A Multi-Criteria Evaluation approach to Delineation of Suitable Areas for Planting Trees (Case Study: Juglans regia in Gharnaveh Watershed of Golestan Province)

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Abstract. For the successful tree establishment, an evaluation of land suitability is necessary. In this paper, we demonstrate how to implement fuzzy classification of land suitability in a GIS environment for afforestation with *Juglans regia* in Gharnaveh Watershed of Golestan Province in Iran. *Juglans regia* is one of the most important agro-forestry species in many rural parts of Iran. Relevant criteria for *Juglans regia* and suitability levels were defined using literature review and expert knowledge and layers were prepared and incorporated into a GIS database. We also defined the fuzzy membership functions for the criteria and assigned some important weights through expert knowledge and Analytical Hierarchy Process. This information was used as input to the weighted linear combination of MCE method. Our results indicate that a low percentage of area is classed as very highly suitable comprising some 645 ha or 11% of area for afforestation with *Juglans regia*. Results of the study also indicate the usefulness of fuzzy modeling of land suitability which provides some information for optimum land-use planning.

Keywords: Multi-Criteria Evaluation, Land suitability, GIS, *Juglans regia*, Gharnaveh Watershed, Iran.

Introduction

Geographical information systems are useful for storing, processing and manipulating spatial databases (Aronoff 1989). The integration of multi criteria evaluation (MCE) within a GIS context helps users to improve decision making processes. In the last decade, MCE received the renewed attention in the context of a GIS-based decision making (Pereira and Duckstein 1993; Heywood *et al.* 1995; Malczewski 1996). The combination of layers in MCE process could be useful in solving the conflicting situations for individuals or groups interested in spatial context (Malczewski 1996, Janssen and Rietved 1990). It is also a powerful approach to land suitability assessments Joerin *et al.* (2001). Alternative methods based on a fuzzy theory or fuzzy logic set is starting to appear in land evaluation studies (Baja *et al.* 2002; Sicat *et al.* 2005). The concept of a fuzzy set was introduced by Asgar Lotfizadeh in 1965 as a quantitative approach to integrate factors such as human reasoning, knowledge, attribute, spatial variation, and measurement error in environmental data (Woodcock and Gopal 2000). These benefits of fuzzy logic application to land suitability have been utilized in recent forestry related studies by Lexer *et al.* (2000) and Ruger *et al.* (2005). The majority of fuzzy logic-based land evaluation systems have been developed to assess agricultural land suitability. (Iless, J. 1999; Burrough 1989; Burrough *et al.* 1992 and Sicat *et al.* 2005) used fuzzy classification to determine the land suitability for various agricultural purposes. Chang and Burrough (1987) were among the first ones who applied fuzzy logic to land evaluation by utilizing fuzzy sets to determine land suitability for apple tree planting in an area located in northeast of China. The MCE approach in assessments have also been performed for rubber tree Van Ranst *et al.* (1996), alfalfa (Kollias and Kalivas 1998), rice Oberthur *et al.* (2000), and maize (Tang and Van Ranst 1992). However, to our best knowledge, so far no fuzzy MCE–GIS integration has been utilized in Iran to solve problems related to afforestation with trees. Hence, this is the first study of this kind trying to set an example for afforestation practice in Iran. It also shows the benefits and disadvantages of approach and any lack of data towards its implementation in Iran.

Materials and methods

Study Area

The study area is located in 55˚30′-56˚20′ eastern longitudes and 37˚ 30′-37˚ 47′ northern latitudes in eastern Golestan Province (Fig. 1). The climate is temperate and semi-arid to semi-humid. The elevation range is 100-1400 meters above sea level and the average elevation is 394 meters. The most important forest tree species in this area are *Quercus iberica, Zelkova carpinifolia*, *Parrotia prsica* and *Betula sp*. The most important pasture species are *herbaalba*, *Kochia*, *Dactylis glomerata*, and *Agropyron sp*. Gharnaveh watershed has an area of 9403 hectares of which 489 hectares is forest, 5834.47 hectares is rangeland and 3080 hectares is agriculture. Neglecting the land capability and developing ecologically improper land uses have increased soil erosion and desertification in the area. The ramifications of this process are land degradation and poverty. Loss formations cover most of the area and it augments the desertification process. Hence, any attempt towards the afforestation of study area with proper species can be of great help in reversing the downgrading environmental situation.

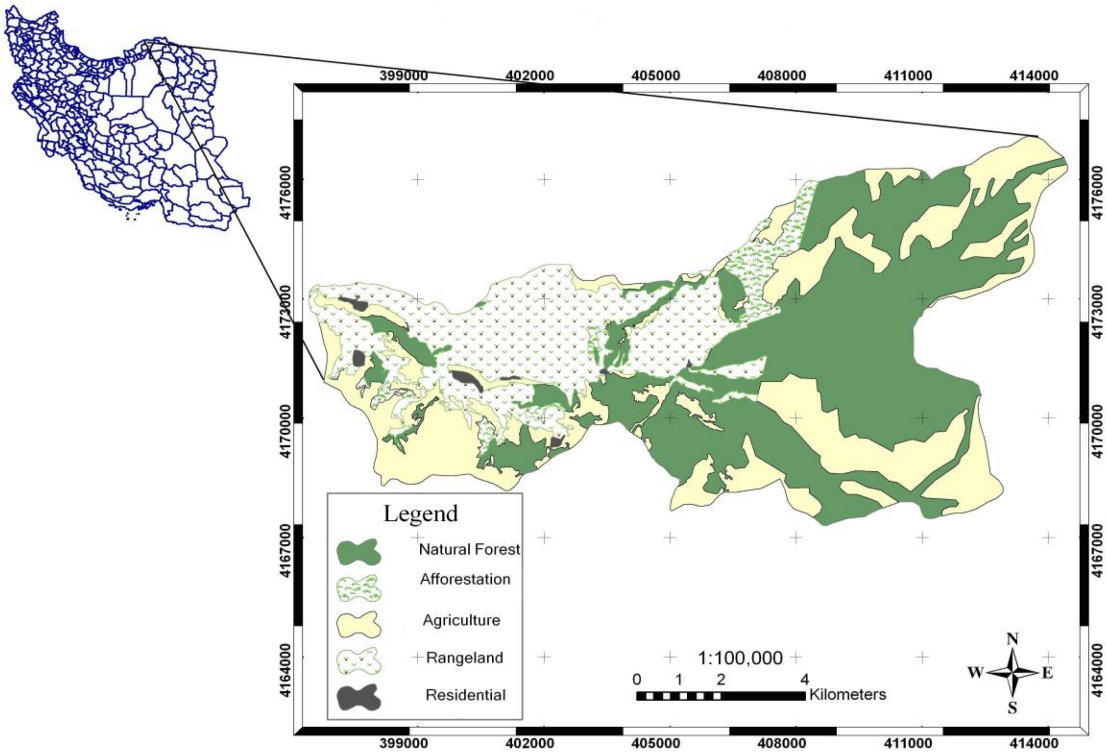


Fig. 1. Location of Study Area in Iran

Juglans regia is an important tree species in Iran, especially in this area as it forms a large component of daily diet of many people and so is highly valued in agro-forestry plans. Furthermore, *Juglans regia* is very important for wood industry. Therefore, *Juglans regia* was selected in this research due to its economic value alongside its ecological importance.

Juglans regia is naturally found in deep valleys with creeks and slopes facing north (Brown 1982). This species is able to flourish in the areas with an annual rainfall mean of 300-600 mm (Mosaddegh 1980). The optimal altitudinal range of *Juglans regia* is between 150-760 m above sea level mean (Barbour 1987, Quinn 1990). It survives in down temperatures as -8 ºC. Mean annual temperature factor for *Juglans regia* is 13.5ºC (Chirici, 2002). The ecological requirements of this species have been described by Ellenberg (1992), and summarized in Table 1.

Table 1. Ecological Requirements of *Juglans regia* (Ellenberg 1992)

Species	Light (Score)	Temperature (Score)	Continentality (Score)	Moisture (Score)	Reaction (pH)
Juglans regia	6	8	2	6	7

In (Table 1), light score 6 means plant generally thrives with more than 10% relative irradiance and in well lit places and occurs in partial shade. Temperate score 8 is a warmth indicator showing tree development in warm lowland sites. Continentality score 2 reflects oceanic condition mainly in the west including Western Central Europe. Moisture score 6 is a moist-site indicator mainly on fresh soil of average dampness absent from both wet and dry ground. Reaction score 7 indicates a weakly basic condition and the tree is never found on very acid soils.

Analytical Methods

Soil database

Information about the soil conditions (pH, sand, silt and clay) at grid sampling points was obtained within the land-form of study area (Booklet of Forestry Plan 2006). Due to inconsistencies in the grid soil sampling database, some data were eliminated; thus, the total number of point data varied from 50 (pH) to 51 (sand, silt and clay). Sand, silt, clay and pH maps were generated using interpolation routine within ARC VIEW 3.2. Besides, soil texture and pH class maps were obtained using field sampling, laboratory tests and GIS routines. The UTM coordinate system was used to locate geographic elements on the maps.

Relief database

The slope (expressed as percentage), aspect and altitude information were obtained from the digital elevation model (DEM) using IDRISI Kilimanjaro. The spatial resolution of data was set at 30 m per pixel. The top shape, wetness index and solar radiation information were obtained from the digital elevation model using Digem (Conrad 2002, 2.0) software.

MCE

The general procedure of MCE included several phases as explained in the following paragraphs. Firstly, the important criteria (factors and constraints) were defined Eastman *et al.* (1995) using literature review and expert knowledge. The second step in the MCE procedure was to define membership functions in order to determine degree of class membership (i.e., from 0 to1) for each criterion. This was also carried out using the best expert judgments. The third step was the application of expert ideas in weighting criteria (Ceballos-Silva and Lopez-Blanco 2003). Eligible factors for *Juglans regia* were maximum and minimum temperature, mean annual precipitation, soil pH, soil texture class, altitude, slope, aspect, solar radiation, wetness index and topographic location. The latter was achieved through the top shape routine in Idrisi Kilimanjaro. Suitability levels for each factor were defined; these levels were used as the basis for construction of criteria maps Perveen *et al.* (2007). Three levels were considered including high suitability, medium suitability and low suitability. The levels were defined referring to the experts' opinion for each factor deemed influencing the success of plantation with *Juglans regia* (Table 2). The fuzzy membership functions were used to standardize the factor maps. A fuzzy set is characterized by a fuzzy membership grade that ranges from 0 to 1 meaning non-membership to complete membership, respectively (Eastman 1999). The fuzzy membership standardizing approach produced several factor maps with the interval ranging from 0 (very low suitability) to 1 (very high suitability) (Fig. 2. Maps 1–9) (Ceballos-Silva and Lopez-Blanco 2003). In the case of numerical factor maps (e.g. soil pH, slope, annual precipitation mean) monotonically decreasing sigmoidal fuzzy membership functions were used. For altitude and mean annual temperature, we used symmetric sigmoidal fuzzy membership functions. For other factors including aspect, solar radiation, wetness index and top shape, the user-defined function options were used (Malczewski 1999). Whole factor maps were applied using FUZZY procedure in IDRISI. To develop criteria weights, the AHP was used that is considered to be one of the most promising methods Eastman *et al.* (1998). Factors were rated according to expert opinion. In the weight calculation step, the pair wise comparison matrix and factor maps were used with the WEIGHT module in IDRISI environment Farajzadeh *et al.* (2007). Once the factor and constraint maps were obtained, each factor map was multiplied by its weight and the results were summed up. To produce the suitability map, the resulting summed map was then multiplied by each of the constraint maps. The MCE module of IDRISI was used in the process (Ceballos-Silva and Lopez-Blanco 2003).

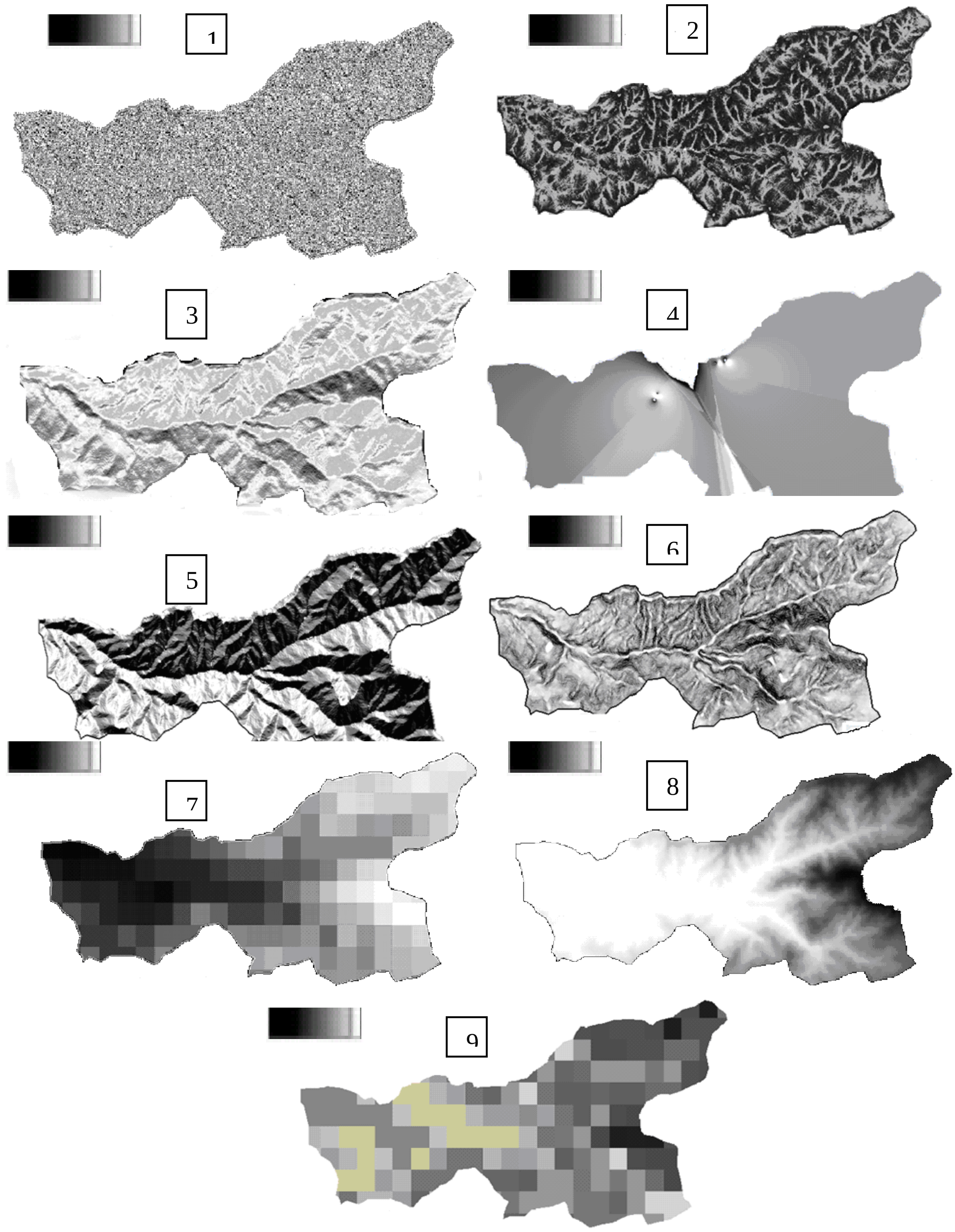
Table 2. Specific Important Suitability Levels of Factors for *Juglans regia*

Factor	High suitability
Soil pH	6- 7.5
Slope	0- 65%
Annual mean	300- 600 mm
Altitude	150- 760 m
Mean annual temperature	13.5 ºC
Aspect	North aspect
Solar radiation	Warmth area
Wetness index	Moist site
Toposhape	deep valleys, along creeks

In this study, we suggested nine criteria upon which we based the forestation suitability assessment. Our selection of these criteria was based on the experts' opinion. In choosing these criteria, we attempted to cover all aspects of a forestation. The AHP method was used to calculate the weights of criteria including pair wise comparisons and weighting matrix establishment. Fifteen local experts were invited to fill in the pair-wise comparison matrices to generate the weighting matrix which is shown in (Table 3).

Table 3. Weighting Matrix for Land Sustainability Assessment

Criteria	Weight
Annual precipitation mean	0.575
Aspect	0.382
Slope	0.316
Annual temperature mean	0.273
pH	0.234
Solar radiation	0.230
Wetness index	0.217
Altitude	0.205
Toposhape	0.199



Levels of Suitability: Low Medium High

Fig. 2. Standardized Factor Maps for *Juglans regia* in Gharnaveh Watershed of Iran Including Suitability Levels: 1- Toposhape, 2- Wetness Index, 3- Solar Radiation, and 4- pH, 5- Aspect, 6- Slope, 7- Precipitation, 8- Altitude and 9- Temperature. Fuzzy Membership Grade was used to define the High Suitability as Shown in (Table 2).

Results and Discussion

The pair wise comparison matrix was constructed with the factors mentioned previously and then, the relative importance of each one was measured through the calculation of weights Perveen *et al.* (2007). The results indicated that the most important factors according to their specific weighting were precipitation (0.575), aspect (0.382) and slope (0.316). Factors with the medium importance were temperature mean (0.273), pH (0.234), solar radiation (0.230), wetness index (0.217), altitude (0.205), and toposhape (0.199). Utilizing the specific weights for each factor, the factor and constraint maps in the MCE module of IDRISI were used to produce the suitability map for *Juglans regia.* The spatial location and suitability rate of areas identified for the establishment of *Juglans regia* are shown in (Fig. 3).

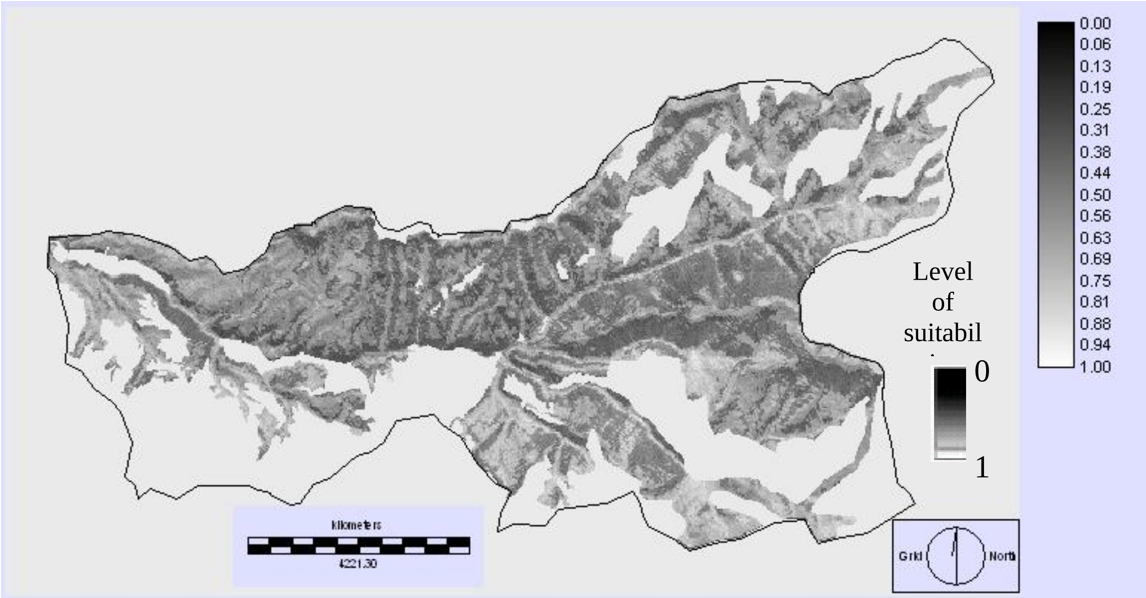


Fig. 3. Map of Suitable Areas for *Juglans regia* in Gharnaveh Watershed of Golestan Province, Iran.

In (Fig. 3), areas with fuzzy values greater than 0.90 were classified as the most suitable. The results showed that high suitability areas are located in the valleys with creeks within elevation interval 150-760 meters above sea level, soil pH level 6-7.5, precipitation 300-600 mm, temperature mean 13.5 ºC, north aspect and warmer areas. These findings are in line with those considered in Table 2. According to Figure 3, the surface area of each suitability class is as follows: high suitability 645.57 ha (11%), medium suitability 3625.89 ha (60%), and low suitability 1833.12 ha (29%). Lexer in 2000 and Ruger in 2005 proposed a three class category for classifying land suitability for afforestation with tree species. A few additional assessment units had moderately high scores just in south east and south west of the best rated units. In Fig. 3, it is evident that the area is generally suitable for plantation with *Juglans regia*. A limitation of our study was the lack of information on soil depth, soil texture and soil pH with an adequate spatial scale. In spite of this, the results are still valuable for planning afforestation activity in the area. The results are open to expert judgments where they can apply new fuzzy memberships and factor weights and examine the results in light of their new inputs. In fact, the method provides a flexible framework for conducting iterative trial and error experiments within the universally accepted and known ecological boundaries governing the growth and flourishing of walnut grooves. Hence, the results are not specifically final leaving the decision makers somewhat free to take actions when planting *Juglans regia*.

Conclusion

One of the main tasks we undertook in this study was to test whether the fuzzy MCE approach could produce accurate and reliable maps of potential areas for forest plantations with *Juglans regia*. Criteria selection is essential for land suitability assessment. Climate, soil and topography components are useful in the identification of suitable areas for *Juglans regia* within MCE. The joint application of AHP and GIS are the core methods for studying land suitability assessment, and these were successfully applied in our case study. The advantage of this approach is to avoid the traditional Boolean classification wherein a pixel either belongs to a class or does not (Clark labs 2004). Instead, a series of factors is created, showing a continuous transition between suitable and non-suitable areas ranging from 0 to 1. We found that multi criteria evaluation technique was crucial in obtaining land suitability information in an accurate and relatively fast way (Ceballos-Silva and Lopez-Blanco 2003). The accuracy of method can be tested through sensitivity analyses in later research projects and also monitoring programs. In this study, we applied the fuzzy MCE approach to identify areas for afforestation purpose. This approach has been used in studies in other countries. However, the application to afforestation is relatively new to Iran. This method was useful to evaluate multiple criteria and canvass expert opinion in order to obtain suitability maps. Trees remove carbon dioxide and other particulates from the air, help control erosion, block winter winds, reduce heating and cooling costs, add value to homes and businesses, and generally create a positive community image (Iles, 1999). By planting *Juglans regia* in suitable areas of Iran, the problem of worsening food and wood shortage and environmental degradation can be reduced to some degree and it contributes to take the pressure off the remaining natural forests and to increase the diversity of vegetation.

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