GEOSPATIAL DECISION SUPPORT SYSTEM FOR HUMAN-CENTRED SUSTAINABLE DEVELOPMENT

Novaline Jacob [a], Satyajit Rakshit, PVSP Prasada Raju, Saibaba J, Krishnan R [b]

Advanced Data Processing Research Institute (ADRIN)
Department of Space, Government of India
203, Akbar Road, Tarbund, Manovikasnagar Post
Secunderabad – 500 009. INDIA
[a] email : novalinejacob@yahoo.co.in
[b] email : krishnan@adrin.res.in

KEY WORDS : Fuzzy logic, linear programming, on-line decision support, agriculture development plan, What if Scenarios

ABSTRACT

A sustainable rural development program, apart from bringing access to spatial information on various themes, should also enable the participants to get query based online decision support. Value-added information needed for a sustainable rural development program, like agriculture development plans, water resource development plans etc., would become accessible not directly from satellite data, but are obtained by integrating primary data layers like land use, soil, rainfall etc, with decision-maker's expert knowledge through analytical modeling techniques. Socio-economic data is an important data that need to be included for any value-added information generation. There is an urgent need to develop a suitable technique which can handle all kinds of data both qualitative and quantitative thematic data, socioeconomic data and also incorporate experts knowledge. And there is a growing demand for completely automating the decision-making process. The present paper deals with a framework developed for Village Resource Center which, can not only be used as a paradigm for thinking about this complex spatial-socio-economic phenomena but can be used as an experimental laboratory for testing ideas and generating "What if" scenarios.

1.0 INTRODUCTION

Today Indian Space Technology has the state-of-art space infrastructure providing end-to-end capability in the field of Earth Observation and Communication. Comprehensive databases on detailed scales extracted from high resolution satellite imageries such as land use, soil, drainage network, canal, road network, can be generated for community centric spatial information query.

A sustainable rural development program, apart from bringing access to spatial information on various themes, should also enable the participants to get query based online decision support. Value-added information needed for a sustainable rural development program, like agriculture development plans, water resource development plans etc., would become accessible not directly from satellite data, but are obtained by integrating primary data layers like land use, soil, rainfall etc, with decision-maker's expert knowledge through analytical modeling techniques. Socio-economic data is an important data that need to be included for any value-added information generation if the scientific efforts put in the field of

- Data collection
(remote sensing, meteorological data etc)
- Information / decision generation
(through modeling)

has to reach Grass-Root level, where the society will be benefited in a Human-Centered Sustainable Development program. Inherent problems in using these non-spatial socio-economic data with spatial natural resource data are not unknown.

There is an urgent need to develop a suitable technique which can handle all kinds of data both qualitative and quantitative thematic data, socioeconomic data and also incorporate experts knowledge. And there is a growing demand for completely automating the decision-making process. There are several instances of generation of value-added information through interactive means by experts. When such development plans have to be generated for another village/area experts need to interact again for suggesting alternate crop etc. The vision of Village Resource Center (VRC) project launched by ISRO is to connect huge number of villages with online decision support facility. It would be an extremely difficult task if the generation of agriculture development plans has to be generated interactively. Since human mind could conceive only limited data at a time, we are not able to use all the quantitative data like soil pH, soil depth, salinity, water depth etc, which is otherwise available for generating land and water resource action plans.

The present paper deals with a framework developed for Village Resource Center which, can not only be used as a paradigm for thinking about this complex spatial-socio-economic phenomena but can be used as an experimental laboratory for testing ideas and generating "What if" scenarios.

1.1 Overview

A rural sustainable development program would aim at optimum land use development, which leads to economic growth, satisfying basic needs and ecological balance.

i) Maximizing the productivity of the land, which would in turn maximize the income at all levels.
ii) Striving towards a greater multiplicity in use of the resources on a sustainable basis.
iii) Ensuring the conservation of valuable ecosystem, giving due considerations to socio-economic factors.

Thus in a rational sustainable land use, if intensive cereal farming involving the use of pesticides as well as chemicals such as nitrate/phosphate is polluting groundwater then, de-intensification or alternative crops must be introduced. Scientific approach which makes use of analytical modeling techniques are essential to suggest suitable changes in land use and reduce the damage to the environment. So the computer based application, as a tool, must be made as efficient, easy to use and as effective as possible.

The present study aims at developing a generic automated methodology for addressing Multi-Objective Multi-Criteria Decision-Making problems. Scientific approach which make use of analytical modeling techniques are essential to suggest suitable changes in land use and to generate action plan for an area for land and water resource development. Conventionally, it is done by a team of scientists from multiple disciplines, who study the natural and logical association of thematic classes. This is a tedious process. For example, if two resource themes are to be studied and each resource theme in turn has five classes, then theoretically there are 25 ways the classes can be associated. And for each association a recommendation or prescription for land resource development like agro-forestry, silvipasture, agro-horticulture, fuel & fodder wood plantation, etc. are suggested. This problem can be cast into a multi-objective multi-criteria decision-making problem.

It is multi-objective in the sense one has to perform site suitability analysis for multiple objectives, which include agro-forestry, silvipasture, etc. Multiple criteria like land use, slope, soil, landform, groundwater prospects, etc, are involved in analyzing each objective. Similarly for generation of water resource action plan one has to perform site suitability analysis for check dam, percolation tank, stop dam, gully plug etc. Though the same problem can be broken into several single objective multi criteria decision-making problem, the procedure is going to be tedious.

Combination of Analytical Hierarchy Process and Compromise Programming techniques worked well in solving Single Objective Multi-Criteria problems like Site Selection for Water Harvesting Structure, Landslide Hazard Zonation (Novaline et al. 2001, Prasada et al. 2001, Prasada et al. 2002). But such a combination cannot be effectively used for solving Multi-Objective Multi-Criteria problems. Though the Multi-Objective Multi-Criteria Decision-Making problem can be broken into several single objective multi criteria decision making problem, solving this problem by applying combination of Analytical Hierarchy Process and Compromise Programming techniques is not going to be straight forward and effective. Moreover only absolute suitability within an objective can be addressed using MCDM techniques. In Multi-Objective Multi-Criteria Decision-Making problems, what is needed is the relative suitability for different objectives. In the present study we propose a Fuzzy classification approach in GIS for solving Multi-Objective Multi-Criteria Decision-Making problem

1.2 Literature Review

Progress in computing sciences, including Geographical Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) can help planners handle this complexity. Senes and Toccolini (1998) combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Hall et al. (1992) and Wang (1994) also use map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone. These classification techniques can be based on boolean and fuzzy theory (Hall et al. 1992) or artificial neural networks (Wang 1994). Recent developments in GIS have drawn upon concepts of fuzzy set theory and multi criteria methodology. Reza (1993) provides an example of a GIS application to show how the Analytical Hierarchy Process (AHP) can deal operationally with fuzziness, factor diversity and complexity in problems of land evaluation. Another is the attention given to the use of methods of multi-criteria evaluation in the GIS context (for example, Janssen and Reitveld 1990). Florent et al (2001) have used an outranking multi-criteria analysis method called ELECTRE-TRI for land-use suitability assessment involving heterogeneous criteria, which are measured on various scales. Combining GIS and MCDA is also a powerful approach to land suitability assessments. GIS enable computation of the criteria while a MCDA can be used to group them into a suitability index. Following a similar approach, Eastman et al. (1993) produced a land suitability map of an industry near Kathmandu using IDRISI (a raster GIS) and AHP (Analytical Hierarchy Process) (Saaty 1987). Jose & Lucien (1993) have used MCDA and raster GIS to evaluate a habitat for endangered species. Some other papers have focused on the technical aspects of combining GIS and MCDA (Jankowski 1995, Laaribi et al. 1996). Jankowski et al. (2001) have addressed a map-centered exploratory approach to multiple criteria spatial decision making, wherein maps becomes a visual index through which the user orders decision options, assigns priorities to decision criteria, and augments the criterion outcome space by map-derived heuristic knowledge. Jan (2002) addresses some of the aspects of decision-making and describes some of the approaches used for solving multi criteria single objective problems and multi criteria multi objective problems.

2.0 LAND RESOURCE DEVELOPMENT FRAMEWORK FOR COMMUNITY-CENTRIC PLANNING

Computer based application, as a tool, can be made available, where a farmer can see the alternate / optimum crop practice, he could adopt for his land.

Socio-economic data plays a vital role if the suggested alternate crop has to be practiced by the farmer. An alternate land resource action plan without considering socio-economic conditions of the farmer will turn to be futile as the farmer will not accept and practice it. It would be ideal to suggest an optimal crop, which is also sustainable, instead of an alternate crop by incorporating the socio-economic conditions like the finance available, labor available, water available etc.

Generation of Land resource action plan for community-centric planning is being cast as a multi-objective multi-criteria decision-making problem and addressed adopting Fuzzy Logic method. Since today databases can be made available at detailed scale and inclusion of socio-economic data becomes essential in the planning process, instead of getting an alternate cropping pattern, optimal cropping pattern can be generated adopting Optimization technique.

The objectives of this research work include:

1. Automatic generation of alternate land resource development plan using Fuzzy Logic approach.
2. Optimal land resource development plan generation by involving socio-economic data, using Linear Programming approach.

2.1 Alternate land resource development plan

Fuzzy land suitability analysis was performed to determine the best alternate land use by taking into consideration the terrain related parameters like the soil texture, drainage conditions, pH, $Cac0_3$ content, organic carbon, slope etc. Using these data layers and based on the decision rules, the model outputs land resource development plans. It is also possible to use the stored fuzzy membership grades for database queries like,
- Find the second most suitable crop for a particular area
- List all the areas that are suitable for both Paddy and Pulses and find the suitability value
- List all the areas that are suitable for Paddy or Pulses and find the suitability value.

2.1.1 Fuzzy Classification in GIS :A fuzzy suitability rating method has been developed in this research. Compared with the conventional approaches, this method provides more information about land suitability. This approach not only solves a multi-objective multi-criteria decision-making problem, but also overcomes the information loss seen in classical set theory-based decision-making (Novaline et al., 1997).

The task of rating land suitability is to classify areas into land use classes according to their land characteristics. By representing areas as vectors in a feature space, one can use the distance between feature vector corresponding to an area and a land use class as a measure of their similarity. The similarity indicates the extent to which the area belongs to the land use class. To measure the similarity, we define a representative vector for each land use class and view the distance between an area vector and the representative vector as the distance between the vector and the class.
If,
C_i = Representative Pattern Vector of Class i
i = land use class
$C_i = (C_{i1}, C_{i2}, C_{i3}, \ldots C_{in})$
n = No. of physiographical characteristics / parameters
A = Area Vector

A generalized family of distance metrics, dependent on the exponent p, for estimating the distance between Area Vector & Class pattern vector can be expressed as (Zeleny 1982, pp. 317) **:**

$$d_E(A,C_i) = \left(\beta_j^p \left[\sum_{j=1}^{n} (C_{ij} - A_j)^p \right] \right)^{1/p} \quad (1)$$

Where β_j is the weight assigned to the parameter j and p ranges from 1 to α.

In Conventional Classification,

$A \varepsilon C_i$, if $d_E(A,C_i)$ < distance to all other land use classes / Objectives.

This decision rule defines sharp decision surfaces between classes such that a vector can be classified into a single class and the classification implies a full membership in that class. Such a method is referred to as a hard partition of feature space. The method developed in this research is characterized by a fuzzy partition of feature space.

The fuzzy classification method enables one to rate an area's suitability by comprehensively taking into consideration all its characteristics and all the land cover classes. An area can be classified into the most similar land cover class. However, the classical set theory-based decision-making leads to serious information loss. This can be explained by taking two areas as examples. In determining their suitability for a given crop, the distances from the vector of the first area to the four classes are 0.50, 0.40, 0.10 and 0.00 respectively. The distances from the vector of the second area to the classes are 0.90, 0.10, 0.00 and 0.00. According to conventional classification, both areas should be classified into class 1. But, clearly the first area is much less suitable for the crop than the second area. The information contained in the distances is discarded when the area's memberships are determined. To make fuller use of the information, a fuzzy partition of feature space can be used. This method helps to suggest first best crop/land use, second best crop/land use and so on for the same area.

In a fuzzy partition, the classes are defined as fuzzy sets. An area can be associated with partial membership and belong to different classes to different extents. A fuzzy set is characterized by its membership function. We define membership function f_c for land use class c as,

In Fuzzy Classification,

$$f_{ci}(A) = d_E(A,C_i) / \sum_{i=1}^{m} d_E(A,C_i) \quad (2)$$

$f_{ci}(A)$ – Membership function f_c for land use class C_i
m – no. of classes
$\sum_{i=1}^{m} d_E(A,C_i)$ serves as a normalizing factor.

For a given area, membership functions are defined for each land use class. By calculating the functions, each area will have membership grades to all the land use classes, indicating the extent to which this area belongs to each of the land use class.
In case, the physiographical characteristics of an area are equal to those of the representative vector of suitability class C, that is

$$d_E(A,C_i)= 0,$$

the membership grade of the area in class C is defined as 1 and the grades in other classes as 0s. This implies that this area can be exactly categorized into class C.

Steps Involved:
Step 1: Normalize the Area values and Pattern Vector values for each class
Step 2: Compute the distance between Pattern Vector and Area Vector
Step 3: Convert the distances into Partial Membership functions

2.2 Dynamic Modeling Environment involving socio-economic data for generating optimum land resource development plan using Linear Programming model

Identification of optimal crop that maximizes productivity with sustainability, balancing the depletion and replenishment of land and water resources, ecology, etc. can be cast as a Linear Programming (LP) problem. The main objective is to maximize productivity and at the same time conserving the environment for sustainable use. This objective is constrained by limited resources and constraints that are ecological, technical or financial in nature.

Land suitability analysis for various crops has to be analyzed in GIS using following parameters: soil, slope, ground water & surface water prospects, water quality, elevation, rainfall, etc. So the coefficient values for the objective function and constraint values on the right-hand-side of the constraint equations would be obtained by performing land suitability and preliminary analysis in GIS. Optimal proportion of area for land use transformations after satisfying the constraints is obtained from LP. LP does not provide a spatial representation for the suggested land use allocations. It would only say how much hectares of each land use should be changed, but would have no indication on which specific hectares should be altered. LP results have been mapped in GIS using criteria of spatial suitability by adopting Multi Criteria Decision Making methods.

Objective: To improve the land resource action plan by incorporating socio-economic data adopting Linear programming technique.

Objective Function:

Maximize profit or
Maximize the employment opportunity or
Minimize water use

Constraints :

- Labor cost
- Cultivation cost
- Water use
- Technical : Land suitability for recommended crop
- Self use requirement (minimum area for each crop)
- Market Price

3.0 HOW THE APPLICATION WILL WORK IN TOTALITY?

Socio-economic conditions like the labor availability, finance availability, etc, can be given as input and an optimum crop, satisfying the socio-economic and technical (land-related) constraints for the area under study can be found out. As the application requires GIS software, Linear Programming tool kits, one can log on to a centralized hub, where the model, the decision rules and the data lie and run the model locally at VRCs by changing the inputs related to socio-economic factors, water availability conditions etc (figure 1).

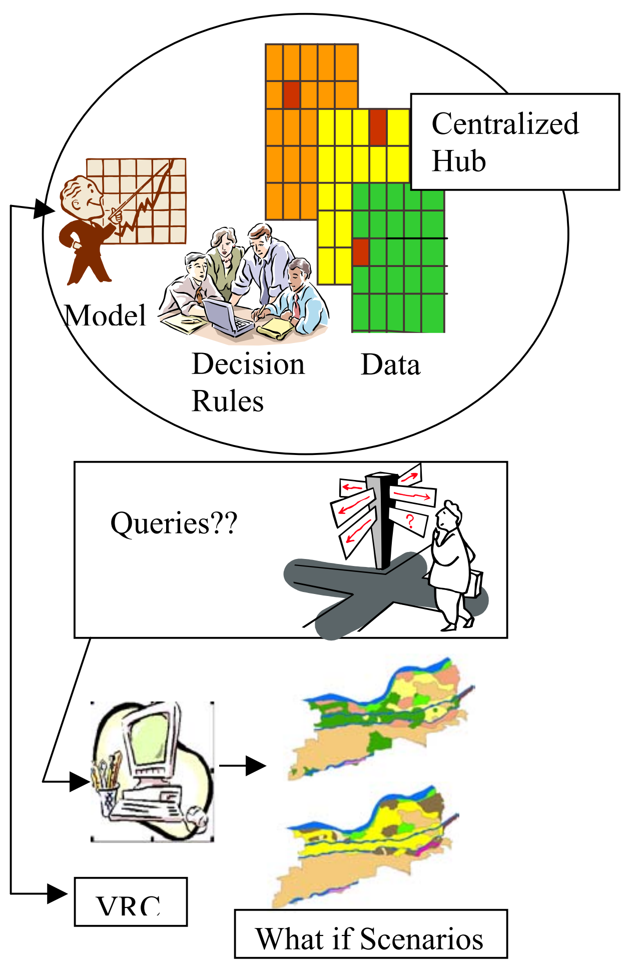

Figure 1. Village Resource Center (VRC) Framework

4.0 WHAT IF SCENARIOS

The implemented framework does not stop with giving a single optimum solution. One can generate several alternatives (figure 2) by choosing the objective function according to his need,

- maximize profit or
- maximize employment opportunity or
- minimize water use

and also by changing the constraint functions,

- labor cost,
- cultivation cost,
- water requirement,
- market price etc.

The framework developed for VRC can not only be used as a paradigm for thinking about this complex spatial-socio-economic phenomena but can be used as an experimental laboratory for testing ideas and generating "What if" scenarios.

5.0 CONCLUSION

A Dynamic Modeling Environment has been created by involving socio-economic data for generating optimum agriculture development plan. Computer based application, as a tool, is made available at VRC, where a farmer can see the alternate / optimum crop practice he could adopt for his land.

The developed online decision support tool "VIVASAI" – **V**RC's **I**ntegrated **V**alue **A**dded **S**upport from **A**DR**I**N, has been installed at the proposed centralized facility (MSSRF, Chennai) in the state of TamilNadu and is being made operational at the VRC at Thiruvaiyaru village. It is built on Client-Server architecture with Visual Basic as front end, and Graphic User Interface in English and in local language. The same framework can be extended to cater to the VRCs planned throughout the country.

Crop suitability criteria can be defined for five ecosystems , namely

1) Irrigated ecosystem – eg. Thiruvaiyaru
2) Rainfed ecosystem
3) Coastal ecosystem
4) Arid ecosystem
5) Hills & mountains

The developed model can use the appropriate criterion for these ecosystems and provide the results. The algorithm and the methods remain the same. Thus the present model developed will cater to the VRCs planned through out the country. The same model can be used to generate water resource development plans also (Novaline et al, 2001). Apart from suggesting optimum cropping pattern, animal husbandry, poultry etc, can also be included in the present framework when criteria for them become available, so that we address a total farming system**.**

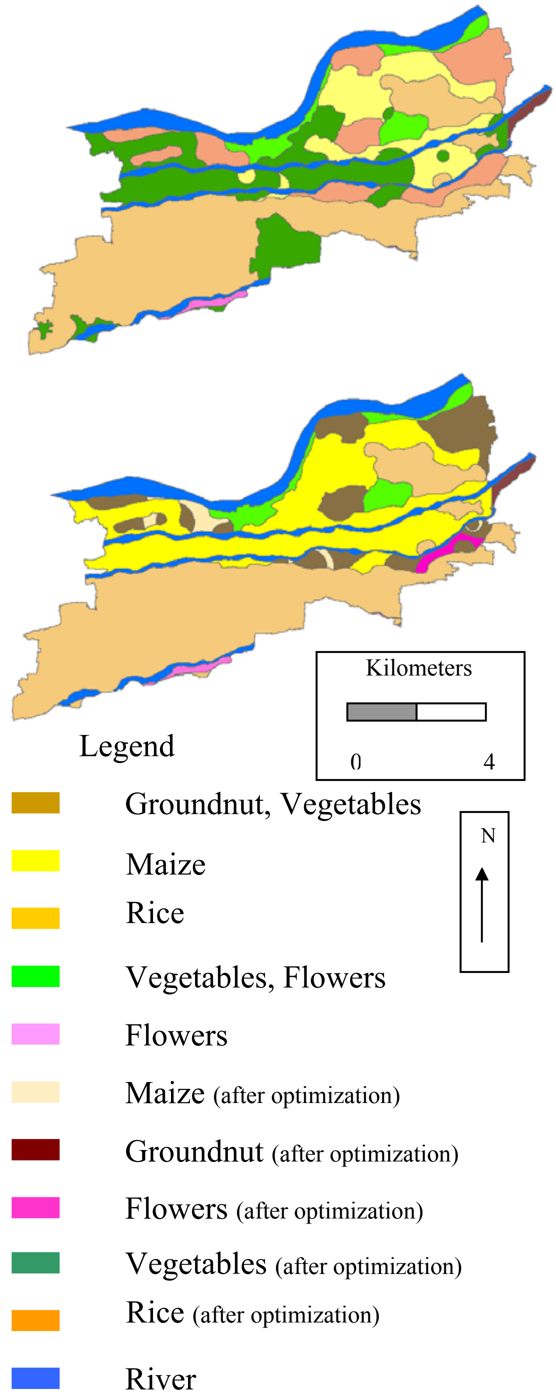

Figure 2. Kharif first best crops optimized for maximum employment (above) and minimum water use (below)

REFERENCES

Eastman, J.R., Kyem, P.A.K., and Toledano, J., 1993, A procedure for multiobjective decision making in GIS under conditions of conflicting objectives. In Proceedings of European Conference on Geographical Information Systems, EGIS'93 (Utrecht: EGIS Foundation), pp. 438-448.

Florent, J., Marius, T., and Andre, M., 2001, Using GIS and outranking multicriteria analysis for land-use suitability assessment. International Journal of Geographical Information Science, Vol. 15, No. 2, 153-174.

Hall, G.B., Wang, F., and Subaryono, 1992, Comparison of Boolean and fuzzy classification methods in land suitability analysis by using geographical information systems. Environment and Planning A, 24, 497-516.

Jan, H., 2002, Geographical Decision Making – Different approaches in IDRISI. http://www.husdal.com/mscgis/gdm.htm.

Jankowski, P., 1995, Integrating geographical information systems and multiple criteria decision-making methods. International Journal of Geographical Information Systems, 9, 251-273.

Janssen, R., and Rietveld, P., 1990, Multicriteria analysis and GIS: an application to agricultural land use in The Netherlands. In Geographical Systems and Regional Planning, edited by H.J. Scholten and J.C. Stilwell (Dordrecht : Kluwer).

Jose, M.C.P., & Lucien, D., 1993, A Multiple Criteria Decision-Making approach to GIS-based Land Suitability Evaluation. International Journal of Geographic Information Systems, Vol. 7, No. 5, 407 – 424.

Laaribi, A., Chevallier, J.J., and Martel, J.M., 1996, A spatial decision aid: a multi criterion evaluation approach. Computers, Environment and Urban Systems, 20, 351-366.

Novaline Jacob & Saibaba J, 1997, GIS & Analytical Modelling technique for sustainable development. In Geographic Information System and Remote Sensing Applications, edited by I .V. Muralikrishna (Allied Publishers Ltd. : India), pp. 509 – 514.

Novaline Jacob, Saibaba J, Prasada Raju, Krishnan R and Subramanian S K, 2001, Site selection for water harvesting structure in watershed development using DecisionSpace. Proceedings of Geomatics – 2001 conference, Published by Indian Institute of Remote Sensing (2001), DehraDun, India, 45-49.

Prasada, R., Novaline, J., and Saibaba, J., 2001, DecisionSpace – A tool for modelling landslide hazards. Proceedings of the International Conference On Remote Sensing & GIS/GPS (ICORG-2001), Published by JNTU (2001), Hyderabad, India.

Prasada, R., Novaline, J., Saibaba, J., Rao, A.S., Das, B.K., Sujatha, G., 2002, DecisionSpace software for locating suitable water harvesting structures in parts of Alwar district, Rajasthan. Proceedings of the National conference on GIS application in micro level planning, Published by National Institute for Rural Development (2002), Hyderabad, India.

Reza, B., 1993, Fuzziness in Geographical Information Systems: Contributions from the Analytical Hierarchy Process, International Journal of Geographical Information Systems, 1993, Vol. 7, No. 4, 315-329.

Saaty, T.L., 1987, Rank generation, preservation, and reversal in the analytical hierarchy decision process. Decision Sciences, 18, 157-177.

Senes, G., and Toccolini, A., 1998, Sustainable land-use planning in protected rural areas in Italy. Landscape and Urban Planning, 41, 107-117.

Wang, F., 1994, The use of artificial neural networks in a geographical information system for agricultural land-suitability assessment. Environment and Planning A, 26, 265-284.

Zeleny, M., 1982, Multiple Criteria Decision Making. New York : Mc Graw – Hill).