An Innovative Method For Forest Fire Risk Zoning Map Using Fuzzy Inference System And GIS

Mohammadali Rajabi, Aliasghar Alesheikh, Alireza Chehreghan, Hassan Gazmeh

Abstract: Forest Fire causes considerable environmental damage and brings about a significant change in the ecosystem of the region. It is a humanistic and national duty to protect against fire the forests. Most of such forest fire incidents result from human nonchalance. Other causes such as thunderstorm, glass objects and etc. are also considered as triggers of such incidents, this paper mainly focuses upon the human factor. The considered parameters such as distance from the road, residential areas, river, slope, climate and type of vegetation, and GIS play a significant role in the analysis and determining the factors impacting fire incidents. GIS was used for the analysis and calculations required in regard with these parameters. Therefore the locations with fire risk are determined by a combination of experimental model, fuzzy inference system and GIS. The obtained results indicate high accuracy and good efficiency. Results discussed extensively in paper. To evaluate the proposed method, the obtained results were compared with fire incidents of past years. The comparison results indicate an improvement in predication by this method in comparison with other methods.

Keywords: Forest Fire Risk Fire Risk Zoning Map, GIS, Fuzzy Inference System, Experimental Model.

1 INTRODUCTION

Forest fire is not dependent on a specific season, but most of forest fire incidents of Golestan Province have occurred when trees have been dry and the ground has been thick with dead leaves. The fact that the region is frequented by tourists has led to widespread fire incidents in Golestan Forest. Tourists' disregard of safety regulations such as not putting out their fire before leaving the region and etc. has led to many undesired and serious fire incidents [1]. The biggest fire incident happened in November 2010 which lasted for several weeks and burned a large area of the forest. Repeated fire incidents have destroyed the soil texture of the region which in some cases has destroyed some plant species and has generally made the plant growth problematic. Studies on the behavior of fire and its impact factors will certainly prepare us for prevention and protection against such incidents [2]. Many countries make use of satellite images for monitoring fire incidents and detecting the burning regions. Forest fires are generally categorized into two types: ground fire and crown fire.

- Mohammadali Rajabi, PhD is an assistant professor at Faculty of Department of Geomatic, Collage of engineering, University of Tehran. PH-0982188334341. E-mail: marajabi@ut.ac.ir.
- Aliasghar Alesheikh, PhD is an professor at Faculty of Geodesy and Geomatics Engineering, Khaje Nasir Toosi University of Technology. PH- 098218887707-303. E-mail: alesheikh@kntu.ac.ir.
- Alireza Chehreghan, Msc Student at Department of Geomatic, Collage of engineering, University of Tehran. PH-0983518280674. E-mail: achehreghan@ut.ac.ir.
- Hassan Gazmeh, Msc Student at at Faculty of Geodesy and Geomatics Engineering, Khaje Nasir Toosi University of Technology, PH- 0980353858494. E-mail: h.gazmeh@gmail.com.

Ground fires mostly consume the dead leaves, shrubs and small trees. This type of fire is used in several regions such as Africa for prevention of unwanted fires. In this system, the speed and direction of wind is simulated by various methods such as Cellular Automata to extinguish fire in certain areas [3]. The second type of fire, the crown fire, is considered as one of the most dangerous and detrimental types of fire[4]. Most of the fires experienced in Golestan forest have unfortunately been of crown type. Controlling this type of fire is of great difficulty and requires advanced equipment. For on-time and optimum allocation of resources and equipment during fire incident, a fire spread simulation system is required. Various factors, such as density and type of vegetation, humidity, temperature, slope, distance from road and residential area, may trigger and affect fire incidents. Such factors can be found more in lawns and bushy areas than in forest areas with oak and beech trees. Humidity, on the other hand, as one of the significant impact factors, has a greater effect on bushy areas than on forests. In case the flammable materials (e.g. the grass) are humid, the risk of fire for such materials reaches its minimum [5]. In general, fire incidents can be classified into three groups: natural fire incidents, intentional man-made fires and unintentional man-made fires caused by human carelessness [6]. The second group, intentional man-made fires, is taken into consideration in this study for preparation of the fire map. The risk potential has been prepared according to fuzzy inference method and using factors such as slope, climate, vegetation, and distance from road, river and residential areas. This potential risk map can be used for preventive operations as well as for optimum and timely allocation of resources and equipment during such incidents. More patrols and sentinels can be deployed in regions with high fire risk during fire seasons. With regard to unprotected regions with great fire potential, access roads can be built to such areas so the transfer time of resources to these regions during fire incidents reaches its minimum. According to Adab [7] can be mentioned as one of the Iranian studies carried out on this subject. They conducted the zoning of fire potential in forest areas of Mazandaran province per all seasons of 2005 as well as a 15-year period based on the Molgan predictive index and using GIS. To evaluate the efficiency of the model, the results of the year 2005 was compared with the number of test fire incidents and then the correlation of the year in question with the past 15 years. The obtained results indicated that the model was of significant efficiency for all seasons save for winter and for all years from a spatial viewpoint. Akbari [8] proposed a simple model for mapping fire risk and fire alarm in forest areas using remote sensing. Regions with high fire risk can be recognized by this model and using satellite images and topographic model of the region. Regions with high risk are determined by formulation of the three factors namely the slope, direction of slope and Normalized Difference Vegetation Index (NVDI), which have an impact on the above issue, and their application on the image. Eskandari [9] assessed the model proposed by Dong, Li-min [10] by its application on Neka area forests as well; the model proved efficient for this area. They conducted the zoning of the area using parameters such as vegetation, slope, geographical direction, height above sea level, and distance from roads and residential areas. Eskandari [9] ultimately showed that 34 percent of the region in question was critically high risk and high risk. He also showed that 40 percent of the area was involved in past year fire incidents. Chuvieco and Congalton [11] can be mentioned as a sample of non-Iranian studies carried out on this subject. They prepared the map of the regions on Spanish Shores critically exposed to fire risk using a combination of TM Image Processed Data and other input in GIS environment. The layers were merged according to AHP. The obtained map of regions was mapped to the regions which were consumed by the real fire incident. The mapping results indicated that 22 percent of the pixels which were situated on high risk areas were actually burnt in past year fires while only 3.47 percent of the low risk areas were involved in the real fire incidents. Alimedia [12] also made a map of Portugal forest regions with high risks of fire based on parameters such as forest species, slope, geographical direction, distance from roads and permanent rivers. The variables were categorized based on their risk ratio and the data were analyzed in GIS environment. The obtained result was 5 classes of risk for the region. The risky regions had slopes of more than 40 percent, direction of 135 to 225 degrees, covered with trees and bushes and were located 30 meters from permanent rivers.Giri and Shrestha [13] studied the causes of forest fires which took place in 1998 in Huay Kha Khaneg resort of Thailand using TM satellite images. Then the burned areas were depicted by interpretation of TM images. For assessing the accuracy and effects of fire, several samples were taken from burned and unburned areas using GPS. The results indicated 88.3 percent classification accuracy for the burned areas. The obtained results suggested various reasons for the fire incident in this resort but most of the causes were determined as unintentional. It was finally suggested to create a database in GIS, comprising variables influencing fire incidents, for topography of high risk areas as well as simulation of forest fire incidents.[10] developed a hybrid method comprising GIS and RS for topography of high risk regions in Baihe Forest area of China; therefore, topographic data were obtained from DEM of the region and information related to vegetation type and application of lands (roads, residential areas, and etc.) were extracted from Landsat ETM+ images. Then the high risk areas were determined by assigning reasonable weights to all layers. The history of fire incidents which had taken place from 1974 to 2001 in the under study forest was reviewed for the efficiency of the method. The results indicated that high risk regions were situated in areas which had already been involved in actual fire incidents. Esra Erten [14] mapped the high risk areas of Gali Puli forests in Turkey using data obtained from GIS and satellites. TM images were used before and after the fire incident. The remaining data were gathered from topographic map (1:25000) and were merged in GIS environment per their weight and significance in fire ignition. The results showed that fire potential is highest in regions which are covered with dry vegetation, have steep slope, face south, and are close to roads and residential areas.

2 Material and Methods

2.1 Parameters Influencing Fire Risk Potential

As mentioned before, various parameters contribute to forest fires. The most important parameters are direction of slope, vegetation, climate, distance from road, river and residential areas [11].

2.1.1 Slope

Observations made in regard with actual fire incidents, both ground fires and crown fires, which had happened in all regions, indicate the fact that fire spreads faster on upward slopes rather than downward slopes [15]. When a pixel is burning, the distance between the flame and ground surface decreases on an upward slope and this leads to heat calorie transfer to the forward pixels. In contrast, when the fire spreads downward, the angle between the flame and ground surface increases which ultimately leads to a decrease in fire spread rate on downward slopes. This has been supported by both experimental and laboratory findings. In fact, the direction of slope and the height of the region play an important role in fire spread.

2.1.2 Vegetation Cover

The most common vegetation cover of the region is dense crown top trees. Other different covers such as shrubs, agricultural lands, bushes and residential areas were also found in the region. Vegetation cover is one of the most significant fire factors. In most of the studies, vegetation is considered as the flammable material [15]. The flammability of each pixel is determined based on the type of vegetation cover. In fact, when the vegetation type is grass, in general and without considering the humidity, the flammability increases, Flammability decreases when approaching the crown trees with thick trunks.

2.1.3 Climate

Significant rainfall and humidity changes is observed from west to east of Golestan province. The Western part of the province, in comparison with the east side, is of greater humidity as it is closer to Caspian Sea. The humidity level of a region can be classified by different methods among which the Do Martin and Karimi Method can be mentioned of which the former method, the Do Martin Method, is employed in this study. According to this method, the region is classified into 6 classes.

2.1.4 Distance from Residential Areas

Residential areas located by the side of forests as well as villages situated inside forests are counted as threats to forests. The inhabitants' inattention, especially during dry seasons and autumn when trees are prone to catching fire, and when large dead leaf litters spread on forest ground, the fire risk heightens dramatically [11].

2.1.5 Distance from Roads

Needless to say, roads are the main channels of a country and most of the trips are land trips made on roads. What makes this

IJSTR©2013
www.ijstr.org

issue important for Golestan Province and the region under study is the fact that roads pass through or by forests. Apart from roads leading to tourist destinations, the transit road of Mashhad-Gorgan also passes through Golestan forests. From a tourist viewpoint, this is an ideal opportunity, but from an environmental viewpoint, this counts as a potential threat to the forest as it may cause fires. Tourist and travellers' inattention to safety rules regarding not starting any fire in the forest or making sure to put out the fire after leaving their camp are considered as the main factors causing fire incidents [4].

2.1.6 Distance from River
During tourist seasons, especially summer, tourists mostly camp by riversides and springs. This issue increases the concentration of people by the side of rivers which is considered as one of the serious threatening factors [15].

2.2 Geographical Information System (GIS)
Studies conducted to date indicate that GIS, combining the vegetation cover maps, topographic maps and other data, offers great assistance with topography of critical or prone-to-fire regions [15]. The variety of factors which affect the ignition and spread of fire necessitate usage of a hybrid analytical method [11]. Therefore, the significance of GIS in data collection and as a supporting decision making system for an efficient management becomes more apparent.

2.3 Fuzzy Inference Systems
Fuzzy Logic was first introduced by Zadeh [16]. Later on in early 1970's, Zadeh introduced linguistic variables and showed that one can implement the ambiguous statements in problems by these variables more easily and in a more understandable way in the form of arithmetic algorithms. One of the advantages of Fuzzy Inference System is the unnecessary of a mathematical model and the possibility to implement the human knowledge using the comprehensible linguistic rules [17]. In fuzzy logic, a component has a degree of membership between 0 and 1, in contrast to definite sets in which a component either belongs to a set or not. For instance, with regard to equation (1), the x component has the membership degree of $\mu_{\tilde{A}}(x)$.

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\} \quad (1)$$

Various membership functions have been introduced to date, the simplest and most applicable of which is the triangular-shaped membership function (with regard to Figure 1 which is defined as equation 2) [18].

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-l)}{(m-l)} & l < x < m \\ \frac{(u-x)}{(u-m)} & m < x < u \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

Parameters l, m and u are shown in Figure 1.

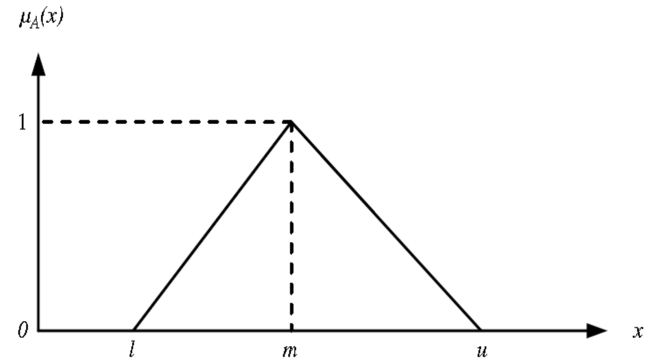

Fig. 1 Triangular Membership Function

The design of fuzzy controllers is one of the broad application areas of fuzzy logic. The main function of controllers, or inferers, is the expression of fuzzy sets which facilitate the resolution of fuzzy processes. Assilan-Mamdani Fuzzy Inference System can be mentioned as one of the most applicable inferers. An inferer's function is presenting the fuzzed input (received through fuzzy convertor process) in fuzzy laws and producing a fuzzy output for each law. In other words, for the result part in the output space, a membership degree is determined for fuzzy output sets based on the membership degree of input sets and the relationship between these input sets. All fuzzy controllers function similarly but their difference lies in their type of implementation. Takagi-Sugeno can be mentioned as another instance of Fuzzy Inference Engines [18]. The Fuzzy Inference Engine used in this study is Assilan-Mamdani whose implementation steps are as follow [18]:

1. Identifying and Naming input linguistic variables and determining their numerical range.
2. Identifying and Naming output linguistic variables and determining their numerical range.
3. Defining the membership function for input and output variables.
4. Determining rules showing the control process.
5. Fuzzifying the input variables.
6. Carrying out the inference for clipping.
7. Defuzzifying the output variables.

Triangular-Shaped membership function was used for linguistic input and output variables. Min-Max method was also used for clipping and center of gravity method was used for defuzzification.

3 Result and Discussion
The region under study is part of Golestan province forests with an area of 55 thousand hectares spreading in Minoodasht town. Minoodasht is surrounded by Semnan and Khorasan province from south, Khorasan province from east, Gonbad-e-Kavoos from west and Kalale town from north. The geographical specification of the region under study is as follows: (Figure 2 shows a view of the region under study). The coordinate system is UTM (WGS 84 Ellipsoid) and zone number is 40.

$$\text{Down Left}\begin{cases}358369.87\text{ m}\\4082589\text{ m}\end{cases}\ \text{Up } Right\begin{cases}373330\text{ m}\\4119765\text{ m}\end{cases}$$

Fig. 2 The region under study.

According to figure 3, the structure used for problem solving is a combination of GIS and a mathematical model. The mathematical model used for the calculation of fire risk potential is a proposed model which is the combination of the experimental mode of Dong, Li-min [10] and fuzzy inference system. Equation (3) shows this model:

$$FR = 7 * V + 5 * C + FO \qquad (3)$$

In this equation, V is the type of vegetation (figure 4), C is the type of climate (Figure 5) and FO is the value of output calculated by fuzzy inference engine. The FO value is calculated by various parameters including the slope of the region (Figure 6), distance from the river (Figure 7 shows the rivers in the region), distance from auto roads (Figure 7 shows the auto roads in the region) and distance from residential areas (figure 5 shows the residential areas in the region). 135 rules extracted from experts' opinion were used to that end. Table 1 shows a sample of those rules. Triangular-shaped membership function was also used for all parameters and the output of fuzzy inference system. The membership function of distance from residential areas is shown by figure 8, membership function of distance from road and river by figure 9, membership function of slope by figure 10, and membership function of fuzzy inference engine output by figure 11.

Table 1- Example of used rules in fuzzy inference system

Rules	if				Then
	"and" Operator				
	C1	C2	C3	C4	Consequence
1	L	L	L	VH	VH
2	M	M	M	M	M
3	H	M	H	VL	VL
4	H	M	M	L	L

VL:Very Low, L:Low, M:Moderate, H:High, VH:Very High

C1: distance from river
C2: Distance from roads
C3: Distance from residential area
C4: Slope value

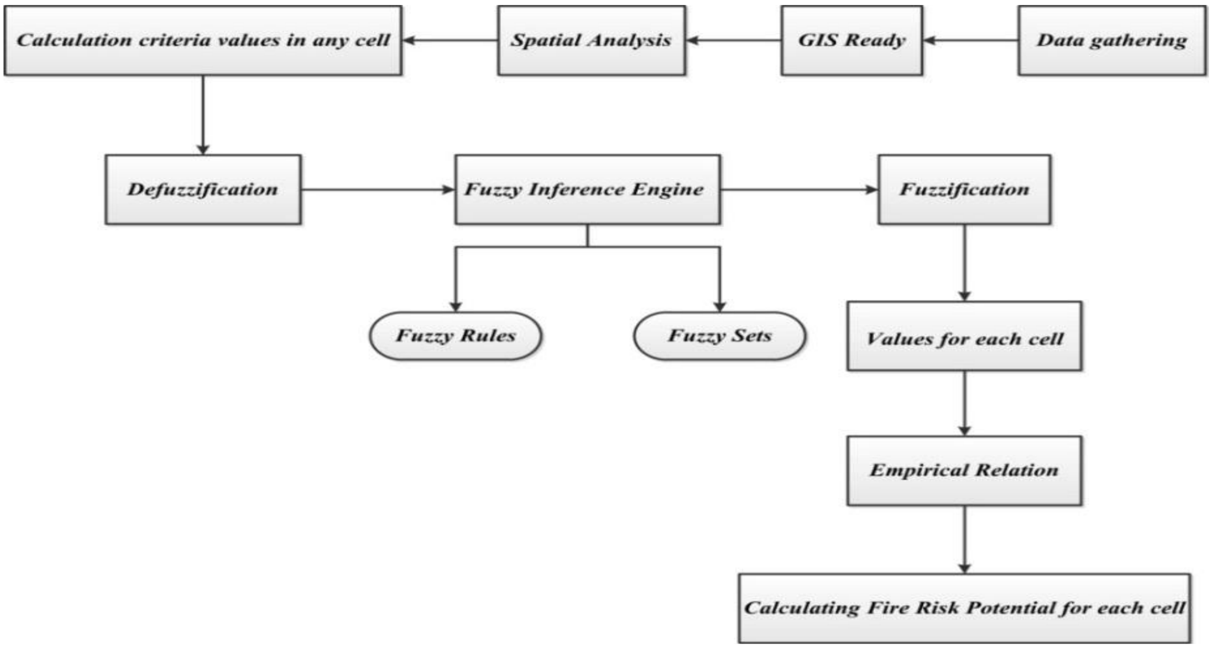

Fig. 3 The proposed structure for problem solving.

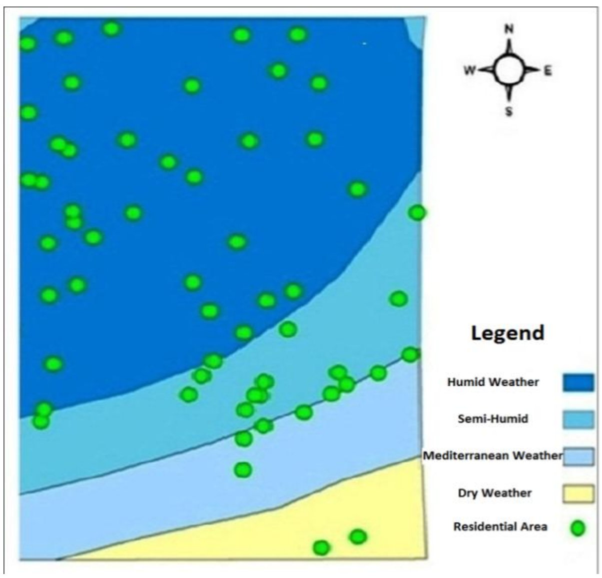

Fig. 5 Climate and residential areas.

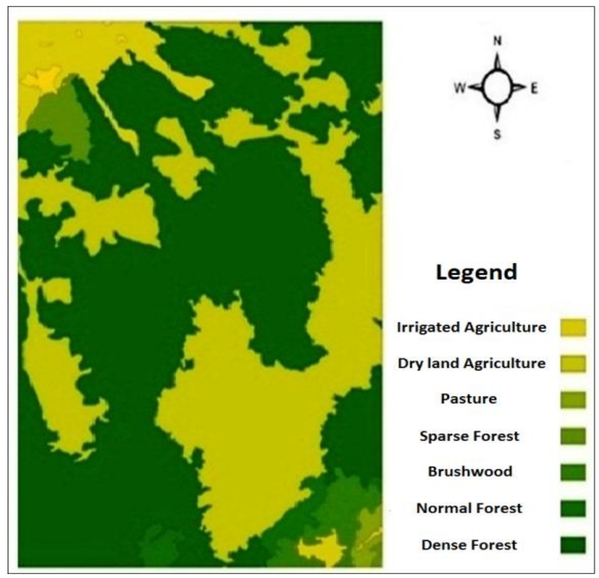

Fig. 4 Vegetation cover.

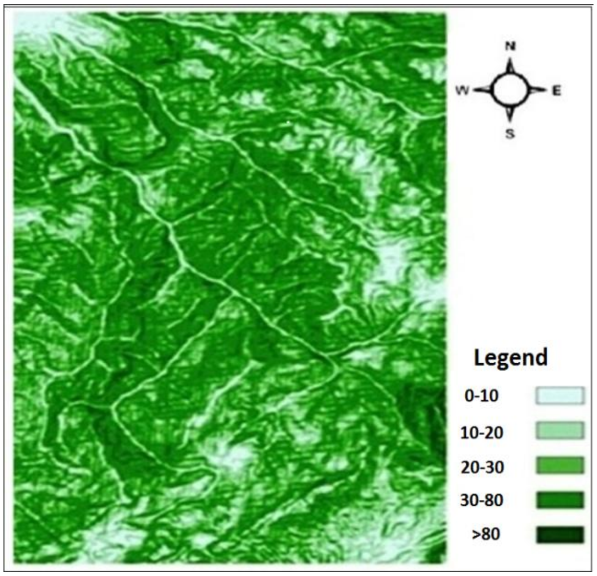

Fig. 6 Slope of region.

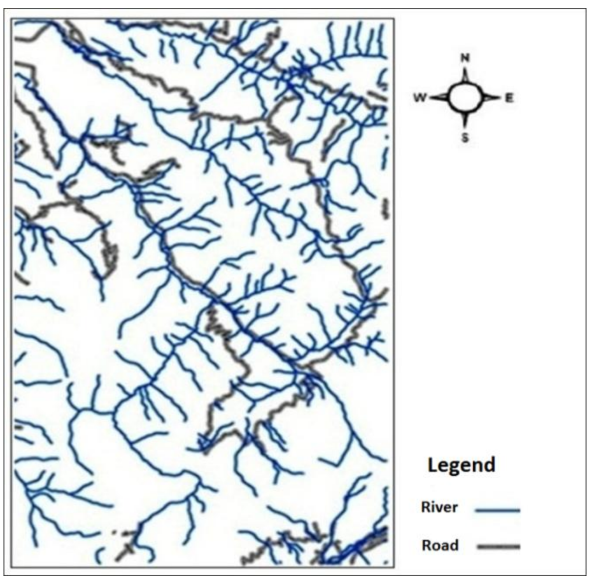

Fig. 7 River and auto road.

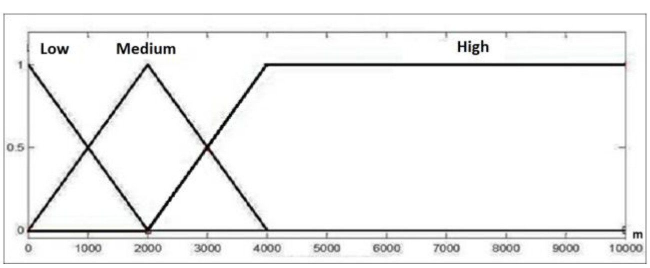

Fig. 8 Membership function of distance from residential areas.

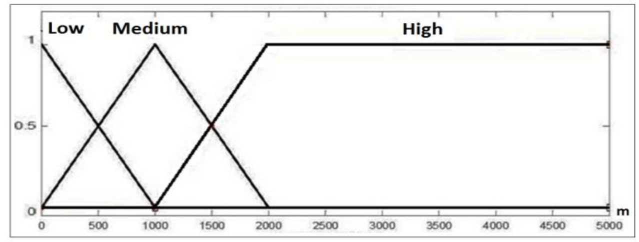

Fig. 9 Membership function of distance from river and auto road.

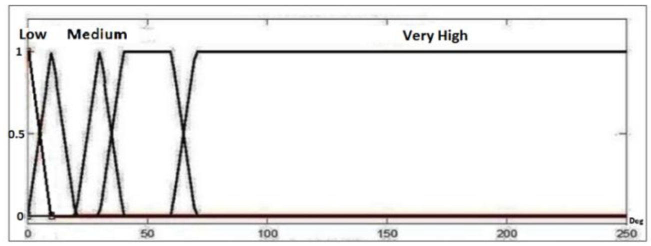

Fig. 10 Membership function of slope.

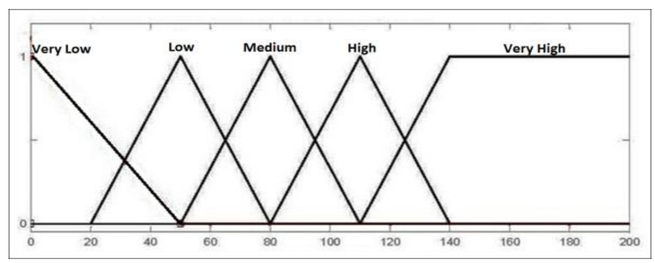

Fig. 11 Membership function of fuzzy inference engine output.

The results of this study ultimately showed that from a total forest area of 55000 hectares, 16.7 percent of the region was recognized as critically risky area, and 24.8 percent of the region as high risk area. The results also indicated that 35.7 percent of area was determined as medium risk area, 19.9 percent of area as low risk area and only 3 percent of the region as very low risk area. All above results are illustrated in figure 12. The data related to past year fire incidents were used so as to verify the accuracy of the results obtained [9]. Figure 13 shows all regions where fire incidents have taken place. The drafted risk potential map was mapped to actual fire incidents of past years. The result of the mapping shows that almost half of the consumed areas, 45.5 percent, were located in critical risky and high risk area, 35.8 percent of the consumed areas in medium risk area, and 18.7 percent of the burned area in low and very low risk area. The mapping results prove the accuracy of the model proposed for mapping of the region with fire potential. In a similar study, Eskandari [9] showed by evaluating Dong, Li-min [10] model that 40 percent of the burned area was located in the critically risky and high risk areas. Therefore, it can be concluded that application of fuzzy concept on parameters and taking expert opinion into consideration leads to a more realistic and efficient model.

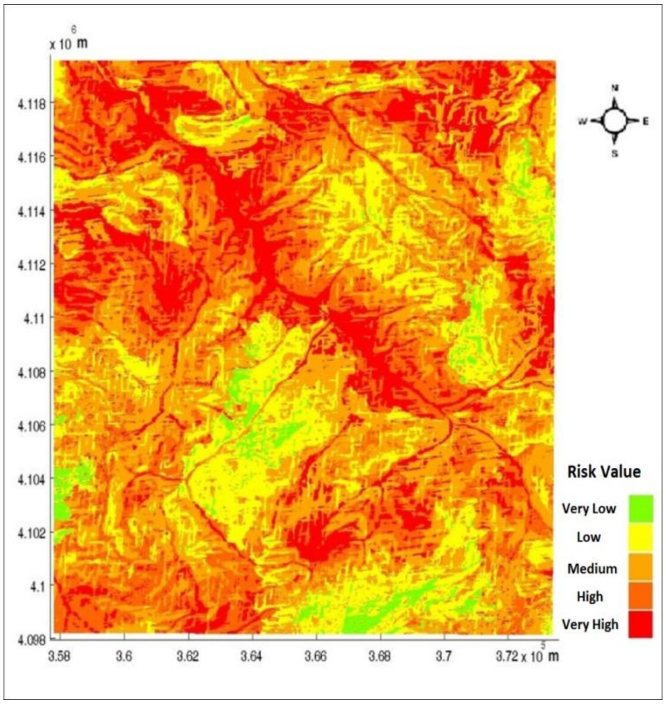

Fig. 12 Fire Risk Zoning Map.

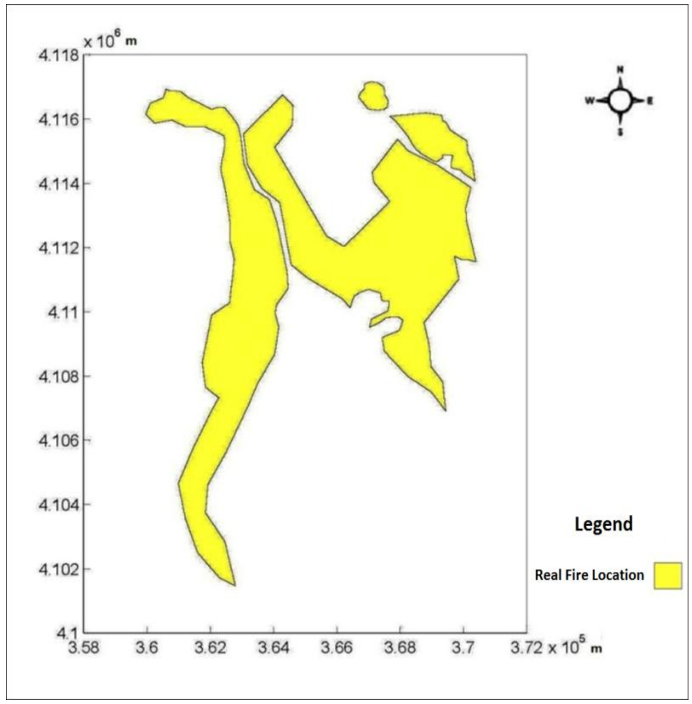

Fig. 13 Areas consumed in past year fire incidents.

4 Conclusion & Recommendations

This study yielded a fire risk potential map based on a combination of GIS and fuzzy inference engine and by incorporating important human factors which play a role in fire forests. The results show that combination of GIS, fuzzy inference systems and experimental model of can be of great avail as a proposed model for management and prediction of forest fires. In fact, the capability of this model for incorporation and modeling of parameters impacting forest fire risk makes the utilization of this model as a tool for management of forest fires inevitable. As results show, most of the regions exposed to fire risk are located in the vicinity of rivers and roads as places which are frequented by tourists and travellers more than other sites. This map can be utilized for efficient allocation of facilities and fire-fighting resources. Regions with higher risks are of greater priority. Also more patrol resources and watchtowers can be employed in fire-prone seasons in regions with higher risks. With regard to unprotected regions with great potential of fire, access roads can be built to such areas so the transfer time of resources to these regions during fire incidents reaches its minimum. Parameters such as slope, climate, vegetation cover, and distance from rivers, roads and residential areas are taken into consideration in this study. Other parameters such as annual rainfall level, direction and speed of wind, and etc. can also be considered for a better result. The fire risk potential map can even be calculated for various seasons. Factors mentioned in this study take the share of human factor into account more. Risk of natural phenomena such as thunder can also be considered in future studies. Although the mentioned phenomenon has a smaller share of fire incidents occurred to date, it can be studied as one of fire triggers. It is also recommended to use the proposed model for other regions to verify its accuracy for other regions as well.

References

[1] Saigal, P.M., A suggested classification of forest fires in India by types and causes., in In: Proceedings of the National Seminar on Forest Fire Fighting1989: Kulamaru, Kerala, India.

[2] Roy, P.S., Ranganath, B.K., Diwakar, P.G., Vohra, T.P.S., Bhan, S.K., Singh, I.J., pandhan, V.C., Tropical forest type mapping and monitoring using remote sensing Int. J. Remote Sens, 1991. 12 (11): p. 2205-2228.

[3] Berjak, S.G. and J.W. Hearne, An improved cellular automaton model for simulating fire in a spatially heterogeneous Savanna system. Ecological Modelling, 2002. 148(2): p. 133-151.

[4] Abhineet Jain, P.S.R., S.A. Ravan, R.K. Singh and K.K. Das, , Fire risk modelling using remote sensing and geographic information system. Current Science 1996. 70(10): p. 928-933.

[5] Kandya, A.K., Kimothi, M.M., Jadhav, R.N., Agarwal, J.P., , Application of GIS in identification of fire prone areas a feasibility study in parts of Junagarh (Gujrat, India). Indian For. , 1998. 124 (7): p. 531–535.

[6] Jaiswal, R.K., Saumitra, M., Kumaran, D.R. and Rajesh, S., Forest fire risk zone mapping from satellite imagery and GIS'. International Journal of Applied Earth Observation and Geoinformation, 2002. 4: p. 1-10.

[7] Adab, H., Habibi Nokhandan, M., Mirzabayati, R., Adabi Firouzrajayi, A.,, Zoning hazard fire in Mazandaran forest based on Molgan index using GIS, in 1th International Conference at Climate Changes and Botani in Khazar Echosystem2008: Mazandaran-Iran. p. 178-189.

[8] Akbari, D., Warning about fire at forests using remote sensing methods, in First National Conference at Society Service2009: Tehran-Iran.

[9] Eskandari, S., Using gegraphic information system as a decision support system at forest fire, in 19th Geomatic National Conference2012: Tehran-Iran.

[10] Dong, X., et al., Forest fire risk zone mapping from satellite images and GIS for Baihe forestry Bureau, Jilin, China. Journal of Forestry Research, 2005. 16(3): p. 169-174.

[11] Chuvieco, E. and R.G. Congalton, Application of remote sensing and geographic information systems to forest fire hazard mapping. Remote Sensing of Environment, 1989. 29(2): p. 147-159.

[12] Alimedia, R., Forest fire risk areas and definition of the prevention priority planning actions using GIS in Fifth European Conference and Exhibition on Geographic Information Systems, EGIS941994: Utrecht: EGIS Foundation. p. 1700-1706.

[13] Giri, C. and S. Shrestha, Technical note: forest fire mapping in Huay Kha Khaeng Wildlife Sanctuary, Thailand. International Journal of Remote Sensing, 2000. 21(10): p. 2023-2030.

[14] Esra Erten , V.K., Nebiye Musaoglu, FOREST FIRE RISK ZONE MAPPING FROM SATELLITE IMAGERY AND GIS A CASE STUDY. ISPRS, 2005.

[15] Chuvieco, E., Sales, J.,, Mapping the spatial distribution of forest fire danger using GIS. Geographic Information System, 1996. 10: p. 333-345.

[16] Zadeh, L., Fuzzy sets. Information and Control, 1965. 8: p. 338–353.

[17] Cox, E., Fuzzy logic for business and industry1995, Rockland, Mass.: Charles River Media.

[18] Andries, P., Engelbrecht,, Computational Intelligence An Introduction2007: John Wiley & Sons Ltd.