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REVIEW ARTICLE

Evaluating models and effective factors obtained from remote sensing (RS) and geographic information system(GIS) in the prediction of forest fire risk: A structured review

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ABSTRACT

Fire, a phenomenon occurs in most parts of the world and causes severe financial losses, even, irreparable damages. Many parameters are involved in the occurrence of a fire; some of which are constant over time (at least in a fire cycle), but the others are dynamic and vary over time. Unlike the earthquake, the disturbance of fire depends on a set of physical, chemical, and biological relations. Monitoring the changes to predict the occurrence of fire is efficient in forest management. **Method:** In this research, the Persian and English databases were structurally searched using the keywords of fire risk modeling, fire risk, fire risk prediction, remote sensing and the reviewed papers that predicted the fire risk in the field of remote sensing and geographic information system were retrieved. Then, the modeling and zoning data of fire risk prediction were extracted and analyzed in a descriptive manner. Accordingly, the study was conducted in 1995-2017. **Findings:** Fuzzy analytic hierarchy process (AHP) zoning method was more practical among the applied methods and the plant moisture stress measurement was the most efficient among the remote sensing indices. **Discussion and Conclusion:** The findings indicate that RS and GIS are effective tools in the study of fire risk prediction.

Keywords: Modeling; Risk Prediction; Fire; Fire Risk Modeling; Remote Sensing; Geographic Information System

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1. Introduction

Fire is considered as one of the main causes of disturbance and change in most natural ecosystems[1]. According to the statistics provided by the organization, forests and rangelands contribute as much as 61.82%. Investigations show that the major Iranian fires occur in these areas[2]. Forest fires are one of the main concerns in many parts of the world not only from an environmental point of view but also from an economic, social, and security perspective[3]. Through the Middle East and North Africa, Iran is ranked as the fourth country in terms of forest fire[4]. Since planning before the fire requires being aware of when and where it is likely to occur, or where it has a more negative effect, the assessment of fire risk is the major component of fire control[5]. Fire risk assessment is one of the basic tasks for forest fire control and management in forest zones and the zones with forest fire risk can be a useful guide for the forest fire management, which is a very important prevention strategy[6]. The high-risk fire zones referred to as zones with the potential of fire or the zones in where the fire easily extends[7]. The most effective way to reduce the damage caused by forest fires is to prevent fire using all appropriate conservation and management measures. Various studies have been conducted to improve the early prediction of fire and detection systems to develop the response strategies during the incident time[8,9]. However, today, with the development of remote sensing technology, satellite imagery is used as the most important tool to control, prevent, and monitor zones for fire and geographic information systems to integrate remote sensing and land-based information. In recent decades, researchers have predicted fire risk zones including fire risk zoning and modeling using remote sensing and geospatial applications[10]. Due to their frequent applications, these sciences play a crucial role in environmental assessments. Numerous studies have been done so far in Iran especially in Golestan Province regarding forest fires. The present study is a structured review aimed at determining the models and effective factors obtained by RS and GIS in predicting fire risk.

2. Theoretical framework and bases

Initially, the definitions related to the issue of fire are discussed that has been mentioned frequently in various papers.

2.1 Definition of fire

Fire is one of the destruction factors causing damage to human life and properties in addition to economic damage and environmental pollution. The imposed damage rate is different depending on the types and severity of the fire, etc. that is also important in different countries and zones where the probability of fire is high, and where the management of fire control and monitoring is more important[11].

2.2 Risk assessment

The incident occurrence possibility refers to the probability of its occurrence and severity. The outcome of the risk assessment should determine whether the risk is tolerable or not[12].

Vulnerability: A combination of two words of risk and fire (the probability of its start and extend) and vulnerability due to a fire (the result of a fire)[13]. In addition, it means assessing the constant and changing factors of the fire environment (fuel, water, air, and topography), which determines the ease of combustion, the speed of expansion, the difficulty of controlling, and the effects of the fires[14].

2.3 Fire occurrence risk

The probability of fire occurrence varies in terms of time and place. Usually, the probability of fire occurrence is determined at various levels, such as low, moderate, high and very high, or with terms like improbable, possible, probable, and high probable[11]. According to the definition of Food and Agriculture Organization, the risk of fire occurrence is through the presence or activity of any effective factor. According to another definition, fire risk is the potential of combustion sources[15].

2.4 Modeling

The process of creating and choosing a model is called modeling. The transformation of a statistical concept into a mathematical language is a kind of modeling. The more math concepts are used, the more valuable the model will be established[16].

2.5 Fire risk map

A digital map is regarded to a specific zone, which is created by combining multiple and effective thematic layers in the event of a fire. To create a risk map, initially, a weight is considered for each layer depending on their effect. The greater the effect of each variable, the higher the weight for that variable will be considered[17].

So far, various models have been used to assess the fire risk, which include comparing the performance of more conventional, more accurate, and more recent models to use the best model in the future research. However, in order to achieve accurate results, it is always necessary to note that which model or method has an acceptable accuracy in generating a potential fire risk map. In order to estimate how and when the fire will have adverse effects, it is necessary to consider a model that will consider the fire and its potential for expansion as well as the fire vulnerability[18]. Considering the most effective factors, the proper weight allocation is very important to select the best forest fire risk model. The use of remote sensing data from satellite due to its features such as wide and integrated view, the use of large sections, the use of different parts of the electromagnetic spectrum to record the phenomena, speed and transmission and the variety of data forms, and especially their repetition, are unique. Therefore, it has been used as a suitable tool for the assessment, monitoring, control, and management of water, soil, forest, and rangeland resources. Today, such images are widely used in various studies of natural resources and the preparation of various maps. For example, Chuvieco *et al.*[19] and Haji Mohammadi & Biranoond[20] used remote sensing and geographic information systems to improve the framework for assessing the risk of fire. The risk of fire based on the probability of occurrence and potential damage can be evaluated and human and natural sources are considered as important sources of fire.

3. Research method

This research was conducted through a structured review aimed at determining the models and factors affecting the prediction of fire incidence in Iran. To this end, the SID, Google Scholar, Magiran and Iran Medex databases were searched for retrieval of internal papers and the ScienceDirect database for the retrieval of English papers during 1995-2017. The English keywords include fire risk prediction, fire risk assessment, remote sensing, and Persian keywords include modeling, risk prediction, fire, fire risk modeling, remote sensing, and geographic information system. The fire risk prediction keywords are combined using the function and once or together. The inclusion criterion is the research papers that used remote sensing and geographic information systems in the field of fire risk prediction. Then, the papers whose full text was available were reviewed. The required data such as introduction, study location, the purpose of the study, data collection sources, and the study area were extracted. Most of the papers have obtained their required data from Modis images and weather stations located in the study area while other satellites including IRS-1D (and LISS-III) have also been used.

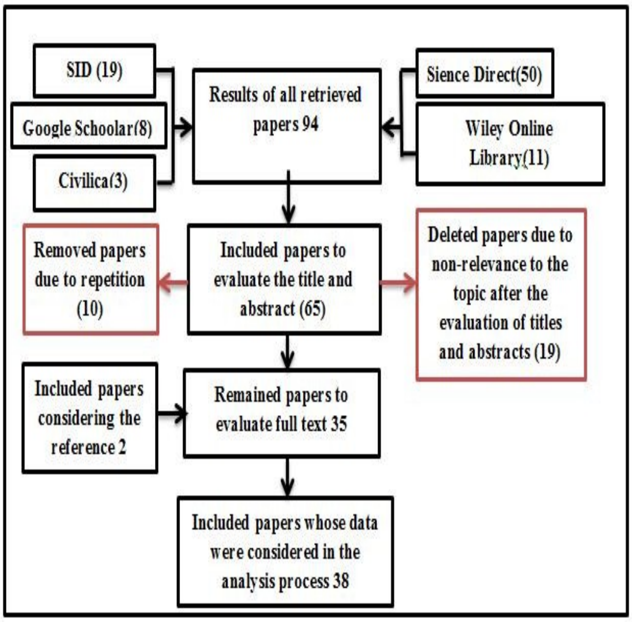

Figure 1. General steps of the method**.**

4. Findings and results

Following the search for the structured keywords in online databases, 50 papers were retrieved. After removing repetitive and unrelated papers, 38 eligible papers were selected for further analysis. The results show that the number of papers in the field of fire risk has increased over time. Various data sources were used to collect data. The studied papers were classified into two categories, namely zoning and modeling. One of the zoning papers such as Mosavari *et al.*'s [21] for fire risk zoning in the forests of Golestan Province has used (slope, direction, altitude, rain, climate, wind speed, moisture, temperature, plant type, plant density) and biological agents (distance from the village, distance from the road). Using the hierarchical analysis method, the factors affecting the occurrence and expansion of fire were compared in paired wise and their coefficient was determined. Eventually, a fire risk map was developed in five classes of very low, low, moderate, severe, and very severe.

Modeling studies include quantitative, qualitative or statistical models that are described below. Murta & Bozer[22], Makia *et al.*[23], Jaiswal *et al.*[7] and Adab *et al.*[4] predicted the vegetation water situation using remote sensing and satellite imagery such as IRS, LISS-III, and MODIS. Nepstad[24] have applied drought indices to predict the risk of fire. The remote sensing data and meteorological data (temperature, relative moisture, and precipitation) and map of vegetation, slope, distance from the road and residential zones were integrated in GIS, as well as measuring the relationship between leaf water content and the normal water index, near infrared band, and confirmation of infrared short wave spectral data. They concluded that vegetation status such as Normalized difference moisture index (NDMI) and Global Vegetation Moisture Index (GVMI) in temperate zones shows the fore model better than the normalized vegetation index (NDMI). They have predicted the zones with fire risk potential with an acceptable accuracy.

Other types of research including the studies of Xu *et al.*[25], Beygi *et al.*[26], Nasiri[27], Chandra [28], Sharma *et al.*[29], Mohammadi *et al.*[30], Mosavari *et al.*[21], Jahdi *et al.*[31], Darvishi *et al.*[32], Behzadfar & Vahid[33], Aghajani *et al.*[34], Huyền & Tuân[35], and other researchers developed the map of fire risk zones by specifying weights via Analytic Hierarchy Process (AHP) or fuzzy logic for factors such as slope, direction, altitude, land use, distance from the road and distance from the canal, type of vegetation and distance from residential zones, and Canopy Coverage percentage. Finally, the fire risk map was prepared using the weight layers and weight coefficient for each of the factors and the zones were classified into four classes of very high sensitivity, high sensitivity, low sensitivity, and moderate sensitivity

Huyen and Tuna obtained the fire risk map using the following model[35]:

$$CFRISK = 0.4379 \times FUI + 0.2190 \times SLI + 0.2437 \times ASI + 0.0994 \times AC \quad (1)$$

CFRISK is the cumulative fire risk index value; *SLI* is the slope index; *ASI* is the aspect index; *ACI* is the accessibility index and *FUI* is the fuel type index.

Adab *et al.* used the following model with regard to the factors affecting fire in the province[4] .

$$HFI = [100v + 50s + 25a + 10.(r + c) + 5e]/10 \quad (2)$$

Where; *v*, *s*, *a*, *r*, *c*, and *e* indicate vegetation moisture, slope, aspect, distance from road, and distance.

They also conducted the forest fire risk zoning in another research using Molgan's fire awareness models based on the atmospheric parameters in determining the potential and severity of forest fires as well as GIS technique. The results indicated that the applied model has a proper efficiency at spatial level annually in all seasons except for winter, which is as follows.

$$G = \sum_{n-1}^{n-m} T - D \quad (3)$$

Table 1. G values for determining the intensity of the fire

Value of ignition index	**Interpretation**
G=300	No fire risk
301<G<500	Low fire risk
501<G<1000	Moderate fire risk
1001<G<4000	High fire risk
G>4000	Very high fire risk

In which, *T* is the air temperature (0°C), Dis saturation vapor pressure deficiency in millimetersis number of days since the rain has passed. The following parameters are presented in terms of the calculation of the intensity of the parameter *G*[36].

In another study[25], a fire risk map was developed using aerial images and the following model.

$$RC = 7 \times VT + 5 \times (S + A + E) + 3(DR + DS + DF) \quad (4)$$

RC is the numerical index of forest fire risk where *VT* indicates the vegetation type; *S* indicates the slope, *A* indicates the aspect and *E* indicates the elevation. *DR*, *DS*, and *DF* indicate the distance from roads, settlements, and farmlands, respectively.

In another study, using Xu's model, the authors investigated the fire risk areas in the northern part of Iran.

Also in another study, Fire Risk Zonation Index model was applied[37]:

$$FRZI = (FTI \times 9) + (ASI \times 7) + (RDI \times 6) + (SLI \times 5) + (ELI \times 4)/10^* \quad (5)$$

Where *FRZI* is the fire risk zonation index; *FTI* is the fuel type index; SLI is the slope index; ASI is the aspect index; *RDI* is the road index; *ELI* is the elevation index.

Other researchers developed a fire risk map for Indian woodlands using aerial photos and GIS. In this research, firstly, the most important factors influencing the fire of the study area were identified. Then, by plotting vegetation map, slope, distance from the road and residential areas, they were weighed based on the sensitivity to the potential of fire and using the index and integration in the GIS environment. The hazardous forest map of the forest area studied in the four classes of fire hazard category is very low to low. The results of this study show a high correlation with fire areas.

$$FR = 10Fi(1-11) + 2Hj(1-4) + 2Rk(1-4) + 3Sl(1-6) \quad (6)$$

In another study, Yin *et al.*[38] used an index FFR for fire hazard modeling, in which the *FFR* forest fire risk index (*V*) is vegetation variable (with 9 classes), *P* near residential areas (with 4 classes), *S* tilt factor (with 5 classes), *A* direction (with 4 classes) and subcategories *i*, *j*, *k*, *l*, *m* classes.

$$FFR = 0.40Vi + 0.15pj + 0.15Ai + 0.15Hm \quad (7)$$

Tran *et al.* used the following risk model to predict the risk of fire[39].

$$SIMap = (FR \times 0.4) + (SR \times 0.2) + (RR \times 0.2) + (SR \times 0.1) + (AR \times 0.1) \quad (8)$$

In which, *SIMap* is susceptibility index map; *FR* is rated forest; *SR* is rated settlement; *RR* is rated road; *SR* is rated slope and *AR* is rated aspect.

Saxena *et al.*[40] identified the fire risk zones using the following models. The results of this research show a good adaptation between fire zones and high fire risk zones.

$$FRZI = 5Vi = (1-10) + 4Aj = (1-5) + 2Sk = (1-6) + 1Rl = (1-10) \quad (9)$$

$$FRZI = (5As + 4El + 5Sl + 9Ft + Dr + 7Hb + 5Rd)/10 \quad (10)$$

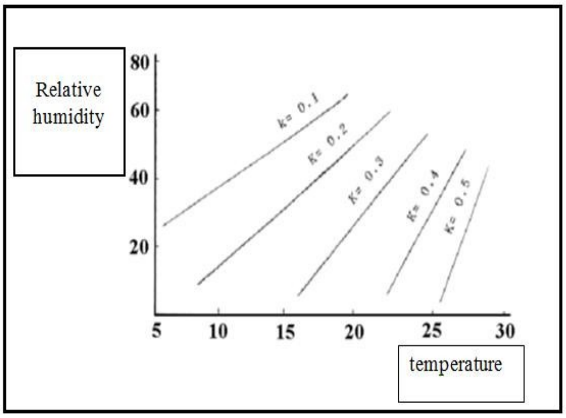

Figure 2. Forest fire risk coefficient through Francilla method.

A study has been conducted, which used Francilla model and applied two main factors of the maximum temperature and the minimum relative moisture compared to the fire risk estimation and the preparation of risk map with different degrees of very severe, severe, moderate, and poor for different month separately at the studied zone[41] (See **Figure 2**).

Vadrevu *et al.*[42] used a fuzzy theory to design a fire risk map with decision-making algorithms in a GIS environment as a framework for preparing a fire risk map. The result of this study was a good demonstration of high-risk zones, which shows that using multi-criteria decision making combined with the GIS environment can be a useful tool to assess the occurrence of a fire. In another research, the use of remote sensing and geographic information systems was developed to prepare a fire risk map[43]. Remote sensing and satellite information systems are the basis of the fire models that are well suited to the risky zones. In this research, the satellite data (1989-2006) were used to survey burned zones. Different classes based on the sensitivity to fire are in the four classes of very sensitive to very low sensitivity. Mohammadinejad & Tavakoli studied the fire status in oak and wild pistachio (Pistacia atlanticaDesf) forests in Lorestan Province using GIS[44]. The results indicate that the most important cause of destruction in the forests of Zagros and west of the country is fire[44].

5. Discussion

This review study was conducted to evaluate the studies on forest fire risk prediction. A review of various studies showed that the thematic field of almost half of the risk zoning studies has been qualitative and moisture stress and temperature and moisture rate were the factors affecting the zoning of vegetation index. A high percentage of studies have used remote sensing and geographic information systems capabilities and reported the incidence of fire. Other papers also have access to information from meteorological stations. The other class of fire modeling studies has been carried out. Among the models made in various studies, three categories of fire risk models are discussed in this study[45]. The resulting map is a qualitative categorization for different zones. These types of models are provided periodically and seasonally. These models can be divided into three general categories:

5.1 Qualitative and quantitative models based on expertise

Quantitative models based on expertise classify the variables of fire using numerical scales carried out based on the weight of the ground observations of the research and expert opinions. The main advantage of this modeling is the possibility to detect the high-risk zone for decision-making and management. Also, these models show the possibility of spreading or starting a fire and identify areas with high fire potential[10,46].

5.2 Quantitative models based on multi-criteria evaluation

Multi-criteria models also use expert knowledge for modeling. This method is useful when the opinions of the experts are diverse in order to reach an agreement between experts. This can be mentioned in the study of Chen *et al.*[47].

5.3 Statistical models

Statistical models are often accurate and these models depend on the spatial properties of the studied area. Therefore, they cannot be used for extrapolation and other areas. These models include linear and nonlinear regression, logistic regression, and Poisson distribution[46,48]. When the fire model is very different or the fire variables are not very clear, the neural network is a suitable method.

Also, models are divided into two groups of long-term and short-term based on the time scale and spatial scale. Long-term models use static parameters such as topography, road networks, and vegetation types. These models show the fire risk model and they are useful for forest management and monitoring to prevent the occurrence of fire. Short-term models use meteorological data and predict the risk of fire on a daily or weekly basis. Some of these systems can be Canadian Forest Fire Danger Rating System (NFDRS) (Carla and Switzerland, 2013). Forest fires are one of the destructive factors of these ecosystems, and efforts should be made to anticipate the occurrence of a fire before it occurs. Correct information about the factors that affects fire and its continuous monitoring can help forest management to prevent this disruptive factor. Therefore, RS and GIS are good tools for zoning high-risk zones for better management. This technology allows researchers to keep monitoring any changes in the level of vegetation indices to create a suitable and dynamic mode for each zone individually[6]. The main elements affecting the fire risk are environmental factors (slope, direction, attitude, rain, climate, wind speed, moisture, temperature, vegetation type, vegetation density) and biological factors (distance from the village, distance from the road)[21]. All of these elements have a different effect. Combining these factors together creates homogenize zones of risk rate that provide a valuable opportunity for forest management. Remote sensing and geographic information system are invaluable and useful software for integrating all factors and achieving results[32,46]. Regarding preparing the fire distribution map, Stolle *et al.*[49] investigated the relationship between the land use and the occurred fires. Vazquez and Moreno examined the distribution model of the fire points, and Juan *et al.*[51] used Cornell method to prepare the fire risk map. The results of the studies show that the vegetation indices and their integration with other factors affecting the occurrence of fire and conducting a comprehensive assessment can be easily done using remote sensing and geographic information system, which is a new method in risk assessment studies. Investigating the fire location with vegetation indices increases the awareness of researchers regarding the incidence of fire. This could give a new and profound understanding of forest management[4]. The studies that have been used to predict the risk of a fire, which have been investigated in this study, are often limited to qualitatively zoning of the maps from low risk to high risk. Due to the high capacity of remote sensing, the continuous monitoring of forests to dynamically and daily express the fire risk has been scarcely considered. Although the technology of geographic information systems is rapidly expanding, it often has the ability to integrate meteorological station and remote sensing information. Nevertheless, it is necessary to pay more attention to the capabilities of this science. This study is one of the first studies that have systematically examined the studies that have been so far carried out on the assessment of fire risk using remote sensing or GIS. Some of the limitations of this study were the fact that some of the studies in the field of fire were aimed to find and control the fire after the occurrence and some other, while the distinction between risk prediction and fire behavior was problematic.

6. Conclusion

Forest is affected by several factors such as human factors and natural factors that are divided into two types of constant factors and variable factors over time. Controlling human factors and monitoring of variable natural factors over time can play an important role in controlling unexpected fires in the forest. The use of geographic information systems and remote sensing to monitor natural hazards is increasing in Iran. Therefore, the attention of forestry managers to the capabilities of this software and attention to the conducted studies in this regard is necessary and useful.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author's contributions

In writing this article, the authors had an equal share of participation and participated in all stages, including writing, editing, arbitration, and all stages of scientific work.

Ethics

In this article, all ethical principles related to scientific-research articles such as validity and authenticity, originality, data collection in a standard manner, integrity, and accuracy of research and etc. are observed.

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