Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 4, No. 3, p. 141-150, 2014
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Oak forest decline zonation using AHP model and GIS technique in Zagros Forests of Ilam Province

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Article published on March 06, 2014

Key words: Oak decline, zonation map, *Quercus brantii,* Ilam Province.

Abstract

Oak trees decline and death of the oak trees are multi-agent phenomena that in the past century have occurred in many of the world's forests. In recent years the phenomenon of oak decline and mortality of trees in the forests of the Zagros Mountain in Iran has occurred. Oak Forests decline of Zagros in Ilam Province are caused by a complex interaction of environmental stresses and pests. Zoning forest areas according to their susceptibility to decline helps to put off operations and reduces catastrophic losses caused through a wise management plan. Therefore, creation of one regional strategy is very necessary to reduce its damages and maintains natural and oak forests. In this study, AHP model and GIS technique have been used to achieve goals. The results shows that mean annual rainfall, mean annual temperature, annual evaporation, annual moisture and dust buffer have major role in decline of Persian oak in the region. These results also show that majority of the study area (51.19%) lied under moderate hazard zone followed by high hazard (36.70%) and low (8.28%). Furthermore, oak decline hazard zonation map can help research centers in environmental management and planning to control this phenomenon.

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Introduction

Climate change is one of the most important environmental problems. In the recent decades the Mediterranean and semi-Mediterranean ecosystems have been faced with climate changes (Nogués Bravo *et al.*, 2008; Parry *et al.*, 2008). Climate changes are mostly influenced by increase in amount of CO_2 and some greenhouse gases in atmosphere. Drought or water deficiency is one of the most critical climatic factors (Mariotti *et al.*, 2008). Rainfall diminution, inappropriate annual rainfall distribution and ground water recharge decreases in forest habitats may compromise tree health and survival (Bréda *et al.*, 2006; Van Mantgem *et al.*, 2009). Warmer and drier conditions are partly responsible for reduced forest productivity (Kirilenko and Sedjo, 2007; Schröter *et al.*, 2005).

Zagros forests, located in the western part of Iran. These forests characterized by a semi-Mediterranean climate, are one of the most important and sensitive ecosystems in Iran. These forests are about five million ha, occurring in the western part of country. The main tree species in these forests are Persian oak (*Quercus. Brantii* Lindl) and it have at least 5,500 years old antiquities (Purhashemi *et al.*, 2004). Oak decline is a serious and often deadly vascular disease of oaks. During the last four years (2009- 2012) several reports of this Oak tree decline were received. Complaining about serious damage and death of many oak trees. The disease has been spread throughout forests of Zagros. The infected tree species included *Q. brantii*, *Q. infectoria* and *Q. libani*. *Q. brantii* (Persian oak) has dominated in all parts of Zagros mountains from north to south, especially on the southern side of mountain in Ilam, Lorestan, Kohgilouyeh va Boyer-Ahmad, Fars and Kermanshah provinces (Fatahi, 1994).

Based on previous studies infections occur in healthy living trees as endophyte and then become invasive under water stress conditions in most reports (Van Mantgem *et al.*, 2009; Hossein, 2013; Mirabolfathy, 2013). On the basis of morphological characteristics, the fungus was identified as *Biscogniauxia mediterranea* and flat-headed borers (*Buprestidae*). *B. mediterranea* has been reported to be aggressive on drought stressed hosts. During the last ten years climate changes has occurred in Zagros forests and resulting drought stress extending desert areas followed by occurrence of the fine dust phenomenon has reduced the photosynthesis of the forest trees and making them more vulnerable to the disease (Fig 1). In spite of tolerance of Persian oak (*Q. brantii* Lindl) species to the range of temperatures from -31°C until +45, the incidence of charcoal disease has been increased dramatically on Persian oak forests. Persian oak represents a new host of B. *mediterranea* and flat-headed borers outbreaks throughout Zagros mountain forests (Mirabolfathy, 2013).

Fig. 1. Oak decline in Ilam forests.

Tree mortality is a complex phenomenon that often several factors including competition, borer beetles and disease outbreaks, environmental stress due to local climate and soil limitations are involved in its occurrence (Franklin *et al.*, 1987; Waring, 1987). So, having an up-to-date map of forest decline risk zoning is great of importance for conserving forest and rangelands in western Iran and even more for protecting the civilians in these areas from the decline. Identify the Multiple factors contributing to tree death and determining of their relative importance is very difficult (Franklin *et al.*, 1987;

Das *et al*., 2011). The majority of previous works done on this subject are inconnection with the identification of factors associated with the phenomenon of oak decline. Applying these factors to produce sensitive areas maps still needs to be investigated. In this study, we apply the factors affecting drying oak trees to create a susceptibility maps.

With the rapid development of Geographic Information Systems (GIS) techniques, GIS is now playing a major role in spatial decision making for forest hazard zonation analysis. One of the most useful applications of GIS for Disaster risk management is the forest decline hazard zonation analysis (McHarg, 1969; Hopkins, 1977; Brail and Klosterman, 2001; Collins *et al*., 2001; Malczewski, 2004). When Disaster risk zonation analysis becomes more complex, Multi Criteria Decision Analysis (MCDA) is very helpful. Progress in computing sciences, including GIS and MCDA can help planners handle this complexity (Joerin *et al*., 2001). The mission of MCDA with GIS is to analyze consider a time trading off the conflict between the many various multi criteria used for disaster risk zonation analysis. This study aims at determining the role of the most important influencing factors on potentials of oak forests decline risk and preparing the map of risk zoning for Ilam Province, Iran.

Materials and methods

Case study area

The studied area was located in Ilam Province within 32°03' to 34°02' N Latitude and 45°40' to 48°03' E Longitude (Fig. 2). Ilam Province is one of the 31 provinces of Iran. It is in the west of the country, bordering Iraq. It has ten cities and covering an area of 20,150 square kilometers, The population of the province is approximately 540,000 people (2005 estimate). The average annual rainfall province is 578 mm. The absolute maximum temperature was 38 °C in August and the minimum temperature was 0.4 °C in February. The number of freezing days in winter was 27 days a year. Wheat is the most common crop cultivated in this province (Jazireii and Ebrahimi, 2003).

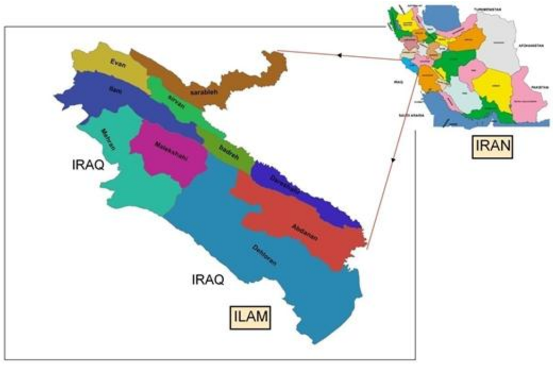

Fig. 2. The location of the study area in Iran.

Forests of Ilam are a part of Zagros Vegetation's, which has 641,000 hectare of forest. The main species of Ilam forests consists; *Quercus brantii*, *Q. infectoria* and *Q. libani* that dominant species is *Q. Brantii* (Fatahi, 1994). It covers a diversity of elevation, slope, population and land-use, etc. The tragedy of the sudden decline of oak trees in Ilam forests is a source of grave concern for the country and requires urgent measures to be taken by the experts to find a solution for the problem.

Methodology

In order to provide oak decline susceptibility maps various methods such as fuzzy logic, statistic methods and Analytic Hierarchy Process (AHP) can be used. The GIS-based susceptibility mapping analysis using AHP approach as the multi-criteria decision analysis (MCDA) was used in this study (Joerin *et al*., 2001).

The AHP is a theory of measurement for dealing with quantifiable and intangible criteria has been applied to numerous areas, such as decision theory and conflict resolution (Vargas, 1990). Using this method, each layer used in forest decline susceptibility zoning is broken into smaller factors, then these factors are weighted based on their importance, and eventually the prepared layers are assembled and the final map is produced. It is based on three principles: decomposition, comparative judgment and synthesis of priorities (Malczewski, 1999). In this method, weight of each layer depends on the judgment of expert, so that the more precise is the judgment, the more compatible is the produced map with reality.

Mapping of the Factors affecting the occurrence of oak decline

The distribution pattern of dried trees in the area will help to select variables (criteria), It is indicative of the conditions that led to their occurrence. So withered tree distribution maps to identify factors affecting their occurrence and for hazard zonation is essential. In this study for preparing the susceptibility maps, fourteen layers including oak decline inventory, lithology, slope, aspect, elevation, climate maps (mean annual rainfall, mean annual temperature, annual evaporation and annual moisture) Dust buffer maps, land cover, distance to stream, distance to residual and distance to road are selected (See Table 1). ArcGis software is used to produce the layer maps which are used in the production of the susceptibility map. It is strongly recommended that forest decline zoning be carried out in a GIS-based system so that the zoning can be readily applied for environment management and can be up-dated as more information is used (Fell *et al.*, 2008). The most important factor in determining the scale of susceptibility map is scale of topographic map and initial data. Another effective factor is the purpose of susceptibility map and the area of study region. According to the area of the region to be investigated, the scale of susceptibility map will be 1:50,000.

Table 1. Criteria and sub-criteria parameters used in the study.

Criteria	Sub-criteria	Data type	Scale
Topographic map	Elevation Slope aspect Slope angle	Point and line	1:50,000
Climate map	annual rainfall annual temperature annual evaporation annual moisture	Polygon	1:50,000
Dust map	Dust buffer	buffer	1:50,000
Geological map	Lithology	Polygon	1:50,000
Land cover	Land cover	Polygon	1:50,000
Distance to stream	Distance to stream	Polygon	1:50,000
Distance to residual	Distance to residual	Polygon	1:50,000
Distance to road	Distance to road	Polygon	1:50,000

Analytical hierarchy process (AHP)

The AHP method was used to define the factors that govern oak decline occurrence more transparently and to derive their weights (Yao *et al.*, 2008). AHP is a multi-objective, multi-criteria decision-making approach which enables the user to arrive at a scale of preference drawn from a set of alternatives (Yalcin, 2008). AHP method includes a matrix-based pair-wise comparison of the effect of each factor for oak declining. AHP is a semi-qualitative method and frequently used with most of researchers. An extensive description about AHP is explained by Saaty (1980) and Saaty and Vargas (2001).

AHP has gained wide application in site selection, suitability analysis, regional planning, and susceptibility analysis (Ayalew and Yamagishi, 2005). Using this method, each layer is broken into smaller factors, and then these factors are compared based on their importance. Matrixes of pairwise comparisons were created by the experts on condition that judgments are evaluated to find suitable alternatives to estimate associated absolute numbers from 1 to 9, the overall importance of each of the individual criteria is then calculated. An importance scale is proposed for these comparisons (See Table 2). The AHP is the rational planning process in locating public facilities (Banai-Kashani, 1989).

Table 2. Scales for pairwise AHP comparisons (Saaty and Vargas, 2001).

Description	Dominant value
Equal importance	1
Moderate prevalence of one over another	3
Strong or essential prevalence	5
Very strong or demonstrated prevalence	7
Extremely high prevalence	9
Intermediate values	2,4,6,8

The weights of factors and parameters were successfully calculated easily for forest land susceptibility with the Expert choice software (Lee and Chan, 2008), keeping in view the consistency ratio (CR). If CR is satisfactory, it does not exceed the desired range, i.e. >0.10 (Saaty, 1980). If the CR value is in an undesirable range, the obtained judgment matrix is needed to be reviewed till these values have improved and are satisfactory. The AHP software, Expert Choice can calculate automatically. Indeed, it was a time consuming procedure to compute the pairwise comparison matrix manually or in MS Excel. Therefore, Expert Choice is a multi-objective decision support tool based on AHP (Saaty and Vargas, 2001). In our study, the resulting CR for the pairwise comparison matrix for oak forest decline zonation was 0.05. This indicates that the comparisons of land characteristics were perfectly consistent and that the relative weights were appropriately chosen in this particular oak decline zonationmodel.

Later on, to compute composite weights, Eastman *et al.*, 1995 stated two procedures for multi-criteria evaluation: the concordance discordance analysis and the weighted linear combination. The function of a weighted linear combination (WLC) procedure where each factor and parameter (Vi) are multiplied by the weight of the suitability parameters (Wi) to get composite weights and then summed as shown in Table 3. WLC is a straight forward linear method calculating composite weights. Similarly, the results of composite weights were used in a weighted sum spatial analysis function. Therefore, the weighted linear technique (Mendoza, 1997; Mohit and Ali, 2006) was applied to yield a susceptibility map by the following formula:

$$\mathbb{E} = \sum_{i=1}^{n} \mathrm{Wi} * \mathrm{Vi} \qquad (1)$$

Where: Wi = relative importance or weight of factors/parameters i\ Vi = relative weight of parameters i, And n = total number of parameters related to the study.

Results

The AHP method was used to evaluate the priority weight of each criteria and sub-criteria (parameters). AHP and the Geographic Information System (GIS) are an integrated technique used to oak forest decline zonation in Ilam Province (Thapa and Murayama, 2008). The derivation of relative composite weights of forest decline susceptibility criteria and sub-criteria was calculated as presented in Table 3. Oak decline hazard zonation map have been extracted using weighted overlay techniques. As described in the previous section, this is based on standard weights which were derived from the AHP process. This map values were then divided into three classes, which represent three different zones in the Oak decline susceptibility map. These are high hazard, moderate hazard, and low hazard zones (Fig. 3). The percentage covering areas of each hazard class are shown in Table 4 along with number of reference oak decline points occurred. Oak decline hazard zonation map shows that majority of the study area (51.19%) lied under moderate hazard zone followed by high hazard (36.70%) and low (8.28%).

Table 3. AHP pairwise comparison matrix and the weights of the criteria.

Criteria	Rainfall	Temperature	Evaporation	Moisture	Dust buffer	D. Stream	D. Residual	D. Road	Land cover	Slope	Elevation	Aspect	Lithology	Eigen values
Rainfall	1	2	2	3	5	6	6	7	7	8	8	9	9	0.2043
Temperature	0.5	1	2	3	4	5	6	7	7	8	8	9	9	0.1717
Evaporation	0.5	0.5	1	4	4	5	5	6	7	8	8	9	9	0.1545
Moisture	0.5	0.25	0.333	3	4	5	6	6	7	7	8	8	9	0.1312
Dust buffer	0.333	0.333	0.25	1	3	4	6	5	6	6	7	7	8	0.1076
D. stream	0.2	0.25	0.25	0.333	1	3	4	5	5	6	6	7	8	0.0802
D. Residual	0.166	0.2	0.2	0.25	0.333	1	4	4	5	7	7	8	9	0.0708
D. Road	0.166	0.166	0.2	0.2	0.25	0.25	1	3	5	7	7	8	9	0.0582
Land cover	0.142	0.142	0.166	0.2	0.2	0.2	0.333	1	3	5	7	8	9	0.0446
Slope	0.142	0.142	0.142	0.166	0.2	0.2	0.2	0.333	1	2	7	9	9	0.0407
Elevation	0.125	0.125	0.125	0.142	0.166	0.145	0.142	0.2	0.2	1	5	6	8	0.0272
Aspect	0.125	0.125	0.125	0.142	0.166	0.142	0.142	0.142	0.142	0.2	1	5	7	0.02
Lithology	0.111	0.111	0.111	0.125	0.142	0.125	0.125	0.125	0.111	0.166	0.2	1	3	0.0114

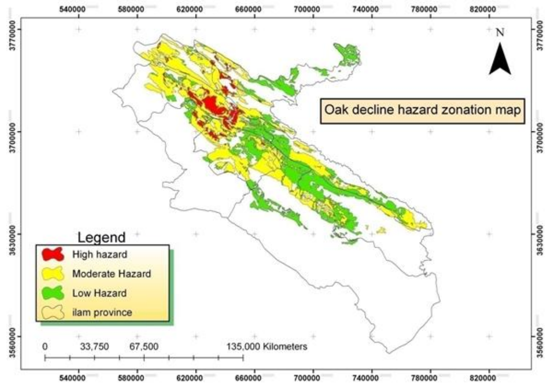

Fig. 3. Oak decline hazard zonation map.

Table 4. Allocation of the reference oak decline points within the defined Oak decline hazard zonation map classes.

Classes	Area (ha)	% Area	Number of dried tree
Low hazard	235248	36.70	3465
Moderate hazard	328129	51.19	7550
High hazard	53127	8.28	417

Discussion

Decline and death of oak trees is multi-agent phenomena in the past century have occurred in many of the world's forests. In recent years the phenomenon of drying and death of trees has occurred in large areas of Zagros forests, so many trees, particularly *Q. brantii* species has been destroyed. Although this phenomenon at regional level has occurred, but in a smaller, local level has emerged with different intensity.

Among the important factors in the phenomenon of oak decline are infestations of oak borer beetle and *B. mediterranea*. These lives factors in some of the world's forests have been identified as secondary factors in the mortality of trees, because in case of occurrence of environmental stresses such as drought and the phenomenon of dust, those are attacked to trees (Mattson and Haack, 1987). In the forest of zagros oak borer beetles and *B. mediterranea* have overflowed after the advent of the recent drought and the followed by drought stress and physiological vulnerability.

Oak decline is a disease complex affecting trees under stress. In Ilam, drought, dust stress and climate change are factors most often associated with infection. Continued stress hastens tree death. Trees that are kept in good health are not as susceptible to the complex. Based on past history, damage from oak decline can be expected during periods of extended drought.

The Oak decline phenomenon is one of environmental hazards which occur in zagros forests (Especially in Ilam province) in recent years. Therefore, creation of one regional strategy is very necessary to reduce its damages and maintains natural and oak forests. Furthermore, oak decline hazard zonation map can help research centers in environmental management and planning to control this phenomenon. In this study, AHP model and GIS technique have been used to achieve goals. The results showed that integration of GIS technique and AHP model is a mighty method for preparationof oak decline hazard zonation map in study area. According to effective factors in oak decline phenomenon occurrence, the study area was zoned as various layers. Finally, oak forest occurrence zones were recognized from very low risk to very high risk. The investigations showed the zones of high and moderate risk are often great relevance with high drought areas (low rainfall, low humidity, high evaporation and high temperatures areas) and with high dust levels areas. Breda *et al.*, 2006 and Van Mantgem *et al.*, 2009 also found that climate change (Atmospheric warming and reduced Precipitation) had most important role in forests decline. Dust, mostly originating from Iraq, is one of the prime factors behind the oak decline in this area.

Among the effective factors, sub-criteria of mean annual rainfall, mean annual temperature, annual evaporation, annual moisture and dust buffer, respectively, with weights 0.2043, 0.1717, 0.1545, 0.1312 and 0.1076 have been identified as the most important factors in the occurrence of decline in oak forests of Ilam. However, these results are consistent with studies by Bréda *et al*., 2006; Van Mantgem *et al*., 2009. In China, substantial tree mortality thought to be a result of climate change has been reported, but the mechanisms and biological details are unclear. In many areas of China, increases in temperature and precipitation over the past 50 years (Yang, 2008) may have increased the incidence of some forest diseases.

The role of other factors reduces according to their weights in oak decline that has been showed in table (3). According to final hazard zonation map, about %8.28 percent (53127 ha) of the Ilam province area have the occurrence of high hazard and the occurrence of moderate hazard (%51.19 equal to 328129 ha). About 70 percent of dried trees occurred in high and moderate hazard areas (See Table 4). So, it seems the map of oak hazard zonation, produced in this research, predicts more than 70 percent of occurring dried trees in the study area and would be helpful data for arranging a better oak decline fighting plan in national and regional forest and rangeland management head quarters. The great extent is showing the oak forest decline occurrence importance in the future that doubles the necessity of its management issues.

Oak decline can be prevented on live oak with a program utilizing both cultural and sanitation practices. Positive identification is made with the aid of laboratory procedures. Once a tree has been diagnosed as having oak decline, follow a complete maintenance program involving fertilizer application, deep watering during summer months, pruning and removal of dead or weak limbs. Treat trees in early stages of decline; destroy those that have no chance of recovery.

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