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On Fuzzy Cluster Modeling in the Analysis of Land Suitability for Crop Cultivation

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Abstract:- Fuzzy clustering is a data analysis technique that, when applied to a set of heterogeneous items, identifies homogenous subgroups as defined by a given model or measure of similarity in fuzzy environment. Moreover, fuzzy clustering methodology has been developed and used in variety of areas like biology, computer science, engineering, medicine etc. In this paper, fuzzy cluster model is developed to analyze the land suitability based on the nutrients requirements of various agricultural crops for cultivation. Finally, to demonstrate the model, an analytic technique for land suitability analysis is given in this paper.

Keywords: Fuzzy Set theory, fuzzy cluster analysis, land suitability analysis.

I. INTRODUCTION

Agriculture helps to meet the basic needs of human and their civilization by providing food, clothing, shelters, medicine and recreation. Hence, agriculture is the most important enterprise in the world. Agriculture can be defined as the systematic and controlled use of living organisms and the environment to improve the human condition. 'Agricultural Land' is the land base upon which agriculture is practiced. Typically occurring on farms, agricultural activities are undertaken upon agricultural land to produce agricultural products. Although agricultural land is primary required for the production of food for human land and animal consumption, agricultural activities also include the growing of plants for fibre and fuels, and for other organically derived products like pharmaceuticals, etc.

Physical, chemical and biological inputs are essential to agricultural systems, and are ultimately supplied by the soil, moisture, sun, plants, animal and biological agents. However, soil is placing an important role in agriculture. Not all agricultural land is capable or suitable for producing all agricultural products. The main limiting factors are climate and topography. Soils with all their variability are also key limiting factors. Depending upon their properties and characteristics they may be appropriate for sustaining the production of certain agricultural products.

Land suitability refers to the ability of a portion of land tolerate the production of crops in a sustainable way. The land suitability classification incorporates crop specific requirements to determine the suitability of the land for the cultivation of several crops. Making effective decisions regarding agricultural land suitability problems are vital to achieve optimum land productivity. The term 'land suitability evaluation' could be interpreted as the process of assessment of land performance when the land is used for specific crop.

Land suitability evaluation is one of the most important problem in agriculture. In many situations, the researchers in the field of agriculture are interested in an assessment of land suitability for cultivation. In 1976, the Food and Agriculture Organization (FAO) published 'A framework for land evaluation' that provides principles for the qualitative evaluation of the suitability of land for alternative uses based on biophysical, economic and social criteria **[5]**. Land suitability analysis under fuzzy environment has been studied by many authors. Fuzzy modeling of farmers' knowledge for land suitability classification was proposed by Scat et al **[11]**. Ali Keshavarzi and others **[1]** have made the case study in Ziaran Region for land suitability evaluation using fuzzy continuous classification technique. Fuzzy logic modeling for land suitability for hybrid poplar across the praine provinces of Canada was proposed by Joss **[6]**. Fang Qiu and others **[3]** has proposed a fuzzy model for land suitability and capability evaluation. Applicability of knowledge and fuzzy theory oriented approaches were proposed to land suitability for upland rice and rubber by Sanchez **[9]**. Mokarram and others **[7]** used fuzzy theory to land suitability evaluation for wheat cultivation in which the result has been compared with parametric method. Fuzzy indicators were applied for agricultural land suitability evaluation by Dmitry **[2]**. Mukhtar Elaalem and others **[8]** and Sarmadian **[10]** proposed fuzzy multi-criteria decision making approach for general land suitability analysis. Another alternative approach to modeling the land suitability analysis process utilizes fuzzy cluster analysis. This type of technique has been used for medical diagnosis by Fordon, Bezdek, Esogbue and Elder **[4]**. In this paper, the fuzzy cluster analysis is used to make the mathematical model for land suitability analysis process.

II. PRELIMINARIES

In this section, we introduce the basic concepts of fuzzy set and fuzzy relation, which are playing an important role in our proposed model for land suitability analysis.

Definition 2.1

Let X be a universal set. Then a fuzzy set 'A' on X is defined by its membership function

$$\mu_A : X \to [0,1] \qquad x \mapsto \mu_A(x) \in [0,1]$$

The value of $\mu_A(x)$ represents the grade of membership of x in X and it interpreted as the degree to which x belong to A.

A fuzzy set 'A' can be characterized as a set of ordered pairs of element and grade $\mu_A(x)$ and noted

$$A = \{(x, \mu_A(x))/x \in X\}$$

where each pair $(x, \mu_A(x))$ is called a singleton.

Definition 2.2

Let X and Y be universal sets then;

$$R = \{((x, y), \mu_R(x, y))/(x, y) \in X \times Y\}$$

is called a fuzzy relation in X × Y.

Fuzzy relations are often presented in the form of two dimensional tables. An m × n matrix represents a contented way of entering the fuzzy relation R.

$$R = \begin{array}{c} \\ x_1 \\ \cdots \\ \cdots \\ x_m \end{array} \begin{array}{c} \begin{array}{cccc} y_1 & \cdots\cdots & \cdots\cdots & y_m \end{array} \\ \begin{bmatrix} \mu_R(x_1, y_1) & \cdots\cdots & \cdots\cdots & \mu_R(x_1, y_n) \\ \cdots\cdots & \cdots\cdots & \cdots & \cdots\cdots \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \mu_R(x_m, y_1) & \cdots\cdots & \cdots\cdots & \mu_R(x_m, y_n) \end{bmatrix} \end{array} \quad \text{-----------------------------} \ (1)$$

A. Fuzzy Cluster Analysis

Clustering or cluster analysis involves the task of dividing data points into homogenous classes or clusters so that items in the same class are as similar as possible. Clustering can also be thought of as a form of data compression, where a large number of samples are converted into small representative prototypes or clusters. Depending on the data and the application, different types of similarity measures may be used to identify classes, where the similarity measure controls how the clusters are found. Some examples of values that can be used as similarity measure include distance, connectivity and intensity.

In non fuzzy clustering, data is divided into crisp clusters, where each data point belongs to exactly one cluster. In fuzzy clustering, the data point can belong to more than one cluster, and associated with each of the points are membership grades, which indicate the degree to which the data points belong to the different clusters. In real applications there is very often no sharp boundary between clusters so that fuzzy clustering is often better suited for the data. Membership degrees between 0 and 1 are used in fuzzy clustering instead of crisp assignments of the data to clusters.

III. MODEL FOR LAND SUITABILITY ANALYSIS USING FUZZY CLUSTER ANALYSIS

Model for Land suitability analysis that use cluster analysis usually perform a clustering algorithm on the set of lands by examining the similarity of the existence and level of nutrients exhibited by each. The level of nutrients present can be designated with degrees of membership in fuzzy sets representing each nutrient category. Often the similarity measure is computed between the nutrients level of the land in question and the nutrient level of land possessing the prototypical nutrient pattern for each possible crops. The land to be evaluated is then clustered to varying degrees with the prototypical lands whose nutrients are most similar. The most suitable lands are those crop clusters in which the land's degree of membership is the greatest. In this paper the Minkowski distance measure to determine the similarity between observed nutrients level and those present in existing indicative clusters.

IV. AN ANALYTIC TECHNIQUE FOR LAND SUITABILITY ANALYSIS

Proper nutrition is essential for satisfactory crop growth and production. The use of soil tests can help to determine the status of available nutrients to evaluate the suitability of land for various agricultural crops. There are at least seventeen elements are considered essential nutrients for plant growth, and 14 of these elements come from the soil. If there is a deficiency or superfluency of any essential nutrients in soil, plants growth and yield may be affected. So the land with suitable nutrient level has to be identified for cultivation of various crops.

In the pathology of type of lands, we consider the following set N of common Nutrients:

N = $\{n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9, n_{10}, n_{11}, n_{12}, n_{13}, n_{14}\}$

n_1 – Nitrogen (N)	n_2 – Phosphorous (P)	n_3 – Potassium (K)
n_4 – Sulphur (S)	n_5 – Calcium (Ca)	n_6 – Magnesium (Mg)
n_7 – Zinc (Zn)	n_8 – Copper (Cu)	n_9 – Iron (Fe)
n_{10} – Manganese (Mg)	n_{11} – Boron (B)	n_{12} – Chlorine (Cl)
n_{13} – Molybdenum (Mo)	n_{14} – Nickel (Ni)	

And also we consider the following set of crops C

C = $\{c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, c_9, c_{10}, c_{11}, c_{12}, c_{13}, c_{14}\}$

c_1 – Rice c_2 – Millets c_3 – Sugarcane c_4 – Groundnut c_5 – Tea c_6 – Cotton

Our aim is to determine the three stages related to land suitability analysis in which fuzzy concepts are inherent:
(i) The Nutrients level observed from the land
(ii) The agricultural knowledge
(iii) The crop assigned to the land

Let us assume that we are given a land L who has the nutrients $n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9, n_{10}, n_{11}, n_{12}, n_{13}, n_{14}$ at their levels given by the following vector:

$$\begin{array}{cc} & \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ L = & \begin{bmatrix} .8 & .9 & .6 & .3 & .7 & .4 & .5 & 0 & .2 & 0 & .5 & .1 & .6 & 0 \end{bmatrix} \end{array}$$

By the data collected from Soil and Water Management Research Institute, Kattuthottam, Thanjavur, Tamil Nadu, India.

Let $\mu_L(n_i) \in [0,1]$ denote the grade of membership in the fuzzy set charactering land L and defined on the set N = $\{n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9, n_{10}, n_{11}, n_{12}, n_{13}, n_{14}\}$ which indicates the level of nutrients in the land.
Each crop is described by a matrix giving the upper and lower bound of the normal range of the requirement of each of the fifteen nutrients.

The crops $c_1, c_2, c_3, c_4, c_5, c_6$ are described as follows:

$$\begin{array}{ccc} & & \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ c_1 = & \begin{array}{c} \text{lower} \\ \text{upper} \end{array} & \begin{bmatrix} .8 & .7 & .5 & .6 & .5 & .6 & .7 & .6 & .4 & .6 & .2 & .1 & .2 & 0 \\ 1 & .9 & .7 & .8 & .9 & .9 & .8 & .9 & .7 & .7 & .5 & .4 & .4 & .1 \end{bmatrix} \end{array}$$

$$\begin{array}{ccc} & & \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ c_2 = & \begin{array}{c} \text{lower} \\ \text{upper} \end{array} & \begin{bmatrix} .7 & .5 & .6 & .7 & .7 & .8 & .4 & .3 & .5 & .4 & .2 & .1 & .3 & 0 \\ .9 & .8 & .9 & .8 & 1 & 1 & .6 & .5 & .7 & .5 & .3 & .3 & .4 & .2 \end{bmatrix} \end{array}$$

$$c_3 = \begin{array}{c} \\ \text{lower} \\ \text{upper} \end{array} \begin{array}{c} \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ \begin{bmatrix} .8 & .5 & .6 & .7 & .6 & .4 & .7 & .6 & .5 & .5 & .6 & .2 & .3 & 0 \\ .9 & .7 & .8 & .9 & .9 & .7 & .8 & .9 & .6 & .8 & .8 & .5 & .5 & .2 \end{bmatrix} \end{array}$$

$$c_4 = \begin{array}{c} \\ \text{lower} \\ \text{upper} \end{array} \begin{array}{c} \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ \begin{bmatrix} .5 & .4 & .7 & .9 & .7 & .6 & .5 & .4 & .6 & .3 & .7 & .2 & 0 & .3 \\ .8 & .5 & .8 & 1 & .9 & .8 & .7 & .6 & .8 & .5 & .9 & .3 & .3 & .4 \end{bmatrix} \end{array}$$

$$c_5 = \begin{array}{c} \\ \text{lower} \\ \text{upper} \end{array} \begin{array}{c} \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ \begin{bmatrix} .9 & .7 & .8 & .6 & .5 & .7 & .6 & .6 & .7 & .3 & .4 & .6 & .2 & .1 \\ 1 & .9 & 1 & .8 & .7 & .8 & .9 & .8 & .9 & .6 & .5 & .9 & .4 & .3 \end{bmatrix} \end{array}$$

$$c_6 = \begin{array}{c} \\ \text{lower} \\ \text{upper} \end{array} \begin{array}{c} \begin{array}{cccccccccccccc} n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & n_9 & n_{10} & n_{11} & n_{12} & n_{13} & n_{14} \end{array} \\ \begin{bmatrix} .6 & .7 & .8 & .5 & .7 & .5 & .6 & .5 & .4 & .5 & .4 & .4 & .2 & 0 \\ 1 & .8 & 1 & .8 & .9 & .7 & .8 & .6 & .5 & .8 & .6 & .7 & .5 & .3 \end{bmatrix} \end{array}$$

Let $\mu_{c_j l}(n_i) \in [0,1]$ denote the lower bound of the nutrient i for crop j, and let $\mu_{c_j u}(n_i) \in [0,1]$ denote the upper bound of the nutrient i for crop j.

We define further a fuzzy relation W from N to C that specifies the pertinence or importance of nutrients in the growth and yield of the crop c.

The fuzzy relation W can be presented as

W =

	c_1	c_2	c_3	c_4	c_5	c_6
n_1	0.8	0.9	1.0	0.7	1.0	0.9
n_2	0.7	0.6	0.8	0.7	0.9	0.6
n_3	0.6	0.8	0.7	0.8	0.9	1.0
n_4	0.7	0.6	0.8	1.0	0.6	0.7
n_5	0.8	1.0	0.7	0.9	0.6	1.0
n_6	0.5	0.4	0.6	0.7	0.6	0.8
n_7	0.6	0.5	0.4	0.7	0.8	0.5
n_8	0.4	0.5	0.6	0.8	0.7	0.4
n_9	0.5	0.4	0.5	0.7	0.4	0.6
n_{10}	0.6	0.5	0.6	0.8	0.4	0.5
n_{11}	0.5	0.3	0.4	0.7	0.5	0.6
n_{12}	0.3	0.1	0.2	0.4	0.7	0.5
n_{13}	0.1	0.2	0.4	0.1	0.3	0.2
n_{14}	0.2	0.1	0.4	0.3	0.4	0.2

Let $\mu_W(n_i, c_j)$ denote the weight of nutrient n_i for crop c_j.

In order to find the suitability of land L for various crops, clustering technique is used to determine to which crop cluster (as specified by matrices c_1, c_2, c_3, c_4, c_5, c_6) the land is most suitable. This clustering is performed by computing a suitability measure between the lands nutrients and those typical of each crop c_j, j = 1, 2, …,6.

To compute this similarity, we use a distance measure based on the Minkowski distance that is appropriately modified; it is given by the formula.

$$D_p(c_j, L) = \left[\sum_{i \in A_j} \left| \mu_W(n_i, c_j)(\mu_{c_j l}(n_i) - \mu_L(n_i) \right|^p + \sum_{i \in B_j} \left| \mu_W(n_i, c_j)(\mu_{c_j u}(n_i) - \mu_L(n_i) \right|^p \right]^{1/p} \text{-------} \quad (2)$$

Where

$$A_j = \left\{ i \,\middle|\, \mu_L(n_i) < \mu_{c_j l}(n_i), 1 \le i \le m \right\}$$
$$B_j = \left\{ i \,\middle|\, \mu_L(n_i) < \mu_{c_j u}(n_i), 1 \le i \le m \right\}$$

Where m equals the total number of nutrients.

Suitability measure between the crop c_j and the land L is calculated using equation (2) with p = 2 (Euclidean distance). Moreover, the distance between the crop c_j and land L is as follows:

$D_2(c_1,L)$	$D_2(c_2, L)$	$D_2(c_3, L)$	$D_2(c_4, L)$	$D_2(c_5, L)$	$D_2(c_6, L)$
0.52	**0.34**	**0.62**	**0.86**	**0.69**	**0.46**

The most suitable crop is the one for which the suitability measure attains the minimum value. From the above data, the land's nutrients levels are most suitable to those typical of crop c_2.

$$\text{(i.e.) } \mathrm{Min}\{D_2(c_j,L)\}_{j=1,2,\ldots,6} = D_2(c_2,L) = 0.34$$

V. CONCLUSION

In this paper, the new mathematical model has been developed to analyze the land suitability for crop cultivation based on the nutrients requirement of various agricultural crops using fuzzy cluster analysis technique. Moreover, the model will be more useful to the farmers to select the suitable crops for their lands to achieve the optimum crop production.

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