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Research

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Application of Multi-Criteria Decision Making Models in Forest Fire Management

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Abstract

The study on effective factors of forest fire prevention policy is helpful to reduce forest fire impacts on extensive environmental damage in the long-term period. In other words, forest fire management is the result of a complex interaction among criteria. The present study aims to create a scientific analysis of the most effective criteria based on TOPSIS and SAW methods in the Arasbaran forest. The five top optimal criteria selection by TOPSIS method introduced that “association and cooperation between the executive and responsible institutions” have the first rank ($CC_i+=0.85$), “Lack of deterrence law in dealing with forest fire offenders in human-caused forest fires” has the second rank ($CC_i+=0.84$) and followed by “Lack of up-to-date scientific information on susceptible areas in the region”, “Increasing the cooperation of NGOs and increase public trust”; and “Lack of forest road network access to ignite regions” ($CC_i+=0.789$; 0.787 ; 0.77 , respectively). The five top optimal criteria resulting from the SAW method showed that “Local people participations” provide the highest score ($FS=0.39$) and followed by “association and cooperation between the executive and responsible institutions” ($FS=0.39$), “Increasing the cooperation of non-governmental organizations (NGOs) and increase public trust” ($FS=0.36$), “Raising awareness of the position of natural resources among local peoples and attracting their cooperation” ($FS=0.35$) and “Optimal Use past experiences” ($FS=0.34$). It is suggested that evaluating the ecological and environmental factors affecting the forest fire occurrence and extension could become a set of complement factors to setting management criteria for demonstrating the best management strategies.

Keywords: Arasbaran forest, Forest firefighting, TOPSIS, SAW.

Introduction

Forests cover about one-third of the earth surface and considered as fundamental natural resources play an essential role in purifying the air and reduction of greenhouse gases effects, carbon sequestration, preventing flood, protect soil and water erosions, and many other advantages to help move fast towards forest sustainable development (Zandebasiri and Pourhashemi, 2016). However, forest fires as complex a natural phenomenon are those which burn forest vegetative cover that operated by various natural and human factors, it can become a threat to the forest ecological and economical services with some potentially negative impacts on ecosystems. A forest fire can cause serious destructing in forest composition, biodiversity, and structure (Sharma *et al.*, 2012; Carvalho *et al.*, 2019). In addition, Forest fires are known as one of the major causes of ecological disturbance and environmental concerns especially in mountainous deciduous forests (Vadrevu *et al.*, 2010).

Iran has witnessed many forest fire events in the past to the present and is a susceptible region of this disaster and forest fires became a significant problem in Iran nowadays According to the Statistics Center of Iran, 610 fires occurred in the forests of Iran and destroyed an area of 5,694 ha from 2000 to 2012. Proper conservation strategies for preventing forest fire occurrences are an

effective way of reducing the damages of this natural hazard (Moayedi *et al.* 2020). Forest fires play an influential role in forest ecosystem services. Therefore, it is essential to predict the forest fires detrimental effects on natural resources and ecosystem services (Vila-Villardell *et al.*, 2020). Researches have recognized that forest fires are enhanced by changes in climates such as longer dry seasons, rainfall reduction, and frequent extreme temperatures (Pourghasemi *et al.*, 2020). Therefore, increasing the frequency and severity of wildfires is a major problem in certain regions of Iran.

Forest fires have become an important issue in recent years. Many studies have been conducted to forest fire susceptibility analysis using various kinds of statistical models and various researches are being done in different parts of the world on different aspects of this issue.

Pourghasemi *et al.* (2020) assessed the forest fire influences and mapping in Fars province in Iran by using machine learning techniques and spatial modeling. Yang *et al.*, (2019) proposed a demand forecasting model based on Index Fuzzy Segmentation (IFS) and TOPSIS in order to effectively predict the number of firefighting helicopters needed in forest fires. Results demonstrated that the demand forecasting model based on these two methods have strong feasibility and rationality, which provides a scientific method for predicting the number of forest firefighting helicopter demand resources. Ghazanfar Pour *et al.*, (2017) identified the most important effective factors of the forest fire control at Golestan Forest in the north of Iran by SWAT and AHP models. The results showed that the measure of solidarity between organizations, the availability of the different parts of the forest, and constructing the forest road network were the most vital factors in forest fire management. Gungoroglu (2017) determined four forest fire risk criteria consisting of socio-economic, topographic, climatic, and stand structure by using the Fuzzy AHP method and produced the risk map in order to low and high risks levels in Turkey. Zandebasiri and Pourhashemi (2016) examined the strengths and weaknesses of some of the MCDM methods consisting of AHP, FAHP, ANP, TOPSIS, VIKOR, WSM, DEA, Voting methods, PROMETHEE, and ELECTRE to choose an optimal one for decision making in forest management. AHP and SWAT methods were preferred among all methods in forest management. Sharma *et al.*, (2012) analyzed the knowledge-based information to make strategies for forest fire management by using a Fuzzy-AHP approach in India. Findings were including the ranges of low to high forest fire risk zones according to environmental features such as topography, climate conditions, slope, aspect and etc.

The present research aims at analyzing the comparison of two multi-criteria decision-making methods included Simple Additive Weighting (SAW) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for determining the most important forest fire prevention factors and management strategies focusing on the Arasbaran Forest region. This study is a novelty study in this case in this region.

Methods and Materials

- Description of the study area

Arasbaran forest (160000 ha) is situated between longitude 46° 39' 50" and 47° 1' 48" E and latitude 38° 43' 41" to 39° 8' 11" N in the East Azarbaijan province, Northwest of Iran. The location of the mountainous study area is shown in Figure 1. The main tree species is broad-leaved consisted of *Quercus macranthera*, *Quercus petraea*, *Carpinus betulus*, *Acer comprestre*, *Acer monspessulanum*, and many shrubs species. *Taxus baccata* and *Juniperus foetidissima* are the most important conifers of this region. The average total annual temperature is 2-17 °C and the average total annual precipitation is 300-600 mm. This area is characterized by special climatic features,

high biodiversity, the presence of rare fauna and flora species. Arasbaran has placed the region among the nine Iranian biosphere reserves under the UNESCO's Man and Biosphere program (SaghebTalebi *et al.*, 2014)

Figure 1. Study area map

- Determination models

According to the objects of this study, 29 criteria were designed (Table 1). Criteria were selected to determine the most important causes of fires and the criteria affecting firefighting management by a specialist team and literature reviewing (Collins *et al.*, 2018; Etongo *et al.*, 2018; Ghazanfar Pour *et al.*, 2017; Amiri *et al.*, 2017). Afterward, questionnaires were designed according to Table 2 for evaluating the importance of each criterion. 15 experts who had an average of 10 years of work experience in the forestry department and more than half of the members had a higher education than a master's degree in Natural Resource Management and were specialists in Forestry and Rangeland and Watershed Management filled out the questionnaires according to their expert opinion. The expert team was asked to determine the value of 1 to 9 for selecting the more effective criteria. The higher numerical value indicated more preference for a criterion.

Table 1. The list of descriptions, positive and negative impacts of all criteria

Criteria	Descriptions	Positive/Negative impact
C1	Association and cooperation between the executive and responsible institutions	Positive
C2	Cooperation and communication of neighboring provinces	Positive
C3	Local people participations	Positive
C4	Optimal Use of past experiences	Positive
C5	Allocating additional funding as appropriate	Positive
C6	Providing detailed management plans	Positive
C7	Lack of firefighters and inadequate implementation of prevention and fire extinguishing operations.	Negative

C8	Poor forest monitoring, especially during peak fire times	Negative
C9	Lack of up-to-date scientific information on susceptible areas in the region such as forecasting maps, determining the amount of damage to the forest, etc.	Negative
C10	Lack of dedicated firefighting equipment (such as clothing and portable tools) and high costs of providing other advanced equipment for the organization (such as helicopters)	Negative
C11	Lack of natural or man-made ponds for water storage	Negative
C12	Lack of equipped search and rescue (SAR) bases inside the forest	Negative
C13	Lack of deterrence law in dealing with forest fire offenders in human –caused forest fires	Negative
C14	Lack of forest road network to access the ignite regions	Negative
C15	Lack of infrastructure for special equipment such as identifying suitable locations for helicopter landing, placing water tanks in the forest, etc.	Negative
C16	Lack of adequate guards, especially in susceptible areas and important areas in terms of endangered plant species	Negative
C17	Construction of stations for measuring effective environmental factors such as anemometer station, temperature recording, etc. in fire susceptible areas inside the forest	Positive
C18	Preparation of identification maps of susceptible areas and their updating.	Positive
C19	Upgrading the wireless and fire alarm networks	Positive
C20	Identifying the susceptible area for firefighting such as natural water reservoirs, rivers, and firelines	Positive
C21	Raising awareness of the natural resources position among local people and attracting their cooperation	Positive
C22	Promoting the position of responsible organizations and cooperation between organizations in charge of crisis management	Positive
C23	Increasing the cooperation of non-governmental organizations (NGOs) and increase public trust	Positive
C24	Reducing the motivation of local youth to help	Negative
C25	Lack of financial credit	Negative
C26	Lack of equipment	Negative
C27	Lack of strategic view of forests and natural resources	Negative
C28	Lack of attention to the degraded areas after the fire and consequently increasing the land-use change	Negative
C29	Lack of empowerment of executive administrations.	Negative

Multi-criteria decision making (MCDM) techniques are useful tools to help decision-makers to select options in the case of discrete problems that refers to making the choice of the best alternative from among a limited set of decision alternatives in terms of multiple, usually

conflicting criteria. In other words, the MCDM technique is based on obtaining the alternative that approaches the most ideal alternative (Roszkowska, 2011). Among many multi-criteria techniques TOPSIS and SAW as the most frequently used methods were selected in this study.

- **Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)**

TOPSIS is one of the widely-used classical multi-criteria decision-making methods that was first developed in 1981 by Hwang and Yoon (Hwang and Yoon, 1981). According to the concept of this method, the alternatives are sorted according to their distance from ideal (positive) and inappropriate (negative) solutions at the beginning. Then, the best alternative should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution (Figure 2) (Balioti *et al.*, 2018; Suder and Kahraman, 2018).

Figure 2. Basic concept of TOPSIS method (A+: positive ideal point, A-: Negative ideal Point) (Balioti *et al.*, 2018).

TOSIS method compares the complex of alternatives by identification of weights for each criterion, standardized weights score for each criterion, and calculate geometric distances between each alternative and the ideal variant according to the best score for each criterion (Holota *et al.*, 2017).

The computational steps of the TOPSIS method are in the following (Seyedmohammadi *et al.*, 2018; Ghasemian *et al.*, 2018; Caliskan, 2017; Holota *et al.*, 2017; Zandebasiri and Pourhashemi, 2016):

1- Establishing a decision matrix (A_{ij}):

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \Lambda & a_{1n} \\ a_{21} & a_{22} & \Lambda & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{m1} & a_{m1} & \Lambda & a_{mn} \end{bmatrix}$$

2- Calculating the normalized decision matrix (R_{ij}) based on the normalized value (r_{ij}):

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \Lambda & r_{1n} \\ r_{21} & r_{22} & \Lambda & r_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ r_{m1} & r_{m2} & \Lambda & r_{mn} \end{bmatrix}$$

- 3- Calculating the weighted normalized decision matrix (V_{ij}) by multiplying the normalized decision matrix (R_{ij}) by its associated weights ($W_{n \times n}$):

$$V_{ij} = R_{ij} \times W_{n \times n} = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix}$$

- 4- Determining the positive ideal (A^+) and negative ideal (A^-) solutions:

$$A^+ = \{(max v_{ij} | j \in J), (min v_{ij} | j \in J'), (i = 1, 2, \dots, m)\} = (v_1^+, v_2^+, \dots, v_n^+) \text{ or } \{v_j^+\}$$

$$A^- = \{(min v_{ij} | j \in J), (max v_{ij} | j \in J'), (j = 1, 2, \dots, n)\} = (v_1^-, v_2^-, \dots, v_n^-) \text{ or } \{v_j^-\}$$

- 5- Calculating the separation measures of each alternative from the positive (D^+) and negative ideal (D^-) solutions using the m-dimensional Euclidean distance:

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad i = 1, 2, \dots, m$$

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad j = 1, 2, \dots, n$$

- 6- Calculating the relative closeness to the ideal solution (CC_i^+), ranking the preference orders, and choose an alternative with the maximum value of CC_i^+ .

$$CC_i^+ = \left[\frac{D_i^-}{D_i^+ + D_i^-} \right]; \quad 0 \leq CC_i^+ \leq 1; \quad i = 1, 2, \dots, m$$

Where:

A_{ij} : Decision matrix

$a_{11} \dots a_{mn}$: value corresponding to i th criteria

r_{ij} : Normalized value

R_{ij} : Normalized decision matrix

V_{ij} : Weighted normalized matrix

W_i : Weight of the i th criterion

A^+ : Positive ideal solution

A^- : Negative ideal solution

D_j^+ : Separation measures (distance) to positive-ideal solution

D_j^- : Separation measures (distance) to negative-ideal solution

CC_j^+ : Relative closeness to the ideal solution

j : the weight of the j th criterion or attribute

- Simple Additive Weighting (SAW)

SAW is a simple and commonly used scoring technique. The SAW method multiplies the normalized value of the criteria (n_{ij}) by the importance of the criteria (w_{gij}) and the criterion with the highest score is selected as the preferred one. In other words, an evaluation score is calculated for each criterion by multiplying the scale value of the criterion to the weight of relative importance and then summing all criteria. Process of SAW, calculating the normalized values for positive and negative criteria as follows (Afshari *et al.*, 2010; Roszkowska, 2011; Seyedmohammadi *et al.*, 2018):

- 1- Constructing a pairwise comparison matrix for criteria ($n \times n$). The weights of criteria have been computed by using the comparison matrix.
- 2- Constructing a decision matrix ($m \times n$). Indicating the relative importance of the criterion in the columns compared to the criterion in the rows.
- 3- Calculating the normalized decision matrix for positive and negative criteria:

- The normalized value for positive criteria:

$$n_{ij} = \frac{g_{ij}}{g_{max}}$$

- The normalized value for negative criteria:

$$n_{ij} = \frac{g_{min}}{g_{ij}}$$

- 4- Evaluation of the final score of each criterion by multiplying the normalized value of the criterion by its importance:

$$FS = \sum (w_{gij} \times n_{ij}) \quad \sum w_{gij} = 1$$

Where:

g_{ij} : Criterion value

g_{max} : Maximum value for each positive criterion

g_{min} : Minimum value for each negative criterion

n_{ij} : Normalized value.

FS : Final Score

Results

The results of optimal criteria selected by the TOPSIS method showed that C1 which was “association and cooperation between the executive and responsible institutions” has the first rank

($CC_i^+=0.85$). C13 which was “Lack of deterrence law in dealing with forest fire offenders in human-caused forest fires” has the second rank ($CC_i^+=0.84$) and followed by C9 (Lack of up-to-date scientific information on susceptible areas in the region such as forecasting maps, determining the amount of damage to the forest, etc.; $CC_i^+=0.789$), C23 (Increasing the cooperation of non-governmental organizations (NGOs) and increase public trust; $CC_i^+=0.787$) and C14 (Lack of forest road network to access the ignite regions; $CC_i^+=0.77$). Therefore, there were recognized as the first top-five criteria. In addition, C17 (Construction of stations for measuring effective environmental factors such as anemometer station, temperature recording, etc. in susceptible areas inside the forest; $CC_i^+=0.17$), C19 (Upgrading the wireless and fire alarm networks; $CC_i^+=0.12$) and C2 (Cooperation and communication of neighboring provinces; $CC_i^+=0.10$) were introduced as the least effective criteria in forest fire prevention strategies by TOPSIS method, respectively (Figures 3, 4 and 5).

Figure 3. Separation measures of positive ideal solution (A+) and negative ideal solution (A-) for TOPSIS model

Figure 4. Separation measures of m-dimensional Euclidean distance of positive ideal solution (Di+). Negative ideal separation solution (Di-) for TOPSIS model

Figure 5. Importance of each criterion after TOPSIS model implementation

According to the results of the SAW method, C3 (Local people participations; FS=0.39), C1 (association and cooperation between the executive and responsible institutions; FS=0.39), C23 (Increasing the cooperation of non-governmental organizations (NGOs) and increase public trust; FS=0.36), C21 (Raising awareness of the natural resources position among local people and attracting their cooperation; FS=0.35) and C4 (Optimal Use of past experiences; FS=0.34) were identified the first top-five most important criteria; and C26 (Lack of equipment; FS=0.12) C10 (Lack of dedicated firefighting equipment such as clothing and portable tools and high costs of providing other advanced equipment for the organization such as helicopters; FS=0.11) and C2

(Cooperation and communication of neighboring provinces; FS=0.10) were the least effectiveness criteria in this method (Figure 6).

Figure 6. Importance of each criterion after SAW model implementation

Discussion and Conclusion

Expert knowledge is a basic source for making effective management decisions. There are many MCDM methods for determining the reasonable factors for management in different sectors of forest (Sharma *et al.*, 2012). According to the results of this study, we determined the top main forest fire management strategies based on Expert's knowledge; and Association and cooperation between the executive and responsible institutions (C1), Local people participations (C3), Lack of up-to-date scientific information on susceptible areas in the region such as forecasting maps, determining the amount of damage to the forest, etc. (C9), Lack of deterrence law in dealing with forest fire offenders in human-caused forest fires (C13) and Increasing the cooperation of non-governmental organizations (NGOs) and increase public trust (C23) were identified and presented by using of TOPSIS and SAW models as two important decision-making methods.

Our results were then compared to those obtained in other areas of the world and comparing these results with other studies displayed that study on the main factors to manage the fires in exotic species plantations of Zimbabwe by Jimu and Nyakudya (2018) supported our results. they also displayed the need of cooperation among government and timber estate owners and community leaders; In addition, perform forest policies, raise education and fire awareness campaigns, strengthen the linkage between indigenous communities and government, managing the maintain fire prevention were introduced as the main strategies in that study area. According to the reports of Eugenio *et al.* (2019), meteorological variables such as precipitation and air temperature are directly and indirectly correlated with the occurrence, propagation and distribution of wildfires. According to their results, fire hazard zonation is an important factor to manage the beginning, the duration and the end of fire hazard. Moayed *et al.* (2020) proposed that providing a high-quality forest fire susceptibility map is an important task for fire risk management. They emphasized on the criterion of the obtain susceptibility analysis of natural hazards and prepare maps as a guide in the risk management and prevention of the fire and fundamental prerequisite for future planning

and risk management in any region. Mourao and Matinho (2019) investigated on the sixty kinds of literature covering 20 years (1997-2017) about forest fire management. Legal criterion and fire legislation were introduced the crucial aspects of fire management strategies. Related studies argued that good knowledge of causes, the relative motivations, and spatial and temporal distribution of forest fires is crucial for the design of prevention policies based on the literature review (Ganteaume *et al.*, 2013).

Different MCDM techniques suit different kinds of decision situations (Eldrandaly *et al.*, 2009); therefore, different kinds of MCDM approaches have been suggested in the decision analysis literature. Sharma *et al.* (2012) recognized the risk zones of forest fire according to the past fire occurrence and prepared low to high-risk zones map by using the FAHP method. The study's result showed the regions with a high, moderate, and low susceptible areas to forest fire with knowledge-based factors. They introduced that emergency management plays an important role in the prevention, control and management of disasters within a quick time period. We used this criterion as Criterion 9 in our study that ranked third in the TOPSIS method. Nilsson *et al.* (2016) presented the combination of two MCDM methods, AHP and TOPSIS to show that this combination was easy to implement in participatory forest planning to create a wide array of management plans. Therefore, the combined MCDM approach can be used for ranking a set of long-term management plans with consideration to multiple objectives. A comparison of the results of ranking in our study revealed that two MCDM methods had similar results so that Criterion 1 and 23 were identified as the best and Criterion 2 as the weakest effective criteria in fire management in both methods. Therefore, we introduce that the combination of TOPSIS and SAW methods can be effective for selecting and ranking the most effective forest fire management strategies. Zandebasiri and Pourhashemi (2016) analyzed the most important MCDM method's strengths and weaknesses in forest management and concluded that the TOPSIS method was the optimal method based on its highest score in evaluation "accuracy of results ". It seems due to defining positive and negative ideal options that cause the accuracy of the method has the highest score among others. The TOPSIS method can evaluate a large number of alternatives and is relatively easy to implement but, the low sensitivity of analysis and team decision making were introduced the disadvantages of this method (Nilsson *et al.*, 2016; Zandebasiri and Pourhashemi, 2016). In addition, Yang *et al.* (2019) demonstrated the ability of the TOPSIS method to research on demand of the required number of forest firefighting helicopters.

On aggregate, with the accomplishment of the present study, forest fire management and firefighting are influenced by various criteria. The results of this study, based on the experts' knowledge of forest firefighting who had much experience in this field and methods of MCDM (TOPSIS and SAW) showed that association and cooperation between the executive and responsible institutions, increasing the cooperation of non-governmental organizations (NGOs), and increase public trust were the most effective factors and communication of neighboring provinces were the least effective criteria in fire management at the Arasbaran forest region.

Declarations:

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

Roya Abedi: data preparation, statistical analysis, and writing the original draft.

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Table 2. Questionnaire

The importance and impact of the following criteria on fire crisis management in Arasbaran forests Please enter the numbers 1 (least important) to 9 (most important) in front of each factor according to your expert opinion: Profile of respondents: Years of work experience: Education: Specialization:											
Impact s	Criteria		1	2	3	4	5	6	7	8	9
Positive	C1	Association and cooperation between the executive and responsible institutions									
	C2	Cooperation and communication of neighboring provinces									
	C3	Local people participations									
	C4	Optimal Use of past experiences									
	C5	Allocating additional funding as appropriate									
	C6	Providing detailed management plans									
Negative	C7	Lack of firefighters and inadequate implementation of prevention and fire extinguishing operations.									
	C8	Poor forest monitoring, especially during peak fire times									
	C9	Lack of up-to-date scientific information on susceptible areas in the region such as forecasting maps, determining the amount of damage to the forest, etc.									
	C10	Lack of dedicated firefighting equipment (such as clothing and portable tools) and high costs of providing other advanced equipment for the organization (such as helicopters)									
	C11	Lack of natural or man-made ponds for water storage									

[illegible]