FOREST FIRE HAZARD ZONE MAPPING USING STRUCTURAL FIRE INDEX: A CASE STUDY

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ABSTRACT: Forest fires are associated with various ecological and physical processes. Assessment of the susceptibility of an area to fire outbreaks is an important appropriate action to the prevention of future possible fire. Forest fires are one of the major natural hazards in the north of Iran. In this study we carry out the Structural Fire Index for mapping of forest fire hazard. For this object, the following variables were derived for a study area: vegetation moisture, slope, aspect, elevation, and distance from roads. Those variables were weighted based on their impact on the forest fire hazard and geographical location. Based on this model, three hazard classes are classified into High, Medium, and Low hazard. For validation of hazard zonation, the numbers of hot spots are used from MODIS dataset since 2001 to 2003. Using histogram by zone showed that the Structural Fire Index presented reasonable hazard zonation because the most hot spots are located in high hazard zone and the lowest once are located in low hazard zone.

1- INTRODUCTION

Wildfires are considered as a serious problem that distressing many terrestrial ecosystems in the Earth system and causing economic damage for people (Butry et al., 2001) such as missing income relative to the land use, destruction and lost property, damages to agriculture, and loss of biodiversity.(Merlo et al 2000. Pettenella et al.,2009) Also It is one of the most important parts of land degradation that is caused by deforestation and desertification. (Hernandez-Leal et al., 2006). There are four steps of analysis and assessment of effective response to wildland fires; (Roy.,2003)

- Determining fire potential risk
- Detecting fire starts
- Monitoring active fires
- Conducting post-fire degradation assessment

This study is focused on fire potential risk and risk zonation. Vadrevu et, al (2009) concluded risk is combined the fuel and its susceptibility to burn (i.e., hazard) and anthropogenic and natural factors as external causes leading to fire ignition. The MiSRaR project from Europe union (2010) defines risk as a combination of hazard and potential damage. (figure 1)

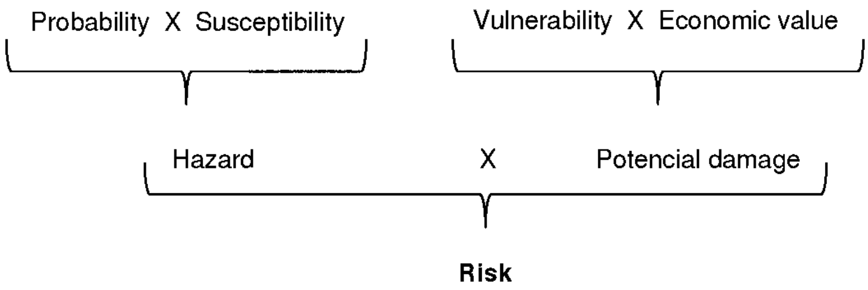


Figure 1, Conceptual model of risk (Probability = Annual probability of occurrence of a fire at that location, Susceptibility= Potential damage from the fire at that location, Vulnerability= Degree of loss of an element at risk, Economic value= Value (in €,$) of an element at risk). (The MiSRaR project,2010)

A comprehensive collection of the information and environmental variables relevant is required to understand fire occurrences. (Krivtsov et al., 2009). Fire proneness depends on many variables such as, vegetation type and density, humidity, vicinity to settlements, distances from roads and others (Chuvieco and Congalton 1989, Roy et al., 1991, Jain et al., 1996). There are many factors that are used for forest fire modeling. Three groups of indices are proposed by the European Union's (EU) Joint Research Center based on their temporal scale (JRC, 2001):

- Structural or long-term indices do not change in short time such as topography, vegetation type, land-cover, Land-use, Slope, Aspect, Distance to roads and vicinity to urban areas, and Elevation. (Pelizzari, 2008)
- Dynamic or short-term indices change moderately continuously over time such as vegetation or weather condition.
- Integrated or Advanced indices contain both structural and dynamic factors.

This research tried to use the structural index for zonation of fire hazard. So hazard and ignition sources are selected; Vegetation status, Slope, Aspect, Elevation, and Distance from roads and urban areas.

Iran is the fourth country in Middle East and North of Africa in forest fire. In the North of Iran most fires happen from August until the end of December because there is a decrease in humidity and increase in winds. (Allard, G.2001). The ECE/FAO reported the average number of fires per year is 130 and the average area burnt per year is 5 400 ha. The maximum one occurred 33 000 ha in 1993. (Alexandrian and Esnault, 1998). Golestan (North East Iran) is the most important forest area. It is located next to the Caspian Sea. (figure 2)The fires in this region are mainly caused by arson. Records explain a normal of 20 to 70 fires in a 10-year record. (Allard, 2001). Therefore, it is necessary to model the risk of forest fire by using GIS and Remote Sensing methods under different models.

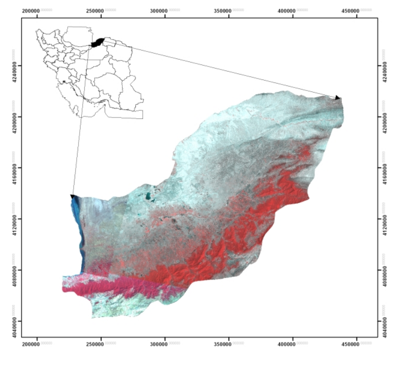


Figure 2, Location of Golestan province (False Color Composite of Landsat ETM+)

2- METHODOLOGY

The Structural Fire Index (SFI) is based on the combination of five predictor variables: (Chuvieco and Congalton 1989) Vegetation moisture; Slope; Aspect; Elevation; Distance from roads and urban areas. The original values of each factor are ranked based on different levels of danger. These variables are reclassified and modified according to their fire danger and a value of 1, 2, 3, 4 or 5 is given to each level from high to low fire danger. The following equation is applied after the reclassification of variables;

$$SFI = 1 + 100v + 30s + 10a + 5r + 2e \quad (1)$$

Where;
v, s, a, r, and e show vegetation moisture, slope, aspect, distance from roads, and elevation.

2-1- Vegetation Moisture;

Dryness and wetness condition is one of the most important parameter in fire hazard. Dryness increases the flammability of the forest. The moisture influences the spreading of the fire. (Siachalou et al, 2009) The Normalized Difference Moisture Index (NDMI) is commonly used to evaluate the moisture of the vegetation. (Wilson et al, 2002, Hemmleb et al, 2006, Sader et al, 2003) it is sensitive to changes in liquid water content in vegetation canopies. (Gao, 1996). Healthy green vegetation is shown as high moisture content by the NDMI index. The following equation defines it; (A. Sader and Jin 2006)

$$NDMI = \frac{(NIR - MIR)}{(NIR + MIR)} \quad (2)$$

Where; NIR is the near infrared spectral wavelength, and MIR is mid infrared spectral wavelength.

2-2- Elevation;

Fire behavior trends are less severe at higher altitude because of higher rainfall. (Chuvieco and Congalton, 1988). (Darmawan et al, 2001). Soil moisture and fuel moisture are influenced by drainage and elevation based on flow direction. (K.Lein and I. Stump 2009).

2-3- Slope;

Slope is one the parameters that influences fire behavior.(Rothermel, 1991). In steeper slopes, rate of fire spread might rise, since flames are angled closer to the surface of ground and wind effects can supply the process of heat convection for the fire produces .(Whelan 1995, DeBano et al. 1998).

2-4- Aspect;

The aspect is regarded as another important factor. Usually there are drier and less dense fuels on southern slopes than northern slopes. Generally, the properties of South aspect slopes are higher temperatures, robust winds, minor humidity and lower fuel moistures because Southern aspects receive more direct hotness from the sun. In the earlier day East aspects get more ultraviolet and direct sunlight than west aspect, as consequence east aspect drier faster. (Vadrevu et al, 2008) and (Chuvieco and Congalton, 1989).

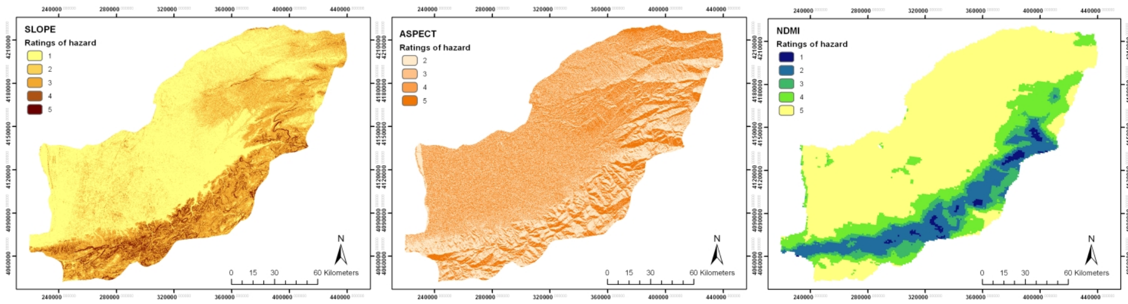
2-5- Distance from roads and urban areas;

Anthropogenic factors are important riskein variables to occur fires near to habitants and roads. (Burrows et al., 2006a; Edwards et al.,2008). It has been known that human activities are one of the basic factor that affecting spread of forest fire (Wirawan, 2000). Due to the more intense human activity, the forest fire hazard is increased and it provides much opportunity for unexpected man-made ignition. (Carrao et al, 2003).

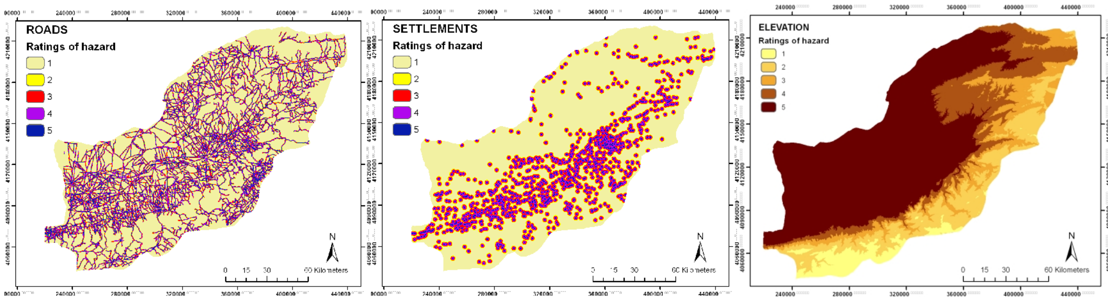
Based on prior information and subjective weights; Elevation, Slope, Aspect, Vegetation moisture, and Distance from roads and urban areas were classified. (table 2 and figure 3), Then Structural Fire Index (SFI) was calculated to map fire risk. (figure 4)

Table 2, Weights assigned to variables and classes for forest fire risk modeling

Variables	Classes	Ratings of hazard	Fire sensitivity
NDMI (MODIS)	>0.36,0.26_0.36,0.16_0.26,0_0.16,<0	1,2,3,4,5	Very Low ,Low, Medium, High, Very High
Elevation (ASTER)	>2000,1000_2000, ,500_1000 , 200_500, <200	1,2,3,4,5	Very Low ,Low, Medium, High, Very High
Slope	<5%, 10_5%, 25_10%, 35_25%, >35%	1,2,3,4,5	Very Low ,Low, Medium, High, Very High
Aspect	North, East, West, South	2,3,4,5	Low, Medium, High, Very High
Distance from roads	>400 , 300_400, 200_300, 100_200, <100 m	1,2,3,4,5	Very Low ,Low, Medium, High, Very High
Distance from settlements	>2000 , 1500_2000, , 1000_1500, 500_1500, <500 m	1,2,3,4,5	Low, Medium, High, Very High



A. The classification of the slope B. The classification of the aspect D. The classification of the NDMI



C. The classification of distance from roads E. The classification of the vicinity of settlements F. The classification of the elevation

Figure 3, The classification of the map variables

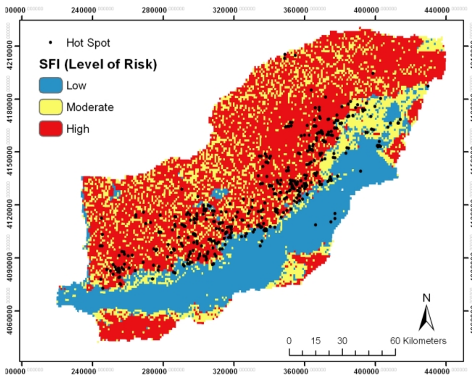


Figure 4, The fire risk zone map based on Structural Fire Index

3- RESULTS

For assessment of Fire Risk Zone Map, the MODIS Hot Spot dataset was obtained since 2001 to 2003 from the Fire Information for Resource Management System (FIRMS) that provides by NASA. (Davies, et al. 2009. Davies et al. 2008.). The number of hot spot in each risk class was counted. It would be justified, that the most hot spot should be located in high risk zone and the lowest one in low zone. Using histogram by zone showed that the SFI presented reasonable risk zonation because the most hot spots of SFI are located in high risk zone. (figure 5)

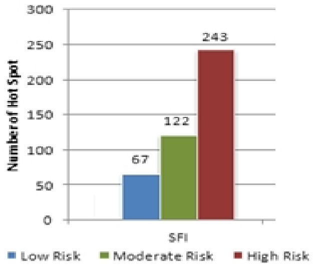


Figure 5, Zonal statistic of Structural Fire Index

4- CONCLUSIONS

The present study was an attempt to integrate remote sensing data and GIS concept to determine risky places and to plan forestry management. Fire risk models are a great approach for precautionary measures for the environmental protection of the forests. The objective of this paper was to assess the Structural Fire Index for forests in northeastern Iran. Spatial assessment of this study revealed that the Structural Fire Index presented a reasonable result. Also this index was used successfully in mediterranean countries such as Spain (Chuvieco and Congalton,1989), and Portugal (Pelizzari, et al,2008), (Caetano., et al 2004). They mentioned this index has a good capability for these countries. As seen in this research, this index can be used for northeastern Iran. Since this index uses subjective weights based on personal judgments, using data mining models can explore the pattern of affected factors on fire and improve the results. (Alonso-Betanzos et al.,2002). In addition, we cannot use same weights and same variables in different regions because forest fire in each part of earth has an own characteristics. Therefore indices should be modified over areas and more simulation results need to compare the other methods.

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