest system accuracy

KAPPA	**accuracy**	**Threshold of index**
0.4002	50.22%	MSI
0.3508	45.01%	NDVI
0.3684	46.07%	WDVI
0.2197	32.21%	OSAVI
0.8178	85.00%	GVMI
0.9170	94.70%	NDWI

2.6 Discussion

An important tool for estimating high fire hazard areas is predicting fire hazard probability in different areas and preparing special management plans in these areas[24]. Fire prediction is considered as a prerequisite for preparing forest fire management plans. The spatial prediction of fire in different regions can be done in different ways. Using modern prediction methods and spatial modeling of fire hazard, and determining fire probability that is one of the most effective strategies on forest fire management, are much considered. Extensive spatial coverage and use of non-visible wavelengths have made remote sensing a good tool for fire prevention and detection, and preparation fire map. The integration capability of Geographic Information System also has made GIS an essential tool for the preparation of fire hazard maps[25].

Due to lower annual precipitation and proximity to arid regions in the eastern part of the country, Golestan Province forests are more vulnerable to fire. Fire occurrences in recent years, especially in 2011, show that the number and extent of fire has been increased over time. In this study, fire data in 2011 and 2015 were used and fire pixels were detected using vegetation indexes map (NDVI, MSI, WDVI, OSAVI, GVMI and NDWI) by remote sensing and GIS, then the effect of each index was considered and monitored for a period of 15 years, in order to obtain normal values. In addition, the threshold of fire hazard was determined for every occurrence day. Using hazard threshold of each parameters and Boolean logic, the risk maps were combined with each other, and areas with high fire hazard potential in Golestan Province have been identified with combining and overlaying of indexes. The results showed that this method is appropriate for preparing fire hazard map. Contrary to previous researches that often assessed zoning of hazard areas, this method presented areas with fire hazard probability of more than 80 percent dynamically as small manageable patches and can be useful for natural resources management of Golestan Province. Based on the results, it is obvious that this study can be useful in evaluating the sensitivity of forest areas and adopting proper management decisions for fire extinguishing. Based on this map, fire-extinguishing facilities can be established in high-risk areas before the fire season.

Conflict of interest

The authors declare that they have no conflict of interest.

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