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Ecological capability assessment for afforestation using GIS- based multiple criteria decision making approach (Case study; Mehran County, Iran)

Reza Ahmadi[1], Hojat Fathi[1], Jalal Noorinejad[2] and Aliakbar Jafarzadeh[3]

[1]Department of Forestry, Islamic Azad University, Science and Research, Tehran, Iran.
[2]Department of Forestry, Islamic Azad University, Science and Research, Ilam, Iran.
[3]Department of Forestry, Sari University of Agricultural Sciences and Natural Resources, Iran.

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ABSTRACT

Due to the process of deforestation and Increasing human population and growing demands for forests, afforestation and the development of forest is and will be of paramount importance. The objective of this research is to identify suitable lands for afforestation and forest development in Mehran County on the western of Iran by using multi criteria evaluation making. Site selection analysis was carried out to find the best suitable lands for forest development and afforestation in an example of promising southern Ilam province, Iran. The GIS models were developed to represent a scenario of land use suitability in the study area using GIS Multi Criteria Analysis Modeling. The factors contributed in the analysis are the Topography, Land cover, Climate, Soil, and Geology. Land suitability maps for afforestation have been extracted using weighted overlay techniques. The total resulting areas for afforestation reveal the importance of forest development in Mehran County, and the suitability of the terrain. The suitable map for afforestation shows that 35.88% of the investigated area is highly suitable, 28.64% is moderately suitable and 35.46% is lowly suitable. According to autochthonous species and adaptive exotic species and their ecological demand suggest species for afforestation in suitable places that ecological demand of the suggested species is similar to ecology specifications of this suitable land that have capability for afforestation. Several species suggested for afforestation in suitable lands such as *Amygdalus arabica*, *Prosopis juliflora*, *Pistasia atlantica*, *Eucaliptus camaldulensis*, *Ziziphus spina-christi*, *Ziziphus numularia*, and *Myrtus communis*.

Introduction

Afforestation has been proposed as a tool for climate change mitigation because the growth of forests on previously unforested land results in a net uptake and storage of carbon from the atmosphere which, it is assumed will slow global warming. The expansion of forest plantations for biofuel production has been proposed as well and is a candidate land cover scenario for specifying representative concentration pathways in the IPCC AR5 protocol (Moss et al. 2010). However, the role of forests in climate remains poorly constrained (Bonan 2008). The global extent of plantation forests in 1990 is estimated at around 135 million ha (FAO 1993; Gauthier 1991; Pandey 1995). About 75% of these plantation forests are in temperate regions and about 25% in the tropics and subtropics; some 5% of are found in Africa, a little more than 10% in each of the American continents, some 20% in the former USSR, and around 25% in each of Asia-Pacific and Europe (Gauthier 1991; Kanowski and Savill 1992). Around 90% of existing plantations have been established for the production of wood for industrial use, and most of the remainder to produce wood for use as fuel or round wood. Some plantation forests are grown and managed, either primarily or jointly, for non-wood products such as essential oils, tannins, or fodder. The provision of a diverse range of other forest benefits and services, including environmental protection or rehabilitation, recreational opportunities, and CO2 sequestration are also primary or secondary objectives for many plantation forests (Evans 1992; Kallio et al. 1987; Lamb 1995; Myers 1989; Sedjo 1987).

It is increasingly becoming clear that natural resources management is indispensable in ensuring environmental sustainability and reducing the risk associated with climate change and increasing demand for ecological goods and services. Natural resources planners therefore need to have at their disposal tools that can objectively help in prioritizing land use allocation.

Land use suitability is a kind of analysis that is used to determine the most suitable tract of land for establishing new land uses, usually among multiple, competing uses (Steiner et al. 2000; Collins et al. 2001; Marull et al. 2007). This analysis depends on multi-criteria evaluation of the concerned land for land development and/or environmental planning purposes. Riveira and Maseda (2006) described two phases of land use planning modeling; land evaluation and Land use allocation. Land evaluation is the suitability of the land for the uses considered, whereas land use allocation is decided according to the results of the land evaluation phase. Land evaluation and Land use allocation overlap and integrate for the site selection phase of the land use planning model. The analysis then groups specific areas of lands in the terms of their suitability for a defined use.

Tele:
E-mail addresses: jafarzadeh82@yahoo.com

Land use suitability analysis has passed through different stages in the history of the development of methodology and theory. Collins et al. (2001) distinguished five stages of land use analysis development. Stage 1: early hand-drawn, sieve mapping; Stage 2: advancement in the literature; Stage 3: computer-assisted overlay mapping; Stage 4: redefinition of spatial data and multi-criteria evaluation; and Stage 5: replicating expert knowledge in the process (current state).

With the rapid development of Geographic Information Systems (GIS) techniques, GIS is now playing a major role in spatial decision making for Land use suitability analysis. One of the most useful applications of GIS for planning and management is the Land use suitability mapping and analysis (McHarg 1969; Hopkins 1977; Brail and Klosterman 2001; Collins et al. 2001; Malczewski 2004). Remote Sensing (RS) also plays an important role in providing the various spatial informations required for the suitability analysis. The integration of GIS and RS is a powerful tool in saving time, yielding good data quality and efficient presentation of results. When land use planning analysis becomes more complex due to the multipurpose of the planning and seeking a balance between development needs and environmental restrictions, the 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 land use planning analysis.

This study aims to investigate the potentials of Mehran County, a extend area near the Ilam province, for implementation of Afforestation.

Materials and methods

Case study area

The studied area was Mehran County, which is located in the Southern Ilam province of Iran (Figure 1). This area has an area of 30.446 ha and is situated in the western part of Iran. Elevations range from 50 to 1000 meters above sea level.

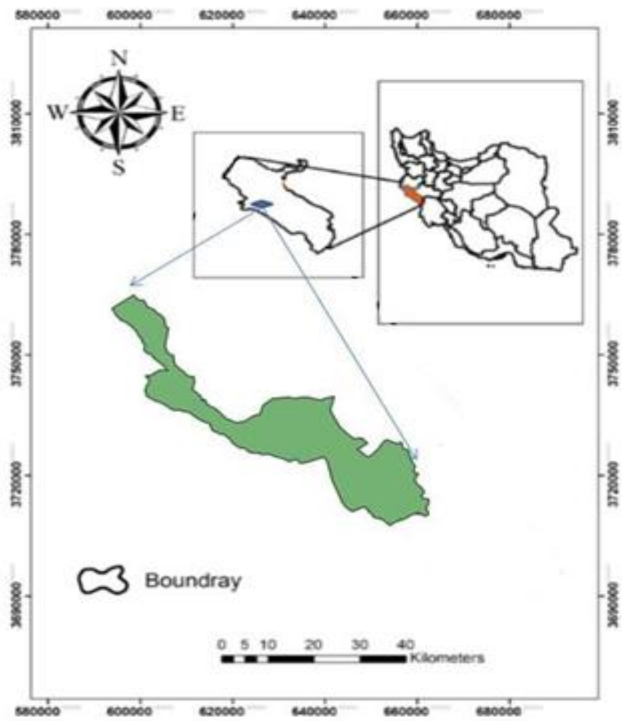

Figure 1. The location of Case study in Mehran, Ilam and Iran

Mehran County contains some of the most important human habitations in the South Ilam province and Agriculture is one of the main sources of income for the population. The agriculture is dependent on groundwater and on managed surface runoff water resources are critical sources of water for this region. The average annual temperatures range from 22 to 26 $^{\circ}$C and the average annual precipitation for the studied area amounts to 290 mm, most of which occurs in April and May. The studied area is characterized by different types of soil and topography that makes it suitable for a variety of land uses and different types of rural production.

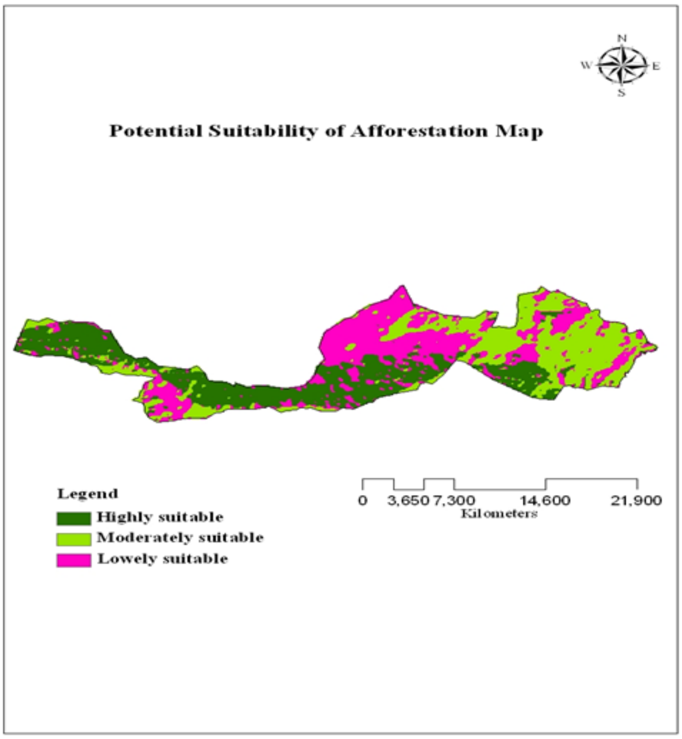

Figure 2. Land suitability map of Afforestation

Methodology

The GIS- based land suitability analysis using AHP (Joerin et al. 2001) approach as the multi-criteria decision analysis (MCDA) was used in this research study. It allows integrated GIS-based land suitability modeling for site suitability (Mendoza 1997). It is a logically ordered procedure that works by breaking down a problem into its smaller and smaller elements which helps decision makers all the way (Saaty 1980). The AHP is a systematic method to guide decision-makers in making decisions to solve the problems based on priorities (Miller 1998). However, AHP manages the several criteria/factors of a problem into a hierarchy related to a tree form arrangement. The goal level is the uppermost level, which defines the problem. The second level is the level of criteria/factors comprising afforestation land suitability. The third level consists of various sub-criteria/parameters. The application of AHP process involves the following steps (Elaalem et al. 2011):

- Criteria or factors contributing to the set of suitable are identified;

- Determine the relative importance of each factor to each other factor, i.e. between pairs of criteria. This is usually done by domain and experts' opinions;

- The consistency of the overall set of pairwise comparisons is assessed using its Consistency Ratio (CR).

Selection of evaluation criteria

Evaluation criteria objectives and attributes need to be identified with respect to the particular situation under consideration. The set of criteria selected should adequately represent the decision-making environment and contribute towards the final goal (Prakash 2003). ‘‘Land suitability assessment is a multiple criteria evaluation process. The attributes of land suitability criteria are to be derived from spatial and non-spatial, qualitative and quantitative information under diverse conditions’’ (Chen et al. 2010a). In land suitability analysis, each evaluation criterion is represented by a separate map in which a ‘degree of suitability’ with respect to that particular criterion is ascribed to each unit of area (Sehgal 1996; Prakash 2003). These ‘degrees of suitability’ then need to be rated according to the relative importance of the contribution made by that particular criterion, towards achieving the ultimate objective. In this study, five main criteria, namely: topography, land cover, climate, soil properties and geology, were selected based on local expert knowledge. Next, eight causal factors (sub-criteria), including: elevation, slope, aspect, soil texture, land cover, isothermal, isometric and geology, were selected. The sub-criteria’s were chosen based on the five main criteria but also under consideration of literature inputs and data availability (Ayalew and Yamagishi 2005). In comparable studies, all five criteria are often used for susceptibility mapping (Ahamed et al. 2000; Prakash 2003; Malczewski 2004; Ranjbar 2007; Reshmidevi et al. 2009; Akmal Rahim et al. 2010; Chen et al. 2010a 2010b; Hossain and Das 2010; Jafari and Zaredar 2010; Jei 2010; Shahadat Hossain and Gopal Das 2010). The evaluation criteria and sub-criteria are listed in Table 1.

Data collection and preparation using GIS

Data preparation is the first fundamental step in land suitability analysis. Our methodology is based on GIS analysis. In our methodology, land suitability is evaluated by applying different GIS analytical techniques, including interpolation and overlay based on multi-criteria analysis and AHP. For this to happen, the following datasets were prepared:

- Digital topographical maps 1: 50000 are used to create DEM and derivate layers such as slope, aspect and hypsometry.
- Soil map 1:50000 are used to derive the soil texture.
- Land cover map through image classification techniques.
- Geology map 1:50000 are used to derive the geology map of study area.
- Meteorological data for a 30-year period (Iranian Meteorology Organization) were used to create climate maps including: isothermal and isometric.

After these spatial datasets were prepared, including all necessary geometric and thematic editing of the original datasets, a topology was created. All vector layers were then converted into raster format with 20 m resolution and the spatial datasets were processed in ArcGIS. Slope, aspect and hypsometry were generated from a 20 m resolution DEM which was derived from 1: 50000 topographical maps.

Standardization of criteria

The process of setting the relative importance of each criterion is known as the standardization of criteria (Prakash 2003). In this process scales of 0 to 1, 0 to 10 or 0 to 100 (etc.) are normally used for criteria standardization. A pairwise comparison technique is typically used for rating and standardizing the ordinal values (Malczewski 2004). This technique is an extension of the classic binary logic, with the possibility of defining sets without sharp boundaries and allowing for partial assignation of elements to a particular set. A fuzzy set is essentially a set whose members may have degrees of membership between 0 and 1, as opposed to a classic binary set in which each element must have either the value 0 or 1 as their membership degree (Malczewski 2004). In this particular land suitability analysis for northern Iran’ the criteria are represented by GIS dataset layers. These criteria at the lowest level, and the resulting memberships of different suitability classes, were subsequently standardized using the maximum Eigenvectors approach on a 0 to 1 scale.

Development of the pairwise comparison matrix

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 (Table 2). The AHP is the rational planning process in locating public facilities (Banai-Kashani 1989).

Computation of the pairwise comparison matrix

In our study of the implementation of the pairwise comparison matrix, experts’ opinions were asked to calculate the relative importance of the factors and criteria involved. The calculated pairwise comparison matrixes for afforestation suitability within the case study area are shown in Tables 3; in addition, the details of the weights used for the evaluation criteria are listed in Tables4.

The weights of factors and parameters were successfully calculated easily for land suitability 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. 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 2007). In our study, the resulting CR for the pairwise comparison matrix for afforestation suitability 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 land suitability evaluation model.

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 4. 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. This function multiplies and sums up the layers to produce suitability maps for afforestation which are presented in Fig. 4. Therefore, the weighted linear technique (Mendoza 1997; Mohit and Ali 2006) was applied to yield a suitability map by the following formula:

$$E = \sum_{i=1}^{n} wi * vi \qquad (1)$$

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 assess suitable land for afforestation development in Mehran County (Thapa and Murayama 2008). The derivation of relative composite weights of land suitability criteria and sub-criteria based on land suitable for afforestation was calculated as presented in Table 4.

Land suitability maps for afforestation (Figures 2) 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. The total resulting areas for afforestation reveal the importance of forest development in Mehran County, and the suitability of the terrain. The suitable map for afforestation (Figure 2) shows that 35.88% of the investigated area is highly suitable, 28.64% is moderately suitable and 35.46% is lowly suitable. Together, the two categories 'highly suitable' and 'moderately suitable' make up 49.33% of the total area.

This area is characterized by a suitably sloping and elevation topography, productive soils with good texture for seedling and the existing groundwater resources that are very important for irrigation.

Land suitability has been extracted by weighted overlay techniques based on MCDM using GIS methods, a process that has resulted in information being portrayed on a land suitability map. The results have clearly indicated in which areas in Mehran County the intensity of land use for afforestation should increase, decrease or remain unchanged. The respective areas indicated as being suitable for forest development within the case study area are shown in Table 5.

Discussion

Natural resources management is indispensable in ensuring environmental sustainability and reducing the risk associated with climate change and increasing demand for ecological goods and services. Natural resources planners need to have at their disposal tools that can objectively help in prioritizing land use allocation. Traditional application of land use change model based on economic model, trend analysis, and or scenario analysis present some challenges of data availability and reliability necessary for implementation of the models. However, with the advent of information technology, GIS and remote sensing, biophysical data known for having influence on land use allocation can easily be accessed. The current study explores the application of GIS-Multi-criteria analysis in modeling future land use scenarios for resources planning and management using easy to construct biophysical parameters known for influencing future land use allocation. The decision problems in this study are to find the best spatial allocation of land to future afforestation and forest development, which are considered to present critical land use change in the study area. The afforestation scenarios are meant to offset the pressure on the native forest resources due to the increased demand for fuel and timber and also to contribute to the environmental protection. According to the application of Land-use planning principles and with the use of GIS, finding the suitable places for afforestation and green area development was done in this region.

This study has focused the use of integrated multi-criteria AHP with GIS to determine the suitability of the land for afforestation in the County of Mehran. GIS-based AHP as MCDA in the land suitability analysis approach can be useful to determine suitable land. Therefore, this study presented the advantages of integrated GIS-based land suitability analysis and a solution for such complicated decisions. It can also provide an important guidance for future land use changes and cost effective solutions in the cities, where conditions are similar as in Iran.

GIS-based AHP as a multi-criteria evaluation approach was applied in the present study. The main advantage of this approach is that it can be done quickly utilizing the data processing and capabilities of GIS in the land use decision making process (Store and Kangas 2001). Therefore, the results of this study will be useful with GIS-based land suitability analysis modeling in land-use planning and development plans in the future. The development plans can be successful if this study methodology is included in the planning process.

In similar with various studies (Baskent and Keles 2005; Baskent et al. 2008; Kangas 2000), GIS provided valuable information for spatial forest management planning in adjacency, proximity and juxtaposition of patches. In addition to the refinement of compartment maps, GIS was also applied in managing and visualization of ecological data in different stages.

The AHP (Saaty 1990 and 2008) is a known and common multi attribute weighting method for decision (Forman and Ann-Selly 2002; Gonzalez et al. 2007; Tseng et al. 2008; Venkata 2007). AHP is a comprehensive, logical and structural framework, which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure. AHP allows the consistent comparison of both qualitative and quantitative criteria or alternatives, since different scales of input information are transformed to uni-dimensional priorities (Wolfslehner et al. 2005). Use of AHP for assigning the weights of relative importance to the objectives is relatively new (Venkata 2007). The use of AHP insures that the suitability maps are comparable for all land uses (Martins and Borges 2007). In this research, using AHP, consistent weight of all of criteria and sub- criteria for all land use, through pairwise comparison was evaluated, properly and confirmed result of previous studies in related with AHP. In addition, within AHP the criteria and sub-criteria influencing the ecological suitability of land uses were defined, properly and perfectly (Table 1). Although the AHP (Saaty 2008) method is widely accepted in solving multi criterion problems, the accuracy of the results depends on accuracy of spatial data. Moreover, the selection of land suitability assessment parameters, priority weights within the AHP framework are greatly influenced by objectives, location, maps, people involved in discussions and key informants. In this research, AHP in combination with RS and GIS were three major tools in a manner that reached the correct solution to assist the decision maker in determining appropriate values for the ecological suitability criteria. A CR<0.10 indicates a reasonable level of consistency among pairwise comparisons (Martins and Borges 2007). In this study, consistency ratio coefficients for the final weightings were fall in the acceptable range.

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

criteria	sub-criteria
Topography	Hypsometry Slope Aspect
Soil	Soil texture
Climate	isothermal Isometric
Land Cover	Land Cover
Geology	Type of

Table 2. Scales for pairwise AHP comparisons

Intensity of relative importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals of above non-zero numbers.	Values for inverse comparison

Table 3. AHP pairwise comparison matrix for afforestation

Land characteristics	Aspect	Slope	Type of geology	Hypsometry	Land Cover	isothermal	Soil Texture	Isometric
Aspect	1							
Slope	2	1						
Type of geo	4	3	1					
Hypsometry	5	4	3	1				
Land Cover	6	5	4	4	1			
isothermal	7	6	6	6	5	1		
Soil Texture	8	7	8	7	6	5	1	
Isometric	9	8	9	8	7	6	5	1

Table 4. The weights of the criteria for afforestation

Criteria	Aspect	Slope	Type of geology	Hypsometry	Land Cover	isothermal	Soil Texture	Isometric
Eigen values	0.063	0.077	0.102	0.140	0 .158	0.170	0.97	0. 315

Table 5. Resulting overall areas for different suitability classes

Land suitability class	Area (hectares)
Highly suitable	10.927
Moderately suitable	8.722
Lowly suitable	10.797
Total	30.446

According to autochthonous species and adaptive exotic species and their ecological demand suggest species for afforestation in suitable places that ecological demand of the suggested species is similar to ecology specifications of this suitable land that have capability for afforestation. Several species suggested for afforestation in suitable lands such as *Amygdalus arabica*, *Prosopis juliflora*, *Pistasia atlantica*, *Eucaliptus camaldulensis*, *Ziziphus spina- christi*, *Ziziphus numularia*, and *Myrtus communis.*

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