Land Evaluation and Ranking with Using an Incorporate Vision of Parametric Method and Analytic Hierarchy Process

Mohammad Mahdi mozaffari[1], Sona Azarneshan[2], Fereydoon Sarmadian[3], Amin Yazdani[4]

[1]. Assistant Professor, Department of Industrial Management, Imam Khomeini International University (IKIU), and Qazvin, Iran, E-mail: zafarnima@yahoo.com Tel: +98-912-1817133

[2]. Master of Science in Soil Science Engineering, Irrigation and Drainage department, Agricultural Engineering and Research Institute, Alborz, Iran, Email: Sona_azarneshan@yahoo.com

[3]. Associate Professor, Department of Soil Science Engineering, Faculty of Agricultural Engineering and Technology, College of Agriculture & Natural Resources, University of Tehran, Alborz, Iran, Email: Fsarmad@ut.ac.ir

[4]. Department of Industrial Management, Imam Khomeini International University (IKIU), Qazvin, Iran. Email: Amin.yazdani@yahoo.com

Abstract: Land use planning as a solution for many of present problems, emphasizes on land evaluation and possible land use types. Land suitability evaluation is a logical basic for making decisions to determine Land use types. The goal of this paper is presenting the combined methodology of parametric method and AHP to rank lands in general aspect. In this method first lands were evaluated by parametric methods and then AHP method was used for general ranking of lands. With using the combined methodology in shahriar, akhtarabad, results such: determining 17 land units and classifying them using second square method and then ranking lands with AHP method are catched, these results show that the land unit number 5 specified the best preference Of selection to itself and after that land units number 10 and 17 were in second rank And land unit number 6 was in third rank subsequently and …. And the last rank was belonged to land unit number 8. In this research the focus was on the physical aspect and proposed that this method extended in other aspects as environmental, social, economic and political factors.

[Mohammad Mahdi mozaffari, Sona Azarneshan, Fereydoon Sarmadian, Amin Yazdani. **Land Evaluation and Ranking with Using an Incorporate Vision of Parametric Method and Analytic Hierarchy Process.** *Life Sci J* 2012;9(3):1157-1164]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 161

Key words: land Suitability Class, Parametric Methods, Ranking, Analytic Hierarchy Process

1- Introduction

Indiscriminate exploitation of agricultural land and emphasizing the importance of land for human and the world by scientists have led to great attention to land resources (Drohan & Farnham, 2006). Also along with economic development, modification and conversion rate of agricultural land to non-agricultural land has increased over the last 20 years and the necessity for an approach to use land resources for agricultural products is being felt. This approach should be accompanied by determination of the appropriate land use (based on land resources) (Waithaka et. al, 2006). In fact, land suitability assessment estimates the land efficiency for specific uses that are determined in advance and provides a basis for making decisions about land use. Also, it estimates the predicted inputs and outputs. Land suitability deals with two major aspects of land: first, land's physical resources such as soil, topography, climate, etc., second, economic resources such as farm size, availability of labor, management level, marketing conditions, etc., and the amount of each aspect's interference in the study results depends on quality and/or quantity assessment method. Land quality assessment method has been used in this study. It should be noted that the assessment techniques determine the amount of land suitability based on each product and the product's type is considered in selecting the land.

Decision-making support systems have been making progress in recent years. Many practices have facilitated the decision process (Gomez-Ruiz et. al, 2010). Multi-criteria decision-making issues are a dynamic and complex process between two levels of management and engineering (Duckstein & Opricovic, 1980). The management's level determines goals and selects the final optimum option (Jahanshahloo et. al, 2006). One of the applicable decision-making practices is hierarchical analysis in which various options are compared based on a set of criteria and sub criteria and is classified in a hierarchical structure. At each level of hierarchy, the criteria are compared in pairs and their relative priority is achieved. The compatibility of paired comparison matrix is a related factor in the hierarchical analysis and the paired comparison matrix should be completed to calculate it (Gomez-Ruiz et. al, 2010).

The purpose of this study is to provide a compound approach of parametric techniques in land assessment and hierarchical analysis in order that the lands will be ranked and the preferences of land selection will be determined from a wide perspective. The study of ecological security and food supply on the one hand and research on the relationship between the land and the crop production on the other hand are matters of concern. Zhang et al have used Remote Sensing techniques in combination with Geographical Information System (Zhang et. al, 2005), in a research. Using this methodology and FAO manual in land assessment has increased the rate and accuracy of land suitability assessment (Zhang et. al, 2003; Chen et. al, 2002).

2- Literature review

Foley et al, (2005), studied land uses and emphasized that although modern land use practices have increased materials and goods supply in the short term, it may destroy ecosystems in the long term (Foley et.al, 2005). Thus, the land suitability assessment to determine optimal areas for food production and forest lands is essential. Appropriate solutions to solve complicated issues associated with the overuse of land resources for agricultural production and their management does not come from a single policy and designing an advanced technique to use land resources for agricultural productions appears to be essential. This technique should be accompanied by determination of appropriate land use (based on land resources) (Waithaka et. al, 2006).

After over 30 years of land assessment analysis, progress in the development of this method has been disappointing (Samranpong et. al, 2009). Johnson and Gramb stated that failure in predicting crops production and inability to reflect technological changes and economic climate are due to weakness in land assessment techniques (Johnson & Cramb, 1996). In addition, the systems are not able to provide information on production risk and price (which are crucial and important factors for farmers). For this purpose, product-centric models are used to forecast the production. In Thailand, rice models (Jintrawet, 1995), sugar beet models (Promrit & Jintrawet, 2001) and peanut models (Banterng et. al, 2004), have been used and therefore, the relationship between soil characteristics, climate and crop production should be carefully studied to predict crops production (Olson & Olson, 1986; De La Rosa et. al, 1981).

Mandal et al found relationships between cotton production and agricultural-environmental factors (e.g. soil's physiographic conditions, periods of growth, evaporation perspiration and rainfall) in their study. The FAO's soil quality indicator was used to obtain the amount of product in this study (Mandal et. al, 2005). Since most land units are not suitable for all types of land uses, the amount of land unit's suitability for various uses is specified using land assessment, and different suitability cases are determined (Rossiter, 1995).

Land assessment has several stages and it becomes more complex based on the different requirements of users. In local scale, land assessment is facilitated with GIS. Today, many decision-making systems have been developed for land assessment. Hierarchical analysis technique uses the experts' judgment as an input for criteria and solutions. Today, multi-criteria assessment methods are used to solve three-dimensional problems. Malczewski's method used the combination of Multi-Attribute Utility Theory and GIS (Geographical Information System) for three-dimensional expression of issue and set up a background for many studies (Strager & Rosenberger, 2006; Neaupane & Piantanakulchai, 2006; Ayalew et. al, 2005; Thirumalaivasan et. al, 2003; Tseng et. al 2001; Store & Kangas, 2001; Hoctor et. al, 2000).

Above-mentioned studies deal with different views of assessment. Anticipating areas which are exposed to the risk of contamination (due to agricultural activities) is an example of using Analytic Hierarchy Process (AHP), in three-dimensional problems. AHP calculates the weight of each criterion and the three-dimensional image of the optimal solution is shown by GIS software (Thirumalaivasan et. al, 2003). In another research, Ayalew et al predicted the risk of falling with the combination of Analytic network process (ANP) and logical regression (Ayalew et. al, 2005). Strager and Rosenberger studied the prioritization of land protection and used hierarchical analysis to combine the experts' judgment with the geographic display of soil loss (Strager & Rosenberger, 2006).

In Bahadur Thapa and Murayama's paper a combination method of hierarchical analysis and GIS for agriculture is presented (Rajesh & Yuji, 2008). Studying the suitability of olive plantation in natural areas of Spain is one of the researches which have used the combination of hierarchical analysis and GIS (Olexandr et. al, 2009). Regardless of the functional scope of these papers, all of them are a combination of GIS and hierarchical analysis.

3- Methodology

In this study, first land assessment has been done based on predominant products using parametric methods and then the land has been ranked to be selected from a wide perspective using analytical hierarchy analysis. Briefly, next part will discuss the above mentioned methods.

3-1- Analytical hierarchy process

Analytical hierarchy process is used in decision-making to rank options based on a huge goal. The basic idea of hierarchical analysis is to sort goals, standards and issues in a hierarchical structure and achieve two goals: obtaining a complete insight of main relationships in the issue and providing a comparison mechanism with the same method at each level (Saaty, 1990). Paired comparison matrices are used in hierarchical analysis to determine the preference in which the decision maker fills the high elements of the diameter using numerical quantity from comparing variables (equal, more, a bit more, much more, so much more, infinitely more). This comparison is converted to numerical quantities (1; 3; De La Rosa et. al, 1981; Duckstein & Opricovic, 1980; Gomez-Ruiz et. al, 2010) based on Likert scale and the numbers between these numerical quantities (2; Chen et. al, 2002; Drohan & Farnham, 2006; Foley et.al, 2005) are used to explain the preferences which lie between the numerical judgment. The elements of triangle below the diameter matrix are completed with reversed judgment values (the principal of mutuality) (Saaty, 1991). The weight of standards is calculated through paired comparison matrix and the specific vector of criteria weight is obtained. Then, paired comparison matrix is completed for options' levels and the main specific vector is calculated and normalized for each matrix. These normalized specific vectors are combined with paired comparison matrix of options and a column is created in a new matrix which is used to determine the final weight of each option. This particular normalized vector and the matrix are multiplied by paired matrix of standards and final ranking of options is obtained. Although the overall process implies algebraic calculations of simple matrix, the compatibility of matrix is notable. It is essential to make sure that the judgment of decision makers' is compatible in hierarchical analysis. There are different mathematical ways to measure the compatibility of paired comparison matrix. The compatibility index should be less than 0.1 (Gomez-Ruiz et. al, 2010), for determination of the compatibility of paired matrix.

3-2- Land assessment method

Defining various land productivity types and classifying land according to current and potential land suitability for a particular use is the first step in land assessment in FAO method. Qualitative land suitability assessment method consists of three studying phases as follows: 1- Gathering information about land characteristics 2- Determination of vegetative requirements of land productivity types 3- qualitative land suitability classification. In the third step, land qualities are compared with vegetative requirements of various land productivity types and finally land suitability class is determined using one of the limitation or parametric (Sys et. al, 1991), methods. In this study, land suitability classes are determined using parametric method.

Parametric method in land characteristics assessment includes numerical ranking of the different limitation levels of land characteristics in a numerical scale from maximum (usually 100) to minimum number. If land characteristics are optimum for productivity type, it will be attributed to the maximum number in rating (usually 100). However, if some of land characteristics are undesirable, they'll get less number. Then, the assigned grades will be used to calculate the land index. In this method, at first climate assessment is carried out. Climatic characteristics are divided into four groups: Radiation characteristics, Temperature characteristics, Precipitation characteristics and Air relative humidity. Climate index is calculated using rates of each group and is used in land assessment (Table 1) (Sys et. al, 1991).

Table 1; Climate index and classification relationship

Climate class	**Class index**	**amount of Limitation**	**Related degree**
S_1	75-100	No-low limitation	85-100
S2	50-75	Moderate limitation	60-85
S3	25-50	High limitation	40-60
N_1	12.5-25	Extremely High limitation (corrigible)	20-40
N_2	0-12.5	Extremely High limitation (Incorrigible)	0-20

Climate and land indexes are calculable with both Storie and Square Root Methods. In Storie method index is obtained using the formula below:

$$I = A \times \frac{B}{100} \times \frac{C}{100} \times \cdots$$

Where "I" is index and "A, B, C…" are specific rates for different characteristics.

In square root method the index is derived from the formula below:

$$I = R_{\min} \times \sqrt{\frac{A}{100}} \times \frac{B}{100} \times \cdots$$

Where “I” is index, “R_{min}” is the minimum rate and “A, B…” is Other rates which are allotted to different characteristics (except minimum rate).
Suitability classes are defined according to index's values in Table 2.

Table 2; The amount of indexes for various suitability classes (25)

Index	**Land Suitability class**
75-100	S_1 : (Very Suitable)
50-75	*S2* : (Moderately Suitable)
25-50	*S3* : (Marginally Suitable)
0-25	N : (unsuitable)

3-3- The research model and collecting data
The area which has been studied is 7110 ha wide and located in Akhtarabad (shahriar). The lowest point is at altitude of 1188 meters and the highest part is at altitude of 1340 meters. The purpose of this study is to promote optimum use of lands and process satellite images digitally. And, GIS are used to determine land suitability. During the field survey, 19 profiles have been drilled in the area and the different layers of soil profiles were sampled. Then, soil samples were tested both physically and chemically. Next, using RS, Digital elevation model (DEM) and other available maps of region and studying soil's tests results, soil units were separated and 17 land units were designated in the area. After that, vegetative requirements of productivity types were reviewed and matched with land characteristics. And finally, land suitability classes of each unit of lands were determined using FAO framework and Sys method for different uses. The results of above mentioned method were used as input to GIS software for a schematic display of the results of land assessment with parametric method (land maps). Also, they’re used as input for hierarchical analysis technique to rank land from a wide perspective. Figure 1 depicts the research model based on its stages.

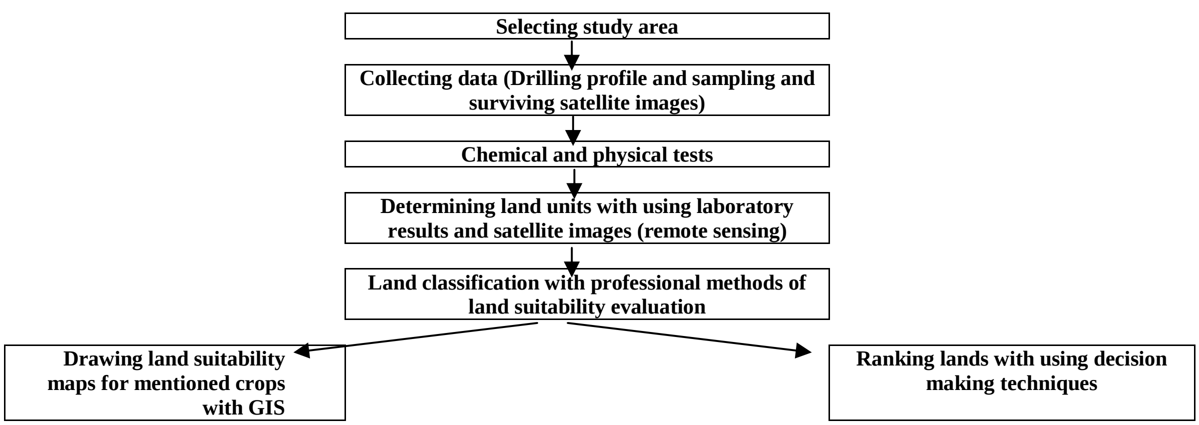

Figure -1 Research stage

4- Finding

4-1- Mapping and physical and chemical analysis of soil samples
After classification and interpretation of satellite images (LANDSAT ETM+), and combination of data from height digital elevation model (DEM), slope maps and soil maps of the area which has been studied, also reviewing the results of physical, chemical and fertility analysis of soil samples, soil unit map were prepared for the area. Soils in this area are placed in Aridisols category. The map of land units was drawn through overlapping slope map and soil unit’s map in the area.
following results were obtained through collecting and analyzing laboratory results, data from interpretation

of satellite images and climatic data and topography maps: 1-the mapping of slope, aspect and height layers of area in GIS 2- soil units and land units mapping 3- land suitability mapping for wheat, barley, canola, corn and cotton 4- ranking lands for cultivation of dominant products in area. The maps mentioned above are represented in Appendix III.

Land index and land suitability classes for one of the products (canola) are presented in Table-3 using both Storie and square root methods (product's land suitability maps and the results of parametric method for other products are given in Appendix I). Table 4 depicts land suitability classes for all products in research using square root method.

Table 3; Parametric methods for canola's data

Land unit	Storie	Suitability class	Square root	Suitability class	Land unit	Storie	Suitability class	Square root	Suitability class
1	26.76	S3	48.32	S3	11	50.74	S2	50.61	S2
2	25.78	S3	41.27	S3	12	27.88	S3	62.5	S2
3	25.8	S3	33.74	S3	13	26.41	S3	48.32	3S3
4	25.25	S3	28.49	S3	14	25.49	S3	30.52	S3
5	28.63	S3	65.1	S2	15	25.19	S3	59.7	S2
6	26.83	S3	52.66	S2	16	26.95	S3	53.99	S2
7	26.02	S3	40.22	S3	17	27.27	S3	49.8	S3
8	0.21	N2	0.81	N2	18	27.85	S3	62.8	S2
9	27.51	S3	58.14	S2					

Table 4; Matrix of land suitability classes based on the square root method

Land unit	wheat	Barley	Corn	Cotton	Canola
Unit 1	S2	S2	S2	S2	S3
Unit 2	S3	S3	S3	S2	S3
Unit 3	S3	S3	S3	S2	S3
Unit 4	S3	S2	S3	S3	S3
Unit 5	S2	S2	S2	S2	S2
Unit 6	S2	S2	S2	S3	S2
Unit 7	S2	S3	S2	S2	S3
Unit 8	N2	N2	N2	N2	N2
Unit 9	S2	S3	S3	S2	S2
Unit 10	S2	S2	S2	S2	S2
Unit 11	S3	S2	S2	S2	S2
Unit 12	S2	S2	S2	S2	S3
Unit 13	S3	S3	S3	S3	S3
Unit 14	S2	S2	S2	S3	S2
Unit 15	S3	S2	S2	S2	S2
Unit 16	S2	S3	S3	S3	S3
Unit 17	S2	S2	S2	S2	S2

4-2- Ranking land suitability classes using hierarchical decision-making method

Considering what mentioned previously, hierarchical tree is made as figure-2 so that crops are criteria and options are land divisions which are obtained through agricultural specialized techniques. Regarding the qualitative assessment of lands and the lack of social and economic factors, in this structure the same preference will be considered for different products. On the other hand, based on land classification with parametric method and using Likert, priority grades are assigned to classes. For example, there are two land units: A and B. If these two units have the same class, the priority grade of units compared with each other will be 1. And, if A is one class different from

B, the priority grade of A compared with B will be 3. If the difference is two classes, the priority grade of A compared with B will be 5. And, if there is three classes' difference, the priority grade will be 7. Finally, if it reaches four classes' differences, the priority grade will be 9.

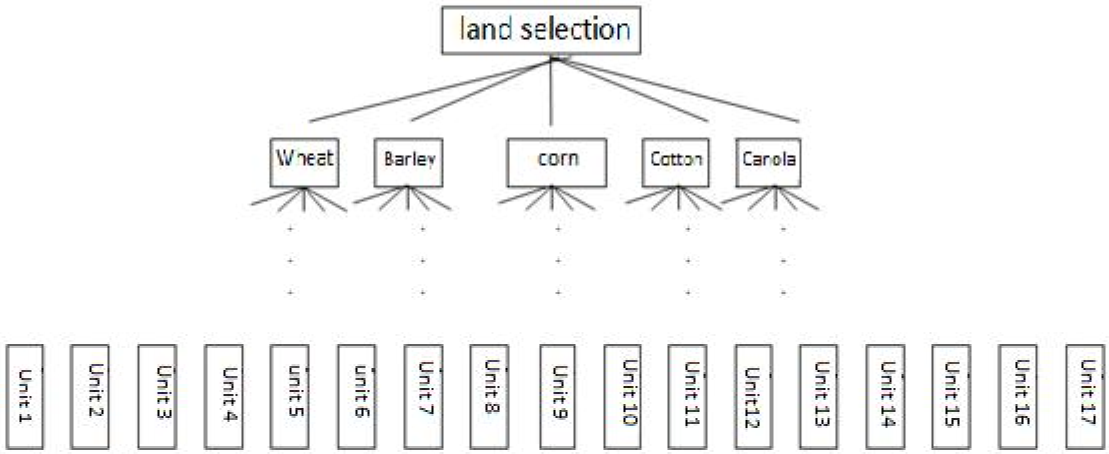

Figure 2; AHP Tree for Selecting Lands

In these modes, the preference of B land unit to A land unit will be 1, 1.3, 1.5, 1.7, 1.9 respectively. The method that has been used in forming paired comparison matrices will adjust all of matrices and the amount of their adjustment will be complete. Products are of equal weight in decision tree due to a lack of social and economic factors, so it is no need to form a paired comparison matrices and weight of each of them is 0.2. Tables of the lands paired comparison matrices are represented in Appendix II based on the criteria. Then, land selection preferences are identified using EXCEL software (Table 5).

Table 5; Ranking lands with hierarchical method

Final weight	**Lands ranking**	**Land unit**
0.0707259	**6**	**1**
0.0407683	**10**	**2**
0.0407683	**10**	**3**
0.0394987	**11**	**4**
0.0826423	**1**	**5**
0.0725989	**3**	**6**
0.0619521	**9**	**7**
0.0099980	**14**	**8**
0.0629787	**8**	**9**
0.0823444	**2**	**10**
0.0717525	**5**	**11**
0.0704281	**7**	**12**
0.0276709	**13**	**13**
0.0723010	**4**	**14**
0.0717525	**5**	**15**
0.0394751	**12**	**16**
0.0823444	**2**	**17**

5- Discussion and conclusion

Making decision is a dynamic process that involves two levels of management and engineering and is used for the best options selection among those that are possible. In these issues, many criteria affect options selection ((Duckstein & Opricovic, 1980)). There are combination practices of decision-making methods. Hierarchical analysis method calculates the weight of each criterion. Then, GIS software displays three-dimensional picture of optimal solution (Thirumalaivasan et. al, 2003).

Unlike this study, the output of parametric method is input for GIS - in this research- to draw the maps mentioned above. And, it is also input for hierarchical analysis method. Ayalew et al also predicted the risk of falling using combination of ANP and logical regression (Ayalew et. al, 2005). AHP is also used in this research to rank agricultural land's selection and is a different use of decision-making techniques and farming professional methods. Strager and Rosenberger emphasized on determination of the priority of areas for land conservation and used group hierarchical analysis (Strager & Rosenberger, 2006). However, AHP is used for determination of the priority of land selection in this study. Regardless of type of product, providing a solution for decision makers to select lands with maximum potential in productivity is the main advantage of this paper. The study in this paper is a new combination of two fields: agriculture and resource management that shows which land unit is preferred to be invested in.

This paper can help decision makers with management level. And, using decision-making methods ranks designated land suitability classes for different crops in engineering level from a wide perspective targeting the best land selection for cultivation. And, it defines the part of land that is more desirable for various crops.

Accordingly, best rank is assigned to the 5th land unit and this land unit is the first option for cultivating various crops. After that, 10th and 17th land units are known the best and the 6th land unit comes third …, so that the lowest rank is assigned to the 8th land unit (considering special outputs for all of the crops, this land unit has N_2 suitability class). Finally, using this method decision-making at high-level management is facilitated and this methodology will link professional knowledge and management level.

Land assessment from both physical and economical perspective is recommended for future studies. Because in this paper only physical aspect is considered and other influential items such as environmental and social factors and also economic and political cases are not involved. On the other hand, according to environmental changes Fuzzy view is recommended to cover the facts in issue better.

Reference

Ayalew L., Yamagishi H., Marui H., Kanno T. 2005. Landslides in Sado Island of Japan: Part II. GIS-based susceptibility mapping with comparisons of results from two methods and verifications. Engineering Geology, 81: 432–445

Bahadur Thapa Rajesh., Murayama Yuji. 2008. Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic nformation system techniques: A case study of Hanoi , Land Use Policy, 25:225–239

Banterng P., Patanothai A., Pannangpetch K., Jogloy S., Hoogenboom G. 2004. Determination and valuation of genetic coefficients of peanut lines for breeding applications, European Journal of Agronomy, 21:297–310

Chen S.L., Liu Q., Yu S. and Lin Z. L. 2002. The evaluation of land resource suitability in Jin'an district of Fuzhou supported by GIS, Geo-Information Science (in Chinese), 4(1): 16–65

De La Rosa D., Cardona F., Almorza J. 1981. Crop yield predictions based on properties of soils in Sevilla, Spain. Geoderma 25:267–274

Drohan P.J, and Farnham T.J. 2006. Protecting life's foundation: A proposal for recognizing rare and threatened soils, Soil Sci, Soc. Am. J. 70(6): 2 086–2 096

Duckstein L., Opricovic S., 1980. Multiobjective optimization in river basin development, Water Resources Research,16 (1) .14–20.

Foley J.A., DeFries A., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N. and Snyder P.K. 2005. Global consequences of land use, Science, 309: 570–574

Gomez-Ruiz Jose Antonio., Karanik Marcelo., Pelez José Ignacio. 2010. Estimation of missing judgments in AHP pairwise matrices using a neural network-based model , Applied Mathematics and Computation, 216:2959–2975

Hoctor T.S., Carr M.H., Zwick P. 2000. Identifying a linked reserve system using a regional landscape approach: the Florida Ecological Network,Conservation Biology, 14 (4):984–1000

Jahanshahloo G.R., Hosseinzadeh Lotfi F., Izadikhah M. 2006. An algorithmic method to extend TOPSIS for decision-making problems with interval data, Applied Mathematics and Computation, 175:1375–1384

Jintrawet A. 1995. A decision support system for rapid assessment of lowland ricebased cropping alternatives in Thailand, Agricultural Systems, 47:245–258

Johnson A.K.L., Cramb R.A. 1996. Integrated land evaluation to generate risk-efficient land-use options in a coastal catchment, Agricultural Systems, 50:287–305

Mandal D.K., Mandal C., Venugopalan M.V. 2005. Suitability of cotton cultivation in shrink-swell soils in central India, Agricultural Systems, 84:55–75

Neaupane K.M., Piantanakulchai M. 2006. Analytic network process model for landslide hazard zonation, Engineering Geology, 85:281–294.

Nekhaya Olexandr., Arriazaa Manuel., Guzmán-Álvarez José Ramón.2009. Spatial analysis of the suitability of olive plantations for wildlife habitat restoration, computers and electronics in agriculture, 6 5:49–64

Olson K.R., Olson G.W.1986. Use of multiple regression analysis to estimate average corn yields using selected soils and climatic data, Agricultural Systems, 20:105–120

Promrit S., Jintrawet A. 2001. A sugarcane flowering model, Thai Journal of Agricultural Science, 34:111–122

10

Rossiter D.G. 1995. Economic land evaluation: why and how, Soil Use & Management, 11:132–140

Saaty T.L. 1990. How to make a decision – the analytic hierarchy process, European Journal of Operational Research, 48:(1) 9–26.

Saaty T.L. 1991. Some mathematical concepts of the Analytic Hierarchy Process, Behaviormetrika, 29 :1–9.

Samranpong Chalermpol., Ekasingh Benchaphun., Ekasingh Methi. 2009. Economic land evaluation for agricultural resource management in Northern Thailand, Environmental Modelling & Software, 24:1381–1390

Store R., Kangas J. 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitatsuitability modeling, Landscape and Urban Planning, 55:79–93.

Strager M.P., Rosenberger R.S. 2006. Incorporating stakeholder preferences for land conservation: Weights and measures in spatial MCA, Ecological Economics, 57:(4), 627–639

Sys C.,van Ranst E., & Debaveye. J. 1991. Land evaluation, part 2:Methods in land evaluation.Agricultural publications, General administration for development cooperation, Brussels

Thirumalaivasan D., Karmegam M., Venugopal K. 2003. AHP-Drastic: software for specific aquifer vulnerability assessment using DRASTIC model and GIS, Environmental Modelling and Software, 18:(4), 645–656

Tseng C.T., Chen S.C., Huang C.S., Liu C.C. 2001. GIS-assisted site selection for artificial reefs, Fisheries Science, 67:1015–1022

Waithaka M.M., Thornton P.K., Herrero M., Shepherd K.D. 2006. Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya, Agricultural Systems, 90: 243–271

Zhang H., Zhang G. L., Qi Z. P. and Zhao Y. G. 2003. Systematic assessment of soil quality at farm level in tropical area of China. Acta Pedologica Sinica (in Chinese). 40(2): 186–193

Zhang Q., Fang H.L., Huang Y. Z., Zhao, X.Y. and Xi, Y.W. 2005. Application of soil CEC to evaluation of soil quality in Shanghai, Soils, (in Chinese) 37:(6): 679–682

9/23/2012