



Evaluating the hazardous potential of the dieback of the Zagros Oak forests using the multi-criteria decision-making methods

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Abstract

Oak dieback and mortality, as a multifactorial phenomenon, have occurred in many forests of the world including Zagros forests in Iran. This phenomenon happens due to the complex interaction of the environmental stresses, pests, and socioeconomic issues. Given the importance of this issue, it is necessary to use an appropriate approach to find the areas with potential for dieback in order to guide the analyses regarding the decisions on forest conservation. Therefore, in the present study, geographic information system (GIS) was used to interfere with the analytic network process (ANP), multi-criteria decision making (MCDM), and fuzzy methods for zoning the susceptible areas of Oak forests in Kohgiluyeh and Boyer-Ahmad province in southwest of Iran. Criteria were selected as effective factors for dieback including slope, aspect, elevation, mean annual temperature and precipitation, pest, and distance from the farmlands. After preparing the initial maps of criteria, the weight of each criterion was calculated according to the experts and ANP and the fuzzy criteria maps were prepared using the membership functions, and the final maps of the areas with potential of dieback were produced by overlapping the criteria layers. The results showed that 45.32% of the Oak forests in the province have high and very high potential for dieback in the central and western parts. As a result, these areas have a higher priority for preventive and protective operation. Among the criteria, pests, temperature, and distance from the farmlands had the highest scores. Overall, the results obtained from the MCDM methods were satisfactory and efficient regarding studying the Oak dieback.

Keywords Dieback potential · *Quercus brantii* Lindl · GIS · Kohgilouyeh and Boyerahmad Province

Introduction

Oak forests of Zagros regions are considered as the most extensive plant habitats and the second natural forest ecosystem

in Iran (Imanyfar et al. 2019; Ahmadi et al. 2014). These forests are located in western Iran, near the northwestern border with Turkey that extend southward along Iraq border and cover 11 Iranian provinces with an area of more than 5 million hectares (Ghobad-Nejhad et al. 2018; Alesheikh and Mehri 2019). The index of Zagros region is *Quercus brantii* Lindl (Persian Oak) which in most parts constitutes a pure community with tree species such as *Pistacia atlantica*, *Amygdalus Scoparia*, *Prunus scoparia*, *Acer monspessulanum*, *Pyrus communis*, and etc. (Hosseini et al. 2017; Taghimollaei 2019). Water and soil conservation, preserving the ecological balance of the area, feeding groundwater aquifers, esthetic values, providing livelihoods for the human and animal communities, and producing subsidiary products, are the most important functions and characteristics of these forests (Karami et al. 2018; Sagheb-Talebi et al. 2014; Kooch Soltani et al. 2018). However, these valuable forests have been undergoing constant changes over the years, and the level of these forests is reducing day by day, as in recent years have been severely affected due to stresses of soil erosion,

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floods, dust, climate change, drought, fire, pests, and land use changes (Taghimollaei 2019; Nourinejad and Rostami 2014; Kooh Soltani et al. 2018; Ghadirian et al. 2018). In general, all of the above mentioned have made the forests of these areas difficult to grow and their vulnerability to environmental stresses has increased several times.

The phenomenon of dieback and decline in a wide range of Zagros Oak forest regions has been considered for over a decade and has been reported in 10 provinces in Iran to date (Karami, et al. 2018; Ghobad-Nejhad et al. 2018; Imanyfar et al. 2019; Hosseini et al. 2019; Taghimollaei 2019). So that according to the latest official statistics of the Organization of Forests, Rangelands, and Watersheds of Iran, so far, 25% of these forests have been suffered severe decline (Karami et al. 2018; Ahmadi et al. 2014; Nourinejad and Rostami 2014; Ghadirian et al. 2018). Browning and drying of the branches in the parts of the tree canopy are the most important early signs of the dieback in an Oak tree leading to fall and death of the tree branches. If the crisis spreads to all the leaves and branches, it will finally lead to complete drying and death of the tree (Fan et al. 2012). However, the tree growth is diminished by the environmental stresses, sap flow becomes slow, and weakness effects are seen on the trees affected by the pests and diseases, and finally, the entire forest ecosystem is endangered with this condition (Hosseini et al. 2019; Nourinejad and Rostami 2014; Catton et al. 2007).

The probable causes and mechanisms of this phenomenon have not been fully investigated in the Zagros forests (Gentilesca et al. 2017; Sohar et al. 2013; Hosseini et al. 2019). There are numerous factors influencing the Oak dieback in the world and determining more important ones seems difficult especially in Iran (Ahmadi et al. 2014; Keča et al. 2016; Hosseini et al. 2017; Imanyfar et al. 2019; Amir Ahmadi et al. 2015; Alesheikh and Mehri 2019). This has also made it difficult to judge and plan in order to cope with this phenomenon (Amir Ahmadi et al. 2015). According to the previous studies, the factors influencing the Oak dieback and decline are classified into the living factors, such as pathogens (fungal diseases), pests and insects, non-living factors, such as drought, frost, and poor soil, and silvicultural factors including tree age, tree competition, and human intervention such as cultivation, land use change, and livestock grazing (Hosseini et al. 2017; Imanyfar et al. 2019; Nourinejad and Rostami 2014; Taghimollaei 2019; Karami et al. 2018; Ahmadi et al. 2014; Attarod et al. 2017; Keča et al. 2016; Gentilesca et al. 2017; Kabrick et al. 2008; Catton et al. 2007).

On the other hand, extent and variety of topography of the affected areas, spatial and multidimensional nature of the data, and factors involved in this phenomenon make it possible to derive the capabilities of the multi-criteria decision-making methods integrated with geographic information system, along with remote sensing to collect, store, and analyze the data and finally, identify the factors influencing this

phenomenon and also the susceptible areas (Ahmadi et al. 2014; Kooh Soltani et al. 2018). These methods provide useful information about the study area and can be simplified compared with the traditional field methods (Imanyfar et al. 2019). They can also be used to guide the managers in making decision and implementing the protection and support policies (Amir Ahmadi et al. 2015). So far, several studies have been conducted in order to identify the areas with potential for tree dieback and determine the effective criteria for it.

Kabrick et al. (2008) in a study examined environmental factors in Oak dieback in the mountainous areas of the US Ozark Mountains and concluded that Oak species decline was more likely to be affected by drought and poor soil of the area. The study results of Linares et al. (2011) on the decline of *Cedrus atlantica* in the northern Mediterranean forests of Morocco showed that climatic factors, insect invasion, and destruction of trees by monkeys were the causes of the decline of *Cedrus* species in these forests. Galiano et al. (2012) in the study on dieback factors of *Quercus ilex* L. in Spain concluded that tree dieback has multi-factor nature that soil depth and individual characteristics of trees are the most important factors affecting the pattern of dried trees. A study by Gentilesca et al. (2017) in the western Mediterranean showed that drought was the most important cause of decline in *Quercus ilex* L. In Iran, Ahmadi et al. (2014) used AHP and GIS technique to map of Oak decline potential in Ilam Province. The results showed that the factors of annual precipitation, temperature, and annual evaporation play a major role in the decline of Persian Oak in the area. The results also show that the majority of the study area (51.19%) is in the medium-risk zone. Amir Ahmadi et al. (2015) investigated the relationship of dieback of *Quercus brantii* Lindl. and topographic conditions in Dena Conservation Forest in Kohgiluyeh and Boyer-Ahmad Province in Iran. The results showed that the higher slopes and southern aspect had higher dieback percentage. The study of Mahdavi et al. (2015) to evaluate the effect of factors affecting the rate and distribution of Oak dieback in forests of Ilam Province showed that by increasing altitude and slope and in south and west aspects, forest density and at low soil depth, rate, and distribution of dried Oak trees increased. Ghadirian et al. (2018) in a study used logistic regression model and 12 environmental factors to identify drought-affected forest areas. The results showed that about 51.3% of the forests in Lorestan Province had risk of dieback. Also, indices of drought, evapotranspiration, and precipitation were the most important effective factors, respectively. Finally, Kooh Soltani et al. (2018) prepared a map of Zagros Oak dieback forests in Lorestan Province using hierarchical-fuzzy analysis. The study results showed that the map prepared by fuzzy operator had the highest accuracy (70%) and the southern and western regions of the province were susceptible to severe forest dieback.

Conservation and protection of the Oak forests in the western Zagros Oak forests is necessary because of their valuable role in protecting the soil and water of the region (Ghadirian et al. 2018). This has led us to consider many damages caused by the Oak dieback to the Zagros forests, both financially and esthetically, in addition to the factors contributing to the development and spread of this phenomenon, as well as identifying and zoning the forest areas with dieback conditions to help protect this valuable ecosystem. Hence, in this study, the factors influencing this phenomenon were investigated and the areas with dieback potential were zoned in Kohgiluyeh and Boyer-Ahmad province in southwest of Iran by the fuzzy and ANP and weighted linear combination (WLC) methods.

Materials and methods

Study area

The study area is Kohgiluyeh and Boyerahmad Province, a relatively high mountainous area in the continuation of the Zagros Mountains in southwestern Iran. The province located between 49°55' to 51°53' east longitude and 29°52' to 31°26' north latitude (Fig. 1). The province has two cold and tropical climates. The tropical climate accounts for 43% of the area and the tropical climate covers 57% of the province (Hedayati Dezfuli 2006). More than 53% of the province's area covers more than 600,000 ha of forest, with more than 80% of it including *Quercus brantii* Lindl. Less than remaining 20%

includes trees and shrubs such as *Pistacia atlantica*, *Acer monspessulanum*, *Amygdalus scoparia*, *Lonicera nummularifolia*, *Pyrus glabra*, *Fraxinus rotundifolia*, *Juniper* sp. (Kohgiluyeh and Boyerahmad Province Land use planning 2015). According to Iranian Forests and Rangelands and Watershed Organization reports, significant parts of the province's forests today are experiencing dieback.

Methodology

In most decisions, instead of one criterion, managers seek to optimize the values of several criteria, both quantitative and qualitative, in response to the raised dilemma. Multi-criteria decision making (MCDM) is one of the most important tools for solving this issue. MCDM issues include a goal or set of goals, a decision maker (DM) or a group of decision makers, a set of evaluation criteria, a set of decision options, a set of decision variables, and a set of results from each option-criterion pair. MCDM is divided into two subsets of the multi-attribute decision making (MADM) and multi-objective decision making (MODM) (Shi et al. 2011).

Multi-attribute decision-making (MADM) involves a number of techniques and methods allowing a range of the subject-related criteria to be scored and weighted and then rated by the experts including techniques dealing with the decision-making process between different criteria and in some cases contradicting each other. The purpose of multi-criteria evaluation is selecting the best alternative based on the ranking through multi-criteria evaluation (Mukhametzhanov and

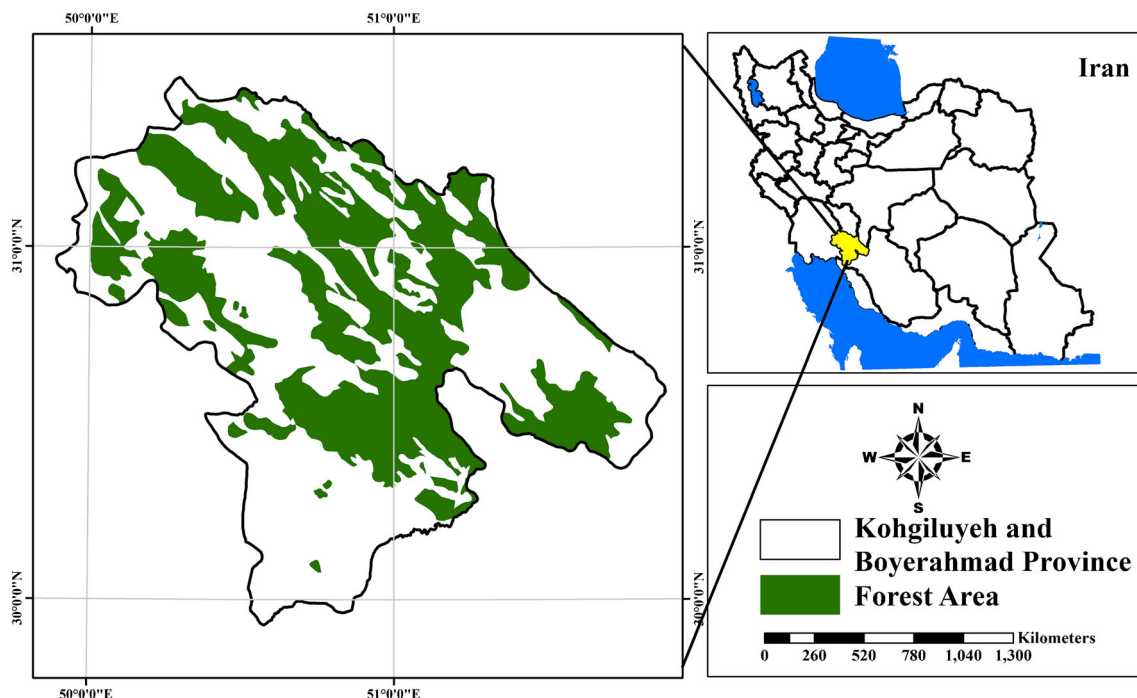


Fig. 1 Location of the study area, its forests in Iran

Pamucar 2018). Simple additive weighting (SAW), technique for order of preference by similarity to ideal solution (TOPSIS), WLC, elimination et choice translating reality (ELECTRE), analytic hierarchy process (AHP), and ANP are the most popular MCDM models. In this study, fuzzy logic, WLC, and ANP methods were used. The steps of the research are described below:

(1) Criteria map

In this study, first, internal, and external reports and papers related to the study were reviewed and we consulted with natural resource experts on possible factors affecting dieback Zagros Oaks (Kooch Soltani et al. 2018). After analysis and analysis, eight factors were selected including slope, aspect, elevation, mean annual temperature (°C), mean annual rainfall (mm), vegetation cover (NDVI), distance from farm land, and pests (borer beetles).

Three topographic factors of elevation, slope percentage, and aspect were prepared using DEM (digital elevation model). After preparation of ASTER digital elevation model (DEM) map for the forest area of the province and using it, slope and aspect raster maps were created in ArcGIS. For producing climate maps of mean annual temperature and mean annual rainfall, 20-year statistical data from the Iranian Meteorological, Synoptic, Rain gauge, and evaporation stations were used. The zoning map of these criteria was constructed based on the Kriging interpolation method (Ghadirian et al. 2018; Hedayati Dezfuli 2006). The socioeconomic factor of distance from agricultural lands is one of the effective and aggravating factors in Oak forest dieback at the provincial level. This map was prepared using GIS layer of farming land which was adapted to Google Earth images. The NDVI of MODIS satellite was used as the data layer of forest density in the region. In the Zagros forests, borer beetles of the Buprestidae family have emerged after recent droughts following drought and physiological stresses and accelerated tree mortality (Rostamian et al. 2017). According to Iranian Forests, Rangeland, and Watershed Organization reports, these beetles were identified as an indicator pest and an effective factor in dieback phenomenon. The zoning map of these pests was constructed using census data provided by the Iranian Forests and Rangelands and Watershed Organization, based on the Kriging method. Eventually, all raster maps were produced at this stage (Fig. 2).

(2) Fuzzy criteria map based on fuzzy logic

The criteria map has different measurement scales, while the multi-criteria evaluation should be matched and scaled. The fuzzy process 0 to 1 based on fuzzy logic and defining appropriate membership functions is used to match and convert maps to comparable units. In other words, the values of

the layers are converted to a unit scale of 0 to 1. In this case, the maximum value, i.e., 1, is assigned to the maximum fuzzy membership, and the lowest value, i.e., 0, belongs to the minimum membership of a fuzzy set (Cheng and Hwang 1992).

For fuzzy raster maps of the study criteria, we used fuzzy logic and defined the appropriate membership functions in GIS (Table 1). The higher values of membership in standardized criteria maps show higher dieback potential in the province's forests (Fig. 3).

(3) Prioritizing the criteria by weighting with the ANP method

Once the evaluation criteria have become standardized comparable scales, the relative weight and importance of each of them should be determined in relation to the purpose. In this study, ANP method was used to determine the relative weight of each criterion. The ANP is a mathematical method used for determining the importance and priority of the criteria in the analysis and evaluation process. This method was invented by Thomas L. Saaty (1996) (Saaty 1996). This is one of the MCDM methods improving the AHP by replacing the network state with the hierarchical one. In fact, the ANP provides an executable framework for general analysis and decision-making collaboration in decision-making and considers all the tangible and intangible factors and criteria having a significant effect on making the best decision, and finally provides the necessary priorities for decision making (Tuzkaya et al. 2008; Zebardast 2010).

According to this method, for determining the criteria influencing the dieback phenomenon of Oak forests, first a pairwise comparative matrix of the criteria was prepared in the form of a questionnaire and was sent to the forest and academic experts in the field of natural resource research. Saaty's numerical scale of 1–9 was used to determine the relative weights of the criteria based on the network analysis model, with number 1 having the least effect and number 9 having the most effect (Saaty and Vargas 2006). After analyzing the experts' opinions, they were entered in the Super Decisions software to determine the weight of the criteria. Then, the obtained weight was applied to the benchmark maps (Table 1).

Determining the weight of the criteria in the process of evaluation of Oak dieback potential in Kohgiluyeh and Boyer-Ahmad Province in a network analysis model includes these steps: define the problem structure and components of the network and the relationships within it, create matrix of paired comparisons, determine relative weight of criteria and priority vectors, form the super matrix and turn it into limit super matrix, and select top options (Zebardast 2010; Saaty 1996). According to the effective criteria of Oak dieback

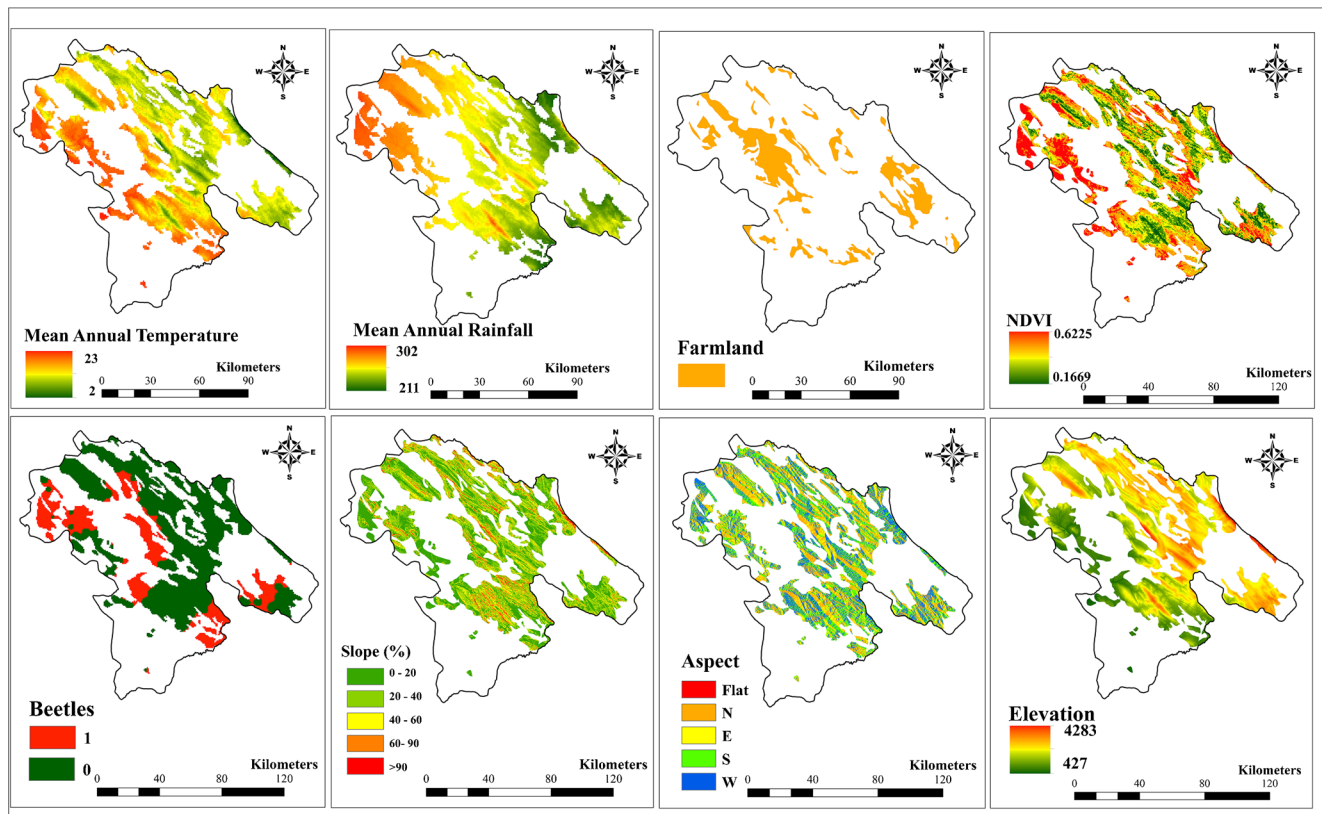


Fig. 2 Map of selected effective criteria for Oak dieback in the study area

considered in this study, the model structure was formed in software Super Decisions (Fig. 4).

(4) Final map of Oak dieback potential by WLC method

Finally, the criteria maps were combined by WLC method by applying the weights obtained from the previous step by

ANP method. In this method, a final value for each criterion is obtained directly from multiplying the relative weight of the criterion by the fuzzy layer of that criterion. Then, these layers are summed. The sum of weights should be equal to 1 (Malczewski 2006) (Equation 1).

$$S = \sum_{i=1}^n W_i X_i \tag{1}$$

Table 1 Type of fuzzy membership function, resources for making layers and weight obtained by ANP method for effective criteria on Oak dieback

Criteria	Sub-criteria	Fuzzy membership function	Weight obtained by ANP method	Source
Topography	Slope	Linear	0.0755	STRM-DEM elevation model
	Aspect	Near	0.109	STRM-DEM elevation model
	Elevation	Small	0.162	STRM-DEM elevation model
Climatic	Mean annual temperature	Linear	0.187	Meteorological stations in the area, ordinary Kriging interpolation model in GIS
	Mean annual rainfall	Small	0.0846	Meteorological stations in the area, ordinary Kriging interpolation model in GIS
Socio-economic	Distance to farmland	Linear	0.175	GIS layer of farming land of Iran, Google Earth images
Vegetation	NDVI	Linear	0.0129	$MODIS\ NDVI = \left(\frac{NIR-RED}{NIR+RED} \right)$
Pests	Beetles	Linear	0.194	Field surveying, ordinary Kriging interpolation model in GIS

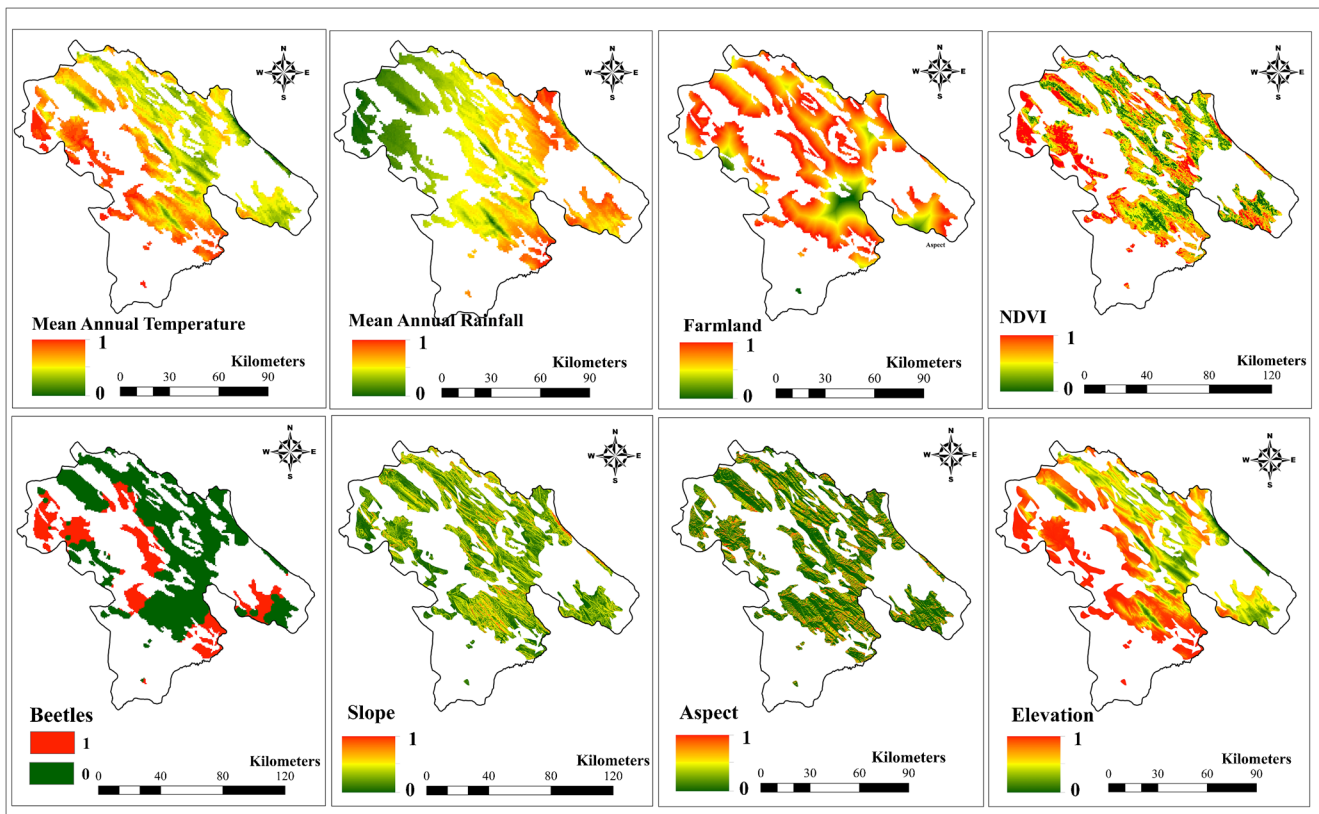


Fig. 3 Standardized maps of effective criteria for Oak dieback in the study area

S : fit for the intended purpose,
 W_i : weight of standard i , by ANP method,
 X_i : fuzzy values of the criterion layer i .

The result of this combination is a map with values between 0 and 1. The areas with 0 value are the most undesired and the areas with the value 1 are the most desired for the given objective (Malczewski 2006).

In the present study, the final map of dieback classes was based on four classes of dieback potential that were low (1 to 25%), moderate (25 to 50%), high (50 to 75%), and very high (more than 75%). The lower numbers close to 0 indicate less dieback potential and lower numbers to 1 indicate areas with higher dieback potential (Fig. 5).

(5) Validation of the final map of the Oak dieback potential

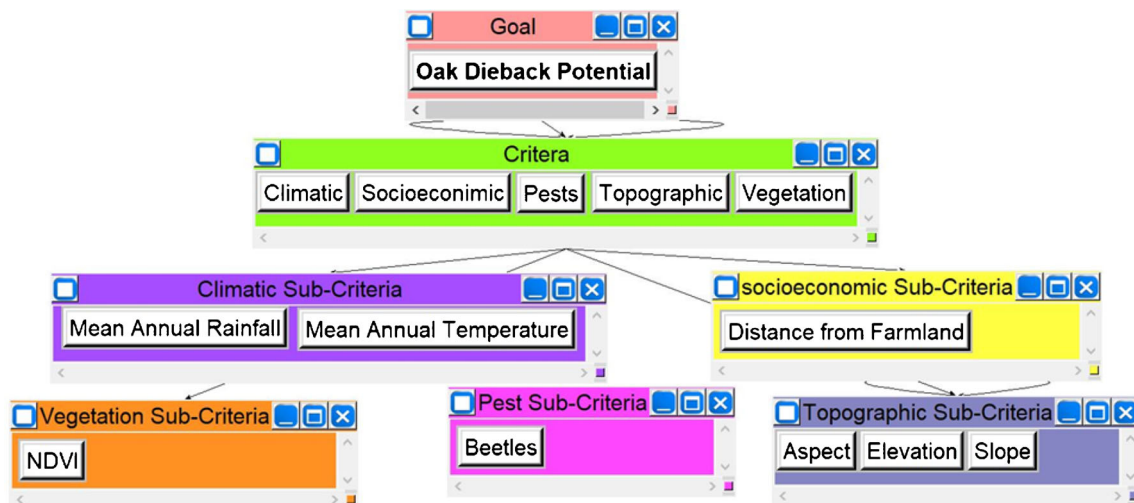
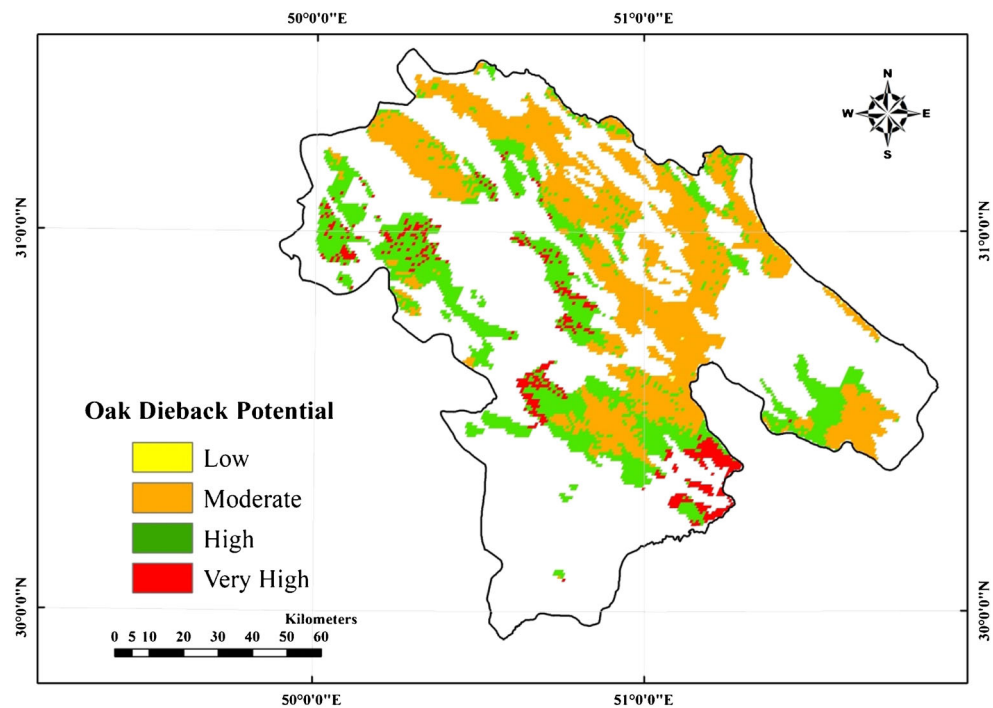


Fig. 4 Network structure of criteria affecting Oak dieback

Fig. 5 Final map of dieback potential classification of Oak forests in Kohgiluyeh and Boyer-Ahmad province by WLC method



Finally, relative operating characteristics (ROC) index was used to validate and evaluate the model and we used over 50% forest area decline map prepared by Iranian Forests and Rangelands and Watershed Organization (Ghadirian et al. 2018).

ROC statistics in the range of 0–1 are calculated by comparing false positive% and true positive% in order to compare a continuous image of merit with a Boolean image where value 1 represents complete spatial agreement and 0.5 indicates random agreement (Nami et al. 2018). ROC statistic is also presented in a graph showing the ratio of the pixels that are predicted by the model to be true positive versus its complement value, i.e., the pixels that are predicted to be false positive. In this graph, true positive % is plotted on the vertical axis and false positive % is plotted on the horizontal axis. ROC statistic values below 0.7 indicate low accuracy, values between 0.7 and 0.9 indicate applicability, and values above 0.9 indicate high accuracy of the model (Fig. 6).

Results

In this study, after analyzing the experts' opinions, nine criteria affecting Oak dieback were selected and weighted using ANP method (Fig. 4). The influence and relative importance of the criteria are presented in Table 1. Accordingly, pests, mean annual temperature, and distance from farmland were generally the highest weights, respectively. Topographic factors with a weight of 0.3465 and then climate factors with a

weight of 0.2734 were the most effective factors for Oak dieback. Among the climatic factors, temperature was the most weighted, and among the topographic factors, the elevation was the most effective. The NDVI had the lowest weight.

Maps of the criteria were produced in the GIS (Fig. 2). The criteria maps were normalized (Fig. 3). According to the maps made, the highest mean annual temperature and the highest amount of rainfall are in the western parts due to the tropical climate. The forests of the province are in the altitude range of 427 to 4283 m and the highest areas are in the eastern part. The southern and western aspects and the slope range were 20 to 40% of the total forest area of the province. The temperature of the province is between 2 and 23 °C and the precipitation is between 211 and 3020 mm, increasing from east to west in both criteria.

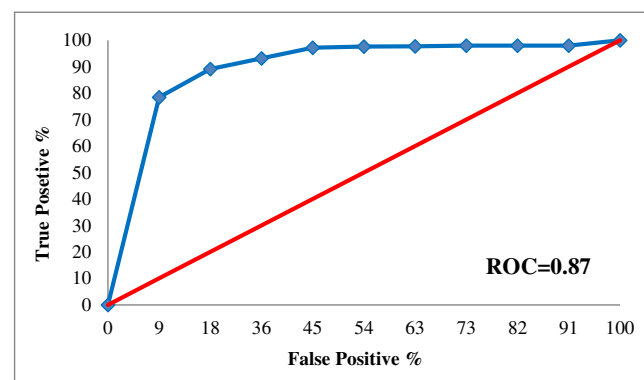


Fig. 6 Accuracy of the final map of dieback potential of Oak forests in study area

In the next step, the dieback potential map based on WLC technique is classified into four classes, low (1–25%), medium (25–50%), high (50–75%), and very high (more than 75%) (Fig. 5). The zoning results of this method in Table 2 showed that 1040.2616 ha of area had low dieback potential, 331,917.7548 ha with moderate dieback potential, 235,767.8612 ha with high dieback potential, and 40,198.6804 ha with high dieback potential. Accordingly, the moderate dieback class has the highest area in the forests of the province (54.51%), which is mostly in the eastern, northeastern, and central parts of the province's forests. At a glance from the eastern to the western part of the province, the potential for dieback has been increased. The low dieback potential class has a very small area. A total of 45.32% of the area has high and very high potential for dieback, mostly in the western and central parts of the province. The accuracy of the map obtained for dieback potential in Kohgiluyeh and Boyerahmad province using WLC method showed ROC index of 0.87. The high ROC indicates the good performance of the multi-criteria evaluation model used in this study (Fig. 6).

Discussion

In recent years, an event is occurring in Zagros forests and increasing daily is dieback in Oak forests (Hosseini et al. 2017; Karami et al. 2018). There are several factors affecting this event that are changed depending on the area and site conditions (Hamzeshpour et al. 2011). Regarding the spatial nature of the study subject, dieback potential of Oak trees was studied in Kohgiluyeh and Boyerahmad Province in southwestern Iran using multi-criteria evaluation methods (ANP and WLC) and fuzzy method based on a range of criteria affecting this phenomenon.

The results of ANP method showed that topographic and climatic factors accounted for more than 61% of the total weight of factors affecting Oak tree dieback in Kohgiluyeh and Boyerahmad Province. Among the topographical factors (slope, aspect, and altitude), aspect criterion had the highest weight. The study results have shown that topographic changes play an important role in predisposing areas for dieback Oak forests in the province. Most areas affected by steep

slopes were in south and west and lower altitudes. Kooh Soltani et al. (2018) also introduced slope, aspect, and elevation above sea level parameters as effective criteria on Oak dieback in Lorestan Province. Studies by Amir Ahmadi et al. (2015) in Dena Conservation Forest in Kohgiluyeh and Boyerahmad Province and Hosseini et al. (2017) confirmed these results. A report by Kabrick et al. (2008) in the US Ozark Mountains showed that red Oak dieback was most pronounced on high slopes and where sandy soils and cations are low. The topographical factors such as slope and aspect have a great effect on the moisture state of a habitat. In sloping areas, trees are more prone to damage due to increased erosion and lower soil depth. Severe mortality generally occurs in warmer and drier aspects. In these points, more heat and more topographic dryness cause more tree stress and dieback (Hosseini et al. 2017).

Among the climatic factors, mean annual temperature showed the highest weight and highest effect on Oak tree dieback. The output map also shows that areas with a higher temperature, mainly in the central and western parts of the province, correspond to the areas with higher dieback potential. A study by Ahmadi et al. (2014), using AHP model, showed that rainfall, temperature, and annual evaporation have played the most important role in the decline of Persian Oak in Ilam Province, while in a study by Ghadirian et al. (2018) in Lorestan Province, evapotranspiration, precipitation, drought index, relative moisture, and temperature were the most important affecting factors, respectively. The study by Attarod et al. (2017) in Lorestan Province showed a significant correlation between climatic factors with the declining classes of Zagros Oak forests.

Among the criteria involved in the phenomenon of dieback in this study, pests had the highest weight so that the areas affected with the pests corresponded to those with high and very high potential for dieback, which is consistent with the results of the studies by Ghobad-Nejhad et al. (2018), Moricca et al. (2012), and Keča et al. (2016) who reported the biological factors, such as *Phytophthora*, *Armillaria*, leaf and borer beetles, and various animals as the effective factors on the Oak decline.

Drought and drought stresses caused by the climate changes are the main causes of Oak tree dieback and decline by reducing water absorption or weakening the trees against other stressors, such as pathogenic fungi and pests (Attarod et al. 2017; Taghimollaei 2019; Linares et al. 2011; Keča et al. 2016).

The physiological weakness of the Oak trees provides conditions for occurrence and outbreak of specific groups of opportunistic pests and diseases consequently leading to the emergence of the forest diseases like the Oak dieback and decline in the Zagros forests in Iran (Mahdavi et al. 2015; Hosseini et al. 2017; Hamzeshpour et al. 2011; Fan et al. 2012; Gentilesca et al. 2017; Sohar et al. 2013). Hosseini

Table 2 Classification of dieback potential area of Oak forest in the study area

Class	Area (%)	Area (ha)
Low dieback potential	0.17	1040.2616
Moderate dieback potential	54.51	331,917.7548
High dieback potential	38.72	235,767.8612
Very high dieback potential	6.60	40,198.6804

(2012) also showed that the pattern of contamination of Oak trees with borer beetles in Lorestan province was consonant with the pattern of tree mortality in the region. He also showed that the rate of contamination was directly correlated with the increase in the stand density and severity of infection with the beetles was higher in higher dieback classes (Hosseini 2012).

Proximity to the farming land, on the other hand, has caused more human intervention in the area, as well as weakening the trees and susceptibility to the pests and diseases. Rostamian et al. (2017) found that about two-thirds of the trees cut and prune by the human beings had been infected with the borer beetles (Rostamian et al. 2017).

Because most pests and diseases infiltrate the tree through tree wounds, they are also cut and prune on the trees, weakening the trees and reducing their resistance against the pests and diseases. Changes in the province's forested lands and the existence of agricultural lands adjacent to these forests in many areas have made these areas to show higher degrees of dieback potential. Hamzehpour et al. (2011) in a study on Oak dieback in Fars province in Iran observed the agricultural lands in 80% of the areas with dieback trees. They also showed that the highest Oak dieback was related to the areas with trees close to the farming land under the influence of severe human intervention and exploitation in the area.

According to the results, a set of biological, non-biological, and socioeconomic factors were involved in the dieback of Zagros Oak trees. The studies by Linares et al. (2011) on the decline of *Cedrus atlantica* in the Mediterranean forests of northern Morocco, Keča et al. (2016) on the decline of European Oak trees, and Gentilesca et al. (2017) have also identified the temperature rise, pathogen and animal invasion, and/or stand density reduction in addition to the drought in the western Mediterranean (in Italy and Spain) as the most important causes of decline of the Mediterranean Oak trees. It is always difficult to identify and determine the causes of tree dieback due to high abundance and diversity of the relevant factors in the forest ecosystems. Various factors contribute to its occurrence, and the long-term function of these factors adds to the complexity of the problem. Also, the interaction between the factors cannot be ignored.

Map of Zagros forest dieback potential in Kohgiluyeh and Boyer-Ahmad Province obtained from multi-criteria evaluation model (ANP and WLC) at a glance shows that all forests in the province are at risk of dieback. But the risk is higher from the eastern to western parts. The present study has shown that a higher potential of dieback was found in these areas. Accordingly, 45.32% of the area has high and very high dieback potential, most commonly found in the southwest to southeast, west, and central areas. However, the moderate dieback class had the largest area (54.51%). The high consistency of the models with the maps of areas with high decline potential of Iran forests and rangelands and watersheds based on ROC index indicates the high validity of the multi-criteria

evaluation model used in this study, which has been less used so far.

In a study, Kooh Soltani et al. (2018) evaluated the efficiency of the MCDM methods using the fuzzy-AHP method for mapping the areas of Zagros forests in Lorestan province, and they showed that the final fuzzy operator map with 70% of accuracy had the highest consistency with the field reality. The map of Oak decline potential in Ilam province obtained using the AHP and GIS methods showed that more than 51% of the study area was at the moderate risk of decline, followed by high-risk (36.70%) and low-risk (8.28%) risks of decline (Ahmadi et al. 2014).

Based on the results of this study, GIS-based MCDM methods are considered as appropriate grounds and efficient tools for data analysis and presentation of the valid results. This method has great potential for solving the spatial problems and selecting the appropriate options based on the multiple criteria and it is a tool for simplifying the complex decisions with different criteria (Eldrandaly 2013). Particularly, in contrast to other methods, such as artificial neural network (Alesheikh and Mehri 2019) and logistic regression (Ghadirian et al. 2018) used so far, it is a newer and more efficient method and it has been shown to have great efficacy for providing the potential dieback maps of Oak forests in the region. The results of this research demonstrated the applicability of the ANP method with respect to the characteristics of the various criteria used in the study and their interactions that have not been applied to such studies so far. This method proposes a network structure in addition to the hierarchical structure of the AHP to address the shortcomings of the AHP method and to solve the complex problems with non-linear structure interdependence and feedback between the criteria. This ability has also led to a great deal of research interest (Eldrandaly 2013). Therefore, this system will be an effective tool for sustainable planning and management of the natural resources and can be generalized to different areas with similar problems and its results can help the managers and planners to take effective steps in order to protect these valuable forests. Finally, considering the various socioeconomic constraints and problems associated with these forests, the numerous threats they have faced over the years, and their close relationship with the phenomenon of tree dieback, the need to prioritize these forests in order to take protective measures as soon as possible would be the first management option.

Conclusion

The overall results showed that pests and average annual temperature are the most effective criteria for this phenomenon. In the next step, fuzzy logic and WLC method were used to construct the Oak dieback potential map.

Regarding the large extent of the areas with high and very high potential for drought and the entire area of the province's forests with potential for dieback, providing a map of dieback by identifying the dieback centers based on the model used in this study can provide the guidance for the natural resource managers to identify the high-risk areas and implement the protective management practices in these areas in order to reduce the effect of this environmental phenomenon by providing the protective and supportive plans.

Regarding the large extent of these forests, it is suggested to conduct similar studies in other areas of these forests based on the model used in this research, and other factors, such as soil type and depth, organic matter content, soil moisture, ecological factors including tree competition, other diseases in the area, and human-related factors should also be considered in studying the Oak dieback.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Ahmadi R, Kiadaliri H, Mataji A, Kafaki S (2014) Oak forest decline zonation using AHP model and GIS technique in Zagros forests of Ilam province. *J Biodivers Environ Sci* 4(3):141–150 <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.654.8481>
- Alesheikh AA and Mehri S (2019) Modeling oak decline using artificial neural networks. *Scientific-Research Quarterly of Geographical Data (SEPEHR)* 28(110): 65–76. (In Persian). <https://doi.org/10.22131/SEPEHR.2019.36612>
- Amir Ahmadi B, Zolfaghari R, Mirzaei MR (2015) Relation between dieback of *Quercus brantii* Lindl. Trees with ecological and silvicultural factors, (study area: Dena protected area). *Ecol Iran For* 3(6):19–27 (In Persian). <http://ifej.sanru.ac.ir/article-1-193-en.html>
- Attarod P, Sadeghi SMM, Pypker TG, Bayramzadeh V (2017) Oak trees decline; a sign of climate variability impacts in the west of Iran. *Caspian J Environ Sci* 15(4):373–384. <https://doi.org/10.22124/cjes.2017.2662>
- Catton HA, George S, Remphey WR (2007) An evaluation of bur oak (*Quercus macrocarpa*) decline in the urban forest of Winnipeg, Manitoba, Canada. *Arboric Urban For* 33(1):22–30 <https://pdfs.semanticscholar.org/1a8d/14848bc9abe437e36d74ece8295712e6a07f.pdf>
- Cheng SJ and Hwang CL (1992) Fuzzy multiple attribute decision making: methods and applications. *Lecture Notes in Economics and Mathematical Systems*, Springer. Springer-Verlag, Berlin Heidelberg. <https://doi.org/10.1007/978-3-642-46768-4>
- Eldrandaly KA (2013) Exploring multi-criteria decision strategies in GIS with linguistic quantifiers: an extension of the analytical network process using ordered weighted averaging operators. *Int J Geogr Inf Sci* 27(12):2455–2482. <https://doi.org/10.1080/13658816.2013.815356>
- Fan Z, Fan X, Crosby MK, Moser WK, He H, Spetich MA, Shifley SR (2012) Spatio-temporal trends of oak decline and mortality under periodic regional drought in the Ozark Highlands of Arkansas and Missouri. *Forests* 3(3):614–631. <https://doi.org/10.3390/f3030614>
- Galiano L, Martínez-Vilalta J, Sabaté S, Lloret F (2012) Determinants of drought effects on crown condition and their relationship with depletion of carbon reserves in a Mediterranean holm oak forest. *Tree Physiol* 32(4):478–489. <https://doi.org/10.1093/treephys/tps025>
- Gentilella T, Camarero JJ, Colangelo M, Nole A and Ripullone F (2017) Drought-induced oak decline in the western Mediterranean region: an overview on current evidences, mechanisms and management options to improve forest resilience. *iForest-Biogeosciences and Forestry* 10(5), p.796. <https://doi.org/10.3832/ifer2317-010>
- Ghadirian O, Hemami MR, Soffianian A, Pourmanafi S, Malekian M (2018) The Zoning of Lorestan Province's forests decline risk using logistic regression model. *J Anim Environ* 10(3):495–502 (In Persian). http://www.ajejournal.ir/article_85032.html
- Ghobad-Nejhad M, Meyn R, Langer E (2018) Endophytic fungi isolated from healthy and declining Persian oak (*Quercus brantii*) in western Iran. *Nova Hedwigia* 107(3–4):273–290. https://doi.org/10.1127/nova_hedwigia/2018/0470
- Hamzehpour M, Kia-daliri H, Bordbar K (2011) Preliminary study of manna oak (*Quercus brantii* Lindl.) tree decline in Dashte-Barm of Kazeroon, Fars province. *Iran J For Poplar Res* 19(2):352–363 (In Persian). <https://www.sid.ir/en/journal/ViewPaper.aspx?id=219305>
- Hedayati Dezfūli A (2006) Investigation of drought and its trends in Kohgiluyeh and Boyerahmad province. *J Meteorol Organ (NIVAR)* 30:73–94 (In Persian). <https://www.sid.ir/Fa/Journal/ViewPaper.aspx?ID=101392>
- Hosseini A (2012) Infestation of forest trees to the borer beetle and its relation to habitat conditions in the Persian oak (*Quercus brantii*) in Ilam Province. *Iran J For Range Protect Res* 9(1):53–66. (In Persian). <https://doi.org/10.22092/ijfpr.2011.106193>
- Hosseini A, Hosseini SM, Calderón JCL (2017) Site factors and stand conditions associated with Persian oak decline in Zagros mountain forests. *Forest Syst* 26(3):e014–e013. <https://doi.org/10.5424/fs/2017263-11298>
- Hosseini A, Hosseini SM, Linares JC (2019) Linking morphological and ecophysiological leaf traits to canopy dieback in Persian oak trees from central Zagros. *J For Res* 30(5):1755–1764. <https://doi.org/10.1007/s11676-018-0805-4>
- Imanyfar S, Hasanlou M, Mirzaei Zadeh V (2019) Mapping oak decline through long-term analysis of time series of satellite images in the forests of Malekshahi, Iran *Int J Remote Sens* 23pp. <https://doi.org/10.1080/01431161.2019.1620375>
- Kabrick JM, Dey DC, Jensen RG, Wallendorf M (2008) The role of environmental factors in oak decline and mortality in the Ozark Highlands. *For Ecol Manag* 255(5–6):1409–1417. <https://doi.org/10.1016/j.foreco.2007.10.054>
- Karami O, Fallah A, Shataei SH, Latifi H (2018) Assessment of geostatistical and interpolation methods for mapping forest dieback intensity in Zagros forests. *Caspian J Environ Sci* 16(1):73–86. <https://doi.org/10.22124/cjes.2018.2783>
- Keča N, Koufakis I, Dietershagen J, Nowakowska JA, Oszako T (2016) European oak decline phenomenon in relation to climatic changes. *Folia Forestalia Polonica* 58(3):170–177. <https://doi.org/10.1515/ffp-2016-0019>
- Kohgiluyeh and Boyerahmad Province Land use planning (2015) Analysis of the status of the province, Natural Resources and Environment, Sabz Andish Payesh Consulting Engineers Company (SAP), 205pp. (In Persian)
- Kooh Soltani S, Alesheikh AA, Ghermezcheshmeh B, Mehri S (2018) An evaluation of potential Oak decline Forest of the Zagros using GIS, RS, FAHP methods. *Iran J Ecohydrology* 5(2):713–725. (In Persian). <https://doi.org/10.22059/IJE.2018.225917.448>
- Linares JC, Taiqui L, Camarero JJ (2011) Increasing drought sensitivity and decline of atlas cedar (*Cedrus atlantica*) in the Moroccan Middle Atlas forests. *Forests* 2(3):777–796. <https://doi.org/10.3390/f2030777>

- Mahdavi A, Mirzaei Zadeh V, Niknezhad M, Karami O (2015) Assessment and prediction of oak trees decline using logistic regression model (case study: Bivareh forest, Malekshahi-Illam). *Iran J For Range Protect Res* 13(1): 20–33. (In Persian). <https://doi.org/10.22092/ijfrpr.2015.102389>
- Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. *Int J Geogr Inf Sci* 20(7):703–726. <https://doi.org/10.1080/13658810600661508>
- Moricca S, Ginetti B, Ragazzi A (2012) Species- and organ-specificity in endophytes colonizing healthy and declining Mediterranean oaks. *Phytopathol Mediterr* 51:587–598. https://doi.org/10.14601/Phytopathol_Mediterr-11705
- Mukhametzyanov I, Pamucar D (2018) A sensitivity analysis in MCDM problems: a statistical approach. *Decis Mak Appl Manag Eng* 1(2): 51–80 <https://www.dmame.org/index.php/dmame/article/view/14/14>
- Nami MH, Jaafari A, Fallah M, Nabiuni S (2018) Spatial prediction of wildfire probability in the Hyrcanian ecoregion using evidential belief function model and GIS. *Int J Environ Sci Technol* 15(2):373–384. <https://doi.org/10.1007/s13762-017-1371-6>
- Nourinejad J, Rostami A (2014) Investigation of oak decline and its relation to physiographic factors in the forests of west of Iran (case study: Ilam Province). *J Biodivers Environ Sci (JBES)* 5(2):201–207 <https://innspub.net/volume-5-number-2-august-2014-jbes/>
- Rostamian M, Kavosi MR, Bazgir E, Babanejad M (2017) The relationship between oak charcoal disease (*Biscogniauxia mediterranea*) and borer beetles in the Zagros forests. *Khorram Abad J Wood For Sci Technol* 24(3):127–141 (In Persian). http://www.ijpp.ir/article_24856_en.html
- Saaty TL (1996) Decision making with dependence and feedback: analytic network process. RWS Publications, Organization and Prioritization of Complexity. Pittsburgh, 370 p
- Saaty TL and Vargas LG (2006) Decision making with the analytic network process: economic, political, social and technological applications with benefits, opportunities, costs and risks. Springer; Softcover reprint of hardcover 1st edition. RWS Publications
- Sagheb-Talebi K, Sajedi T, Pourhashemi M (2014) Forest of Iran: a treasure from the past, a hope for the future. In: Werger M.J.A. (ed.): Plant and Vegetation 10. Dordrecht, Heidelberg, New York, London, Springer: 157
- Shi Y, Wang S, Kou G and Wallenius J (2011) New state of MCDM in the 21st century: Selected Papers of the 20th International Conference on Multiple Criteria Decision Making 2009 (Vol. 648). Springer Science & Business Media. 226 p
- Sohar K, Helama S, Läänelaid A, Raisio J, Tuomenvirta H (2013) Oak decline in a southern Finnish forest as affected by a drought sequence. *Geochronometria* 41(1):92–103. <https://doi.org/10.2478/s13386-013-0137-2>
- Taghimollaei Y (2019) The root results of oak sudden death in plain Barm, Zagros Forest, Fars, Iran. *JOJ Wildl Biodivers* 1:14 [JOJWB.MS. ID. 555558. https://juniperpublishers.com/jojwb/pdf/JOJWB.MS.ID.555558.pdf](https://juniperpublishers.com/jojwb/pdf/JOJWB.MS.ID.555558.pdf)
- Tuzkaya G, Önüt S, Tuzkaya UR, Gülsün B (2008) An analytic network process approach for locating undesirable facilities: an example from Istanbul, Turkey. *J Environ Manag* 88(4):970–983. <https://doi.org/10.1016/j.jenvman.2007.05.004>
- Zebardast E (2010) Application of analytic network process (ANP) in urban and regional planning. Beautiful arts-architecture and urbanism 41(2):79–90 (In Persian with English abstract). https://jfaup.ut.ac.ir/article_22270_en.html