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Application of Fuzzy Expert System to Determine the Degree of Sustainable Development of Mineral Resources

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Abstract: Sustainable development of mineral resources is the result of carefully integrating environmental, economical, and social needs to achieve both an increased living standard in the short term, and maintain the equilibrium of the natural resources to support future generations. The increasing demand of the mineral resources needs sustainable exploitation of these resources. But the worldwide accepted scale to measure the sustainability is not available with us. The objective of this paper is to develop a methodology to determine the degree of sustainable development of the mineral resources. The methodology is based on the fuzzy logic to make the quantification of the sustainable development. Though, there are number of parameters, on which sustainable development depends, we have considered only four major parameters like availability of mineral resources, economical development, societal development, and environmental protection, to evaluate the degree of sustainable development.

Key words: Degree, sustainable development, fuzzy logic.

Introduction

Sustainable development of mineral resources ensures the well-being of the human person by integrating social development, economical development, and environmental conservation and protection into all decision making; fostering intra-generational equity through the alleviation of poverty by concentrating the benefits of development in lesser developed areas; and considering the needs of future generations to ensure that inter-generational equity exists.

The non-renewable nature of mineral resources makes them gradually depleted over time. However, economy of many developing countries like India and particularly their mining cities heavily depends on mineral resources. Accordingly, it is crucial for a mining city to make sustainable use of its mineral resources. This requires evaluation of its ability of sustainable development of mineral resources. The evaluation theories and methods of sustainable development available with us is mainly focussed on evaluation of ability of sustainable development on a national or large regional scale (Bossel, 1999; UNDSD, 1999; Bond et al., 2001; UNDESA, 2001; Ronchi et al., 2002).

Research on sustainable development of resources and especially mineral resources is still in its infancy (Hilson et al., 2000; Zadeh, 1965). In the statistic sense most of the present evaluation indicators of mineral resources are either quantitative or static and are difficult to reflect the quality and trend of sustainable development of mineral resources. Economically they emphasize growth i.e. changes in quantity (e.g. gross, size and rate) and neglect development i.e. change in both quantity and quality (e.g. structural change and ability improvement). In a real evaluation of sustainable development of mineral resources, both quantity and quality are important. In this study we propose a concept of degree of sustainable development of mineral resources in the viewpoints of system science and sustainable development and construct a corresponding fuzzy expert system as an evaluation indicator. We attempt to integrate the factors of availability of mineral resources, economical development, societal development, and environmental protection to determine the degree of sustainable development of mineral resources on a regional basis.

Fuzzy Technique and Expert System

The basic concept underlying fuzzy logic (FL) is that of a linguistic variable, that is, a variable whose values are words rather than numbers. In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. The traditional two-valued logic has proved to be very effective and successful in solving well-defined problems, which are characterized by the precise description of the system being dealt within quantitative form.

Fuzzy set theory is a generalization of traditional set theory and provides a means for the representation of imprecision and vagueness. Zadeh (1965) further developed the corresponding fuzzy logic to manipulate the fuzzy sets. The calculus of fuzzy sets is a very promising tool for dealing with cognitive uncertainty. Since its introduction, fuzzy set theory has attracted the attention of many researchers in mathematical and engineering fields. During the past two decades, fuzzy logic has been successfully applied to many real world problems in various branches of science and engineering. It is a fact that most of the world's knowledge is uncertain and imprecise and hence the description of all real systems inherently contains incomplete and imprecise information. In order to deal with such situations, a fuzzy approach based on fuzzy sets (Zadeh, 1965) is considered to be the most appropriate. The main paradigm of fuzzy rule based system is the fuzzy algorithm (Zadeh, 1973), the essential concepts of which are derived from fuzzy logic. It is basically an expert knowledge-based system that contains the fuzzy algorithm in a simple rule base. The knowledge encoded in the rule base is derived from human experience and intuition. The rules represent the relationships between the inputs and outputs of a system. As depicted in Figure 1, a fuzzy rule based system is composed of four parts: fuzzifier, knowledge base, inference engine, and defuzzifier.

Fuzzifier converts real numbers of input into fuzzy sets and this process is called fuzzification. Let X be the universe of discourse and x is a generic element of X. A fuzzy set A in a universe of discourse X is characterised by a membership function $\mu_A(x)$ which takes values in the interval $I = [0, 1]$. If there is m fuzzy sets associated with a given input x, then fuzzifier would produce m fuzzy sets as $A_1(x), A_2(x) \ldots A_m(x)$ with m membership functions $\mu_{Ai}(x)$, $i = 1, 2 \ldots m$.

The knowledge base comprises a data base and a rule base. Membership functions of the fuzzy sets are contained in the data base. The rule base is a set of linguistic statements in the form of IF-THEN rules with antecedents and consequents, respectively, connected by AND operator. In general, a fuzzy rule based system with multi-inputs single-output (MISO) can be represented in the following manner:

$$R^{(i)}: \text{IF } X_1 \text{ is } B_1^{(i)} \text{ AND } X_2 \text{ is } B_2^{(i)} \text{ AND} \ldots \text{AND } X_n \text{ is } B_n^{(i)}$$

$$\text{THEN } Y_1 \text{ is } D_1^{(i)}, Y_2 \text{ is } D_2^{(i)} \ldots Y_p \text{ is } D_p^{(i)}$$

where $X_1, X_2 \ldots, X_n$ are the input linguistic variables and $Y_1, Y_2 \ldots Y_p$ are the output linguistic variables, $B_1^{(i)}, B_2^{(i)}, \ldots B_n^{(i)}$ and $D_1^{(i)}, D_2^{(i)}, \ldots D_p^{(i)}$ are linguistic values defined by fuzzy sets on $X_1, X_2 \ldots X_n$ and $Y_1, Y_2 \ldots Y_p$ respectively.

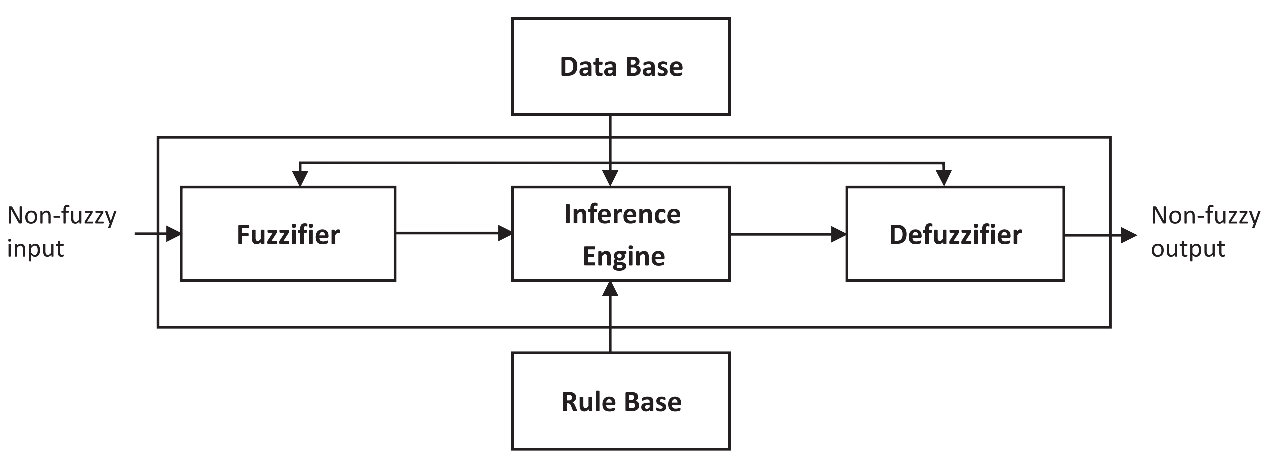

Figure 1: The structure of fuzzy expert system.

The inference engine is the kernel of a fuzzy rule based system, which employs IF-THEN rules from the rule base to infer the output by a fuzzy reasoning method (Yager, 1984). Fuzzy reasoning (also known as approximate reasoning) is an inference procedure used to derive conclusions from a set of fuzzy IF-THEN rules and from one or more given conditions (Jang et al., 1995). The basic operations of fuzzy reasoning are: (i) to compare the input variables; the membership functions on the premise part to obtain the membership values of each linguistic label, (ii) to combine the membership values on the premise part to get firing strength of each rule, (iii) to generate the qualified consequent (either fuzzy or crisp) of each rule depending on the firing strength, and (iv) to aggregate the qualified consequents to produce a crisp output.

The defuzzifier converts the fuzzy output obtained by inference engine into a non-fuzzy output real number domain and this process is called defuzzification.

Development Methodology

There is a very complex relationship between sustainable development with the dependent parameters (societal development, economic development, environmental protection and availability of mineral resources). The present model is a multi-inputs single-output (MISO) system. The present model shown in Figure 2 is one such system with societal development, economic development, environmental protection and availability of mineral resources as the input parameters and degree of sustainable development as the output. This relationship between inputs and output can mathematically be expressed as

$$V = f(U_1, U_2, U_3, U_4)$$

The methodology for the development of the fuzzy model involves the following steps.

Step I: Identification of the System's Variables

The first and most important step in modelling is the identification of system's input and output variables. The relationships between them will specify the objective of the model. The present model considers four input variables (economical development, societal development, environmental protection and availability of mineral resources) and one output variable (degree of sustainable development). Though the development of each input variables are measured on the basis of various subcomponents indicators, these will not be covered in this work.

Step II: Determination of the Ranges of Input and Output Variables

The second step is to determine the ranges of the input and output variables. These variables in fuzzy modelling are defined as linguistic variables whose linguistic values are words or sentences in a natural or synthetic language (Zadeh, 1994). Table 1 shows the linguistic variables, their linguistic values and associated fuzzy intervals. The fuzzy interval for each input variables is a normalised value range from 0 to 1, as there is no standard indicator to measure the individual variables development.

Step III: Selection of the Membership Functions for Various Inputs and Output Variables

The next step is to express linguistic values in the form of fuzzy sets, which are represented by its membership functions. The membership functions are constructed from several basic functions such as piecewise linear functions, the Gaussian distribution function, the sigmoid curve, quadratic and cubic polynomial curves. The

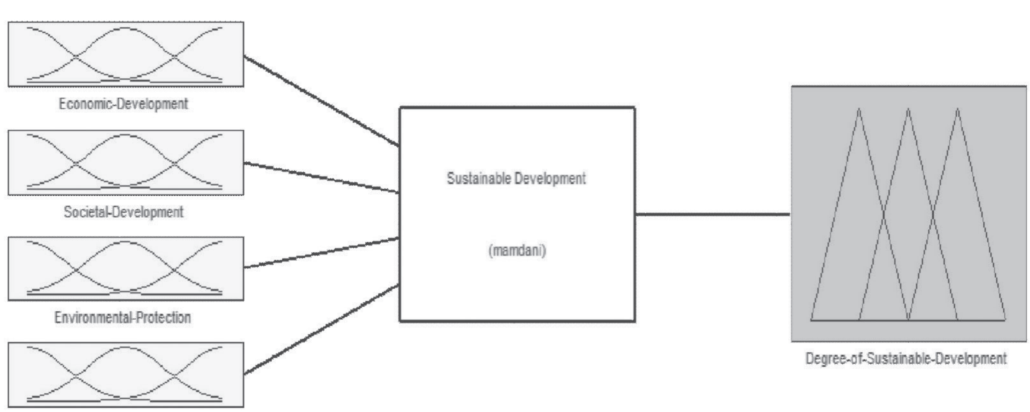

Figure 2: Input and output of the system.

Table 1: Inputs and output with their associated fuzzy values

Sl. No.	*System's variables*	*Linguistic variables*	*Linguistic values*	*Fuzzy intervals*
1	Inputs	Economical development	Low (L)	0–0.33
			Medium (M)	0.25–0.75
			High (H)	0.67–1.00
2		Societal development	Low (L)	0–0.33
			Medium (M)	0.25–0.75
			High (H)	0.67–1.00
3		Environmental protection	Poor	0–0.33
			Average	0.25–0.75
			Good	0.67–1.00
4		Availability of mineral resources	Low (L)	0–0.33
			Medium (M)	0.25–0.75
			High (H)	0.67–1.00
5	Output	Degree of sustainable development of mineral resources	Extremely small	0-0.125
			Very very small	0–0.250
			Very small	0.125–0.375
			Small	0.25–0.50
			Medium	0.375–0.625
			High	0.50–0.75
			Very high	0.625–0.875
			Very very high	0.75–1.00
			Extremely high	0.875–1.00

triangular membership function is the simplest one and is commonly used due to its computational efficiency. The membership functions for all inputs and output are shown in Figures 3a–e.

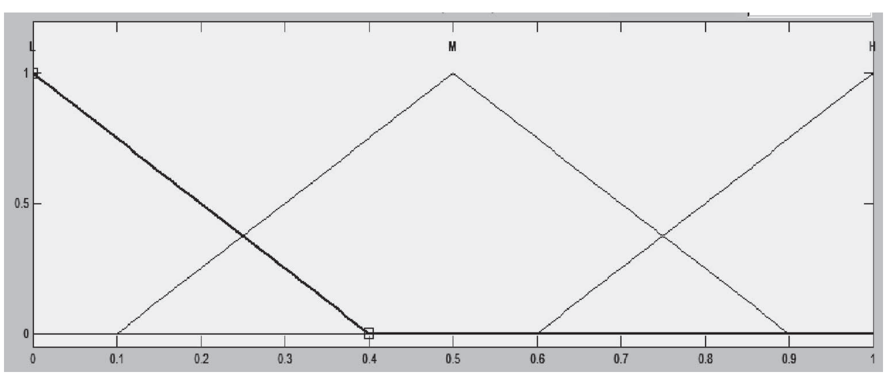

Figure 3a: Membership function for economic development.

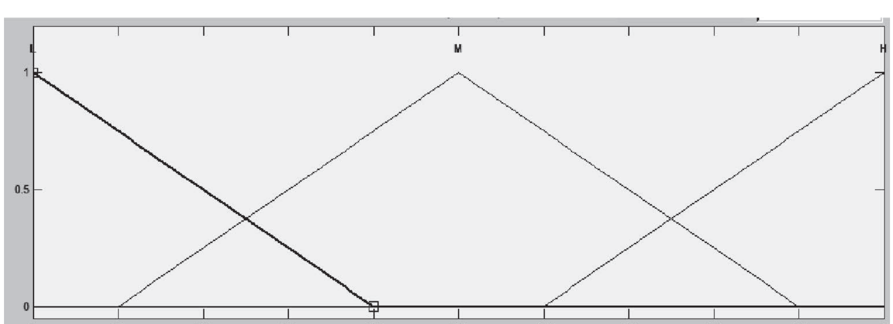

Figure 3b: Membership function for societal development.

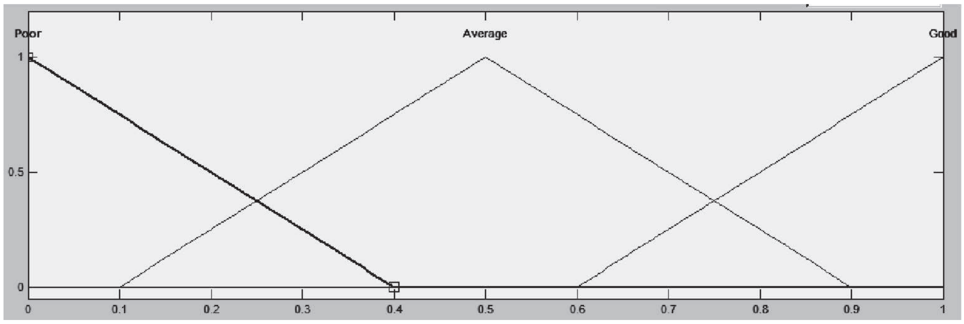

Figure 3c: Membership function for environmental protection.

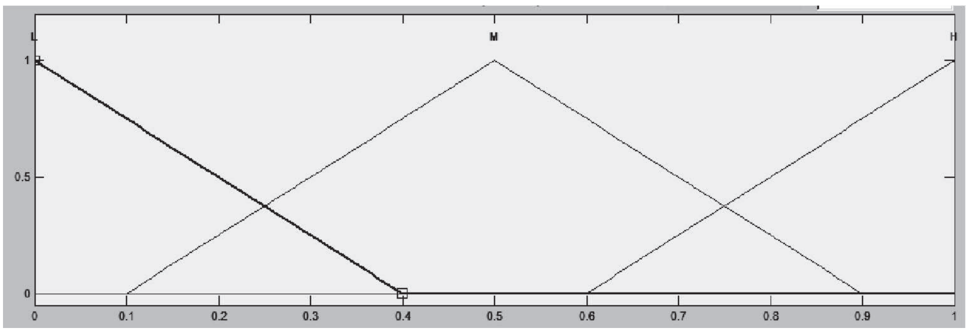

Figure 3d: Membership function for availability of mineral resources.

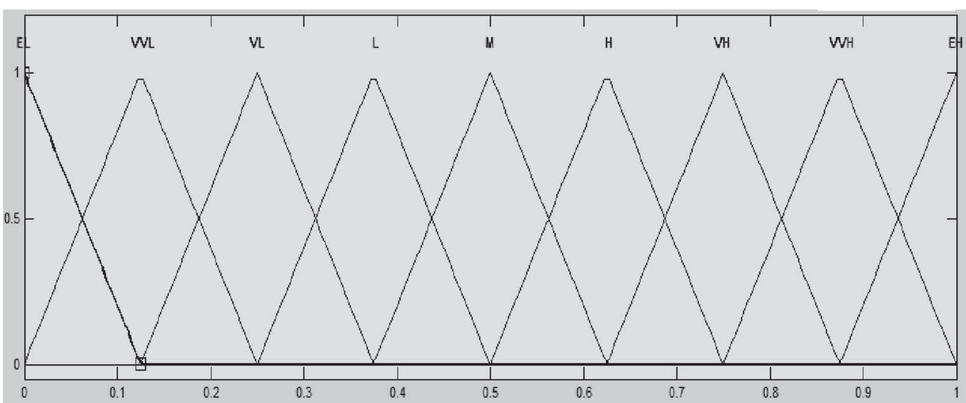

Figure 3e: Membership function for degree of sustainable development.

Step IV: Formation of the Set of Linguistic Rules
Finally, the relationships between inputs and output are represented in the form of IF-THEN rules. A set of rules for illustration purposes is shown in Table 2.

The model employs Mamdani inference method, wherein the membership functions of both the input and output variables are assumed to be fuzzy sets. The prediction model to determine the degree of sustainable

Table 2

Rule	*If E. D.*	*And S. D.*	*And E.C.*	*And A.M.R.*	*Then D.S.D.M.R*
1	H	H	H	H	EH
2	H	H	H	M	VVH
3	H	H	H	L	VH
4					
⋮					
79					
80	L	L	L	M	VVS
81	L	L	L	L	ES

development expressed in the form of simple IF-THEN rules has been implemented on Fuzzy Logic Toolbox of MATLAB, 6.1.

Results and Discussion

The graphical representation of the rule base is shown in Figure 4. The rule base indicates that probability of degree of sustainable development is 0.632 in a particular area, where economical development (ED), societal development (SD), environmental protection (EP) and availability of mineral resources are 0.753, 0.655, 0.530 and 0.661 respectively. Degree of sustainable development in the model has been computed as a function of economical development (ED), societal development (SD), environmental protection (EP) and availability of mineral resources. The model has been implemented using Mamdani inference techniques. The results are summarised in 3D plots in Figure 5. Figure 5 shows degree of sustainable development as a function of economical development (ED) and societal development (SD) as the input while the third (environmental protection) and fourth input (availability of mineral resources) is taken as the default value. The model clearly indicates that as either the economical development or societal development increases, the degree of sustainable development also increases. The model clearly indicates that maximum degree of sustainable development is found for maximum societal development and economical development. Similarly, the prediction model for degree of sustainable development with other combinations of inputs and associated default variables are same as the membership functions for all the variables are uniformly distributed.

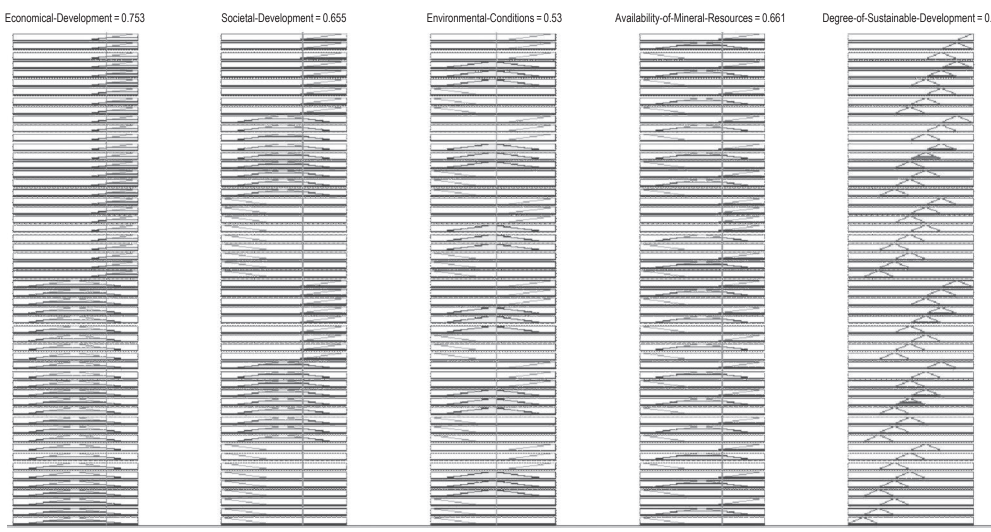

Figure 4: Rules and their graphical representation.

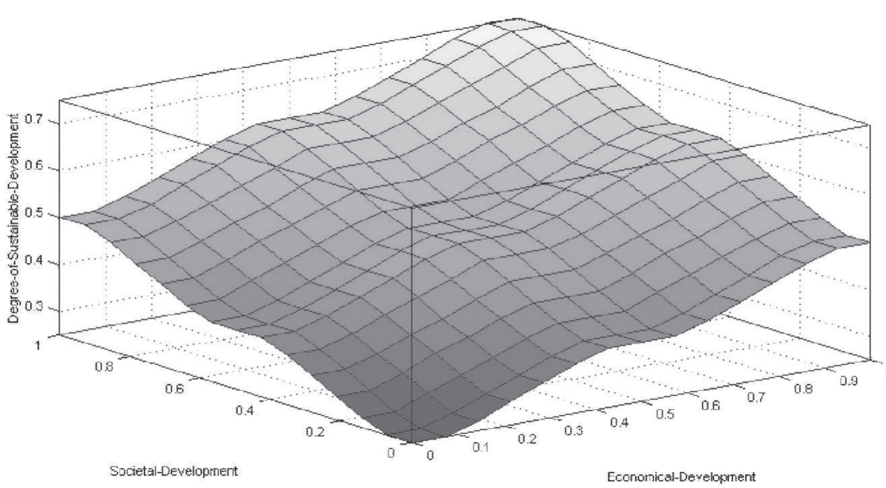

Figure 5: Output model for degree of sustainable development with societal development and economical development as the inputs.

Conclusion

The main thrust of this work has been to apply fuzzy techniques for the prediction of degree of sustainable development as a function of economical development (ED), societal development (SD), environmental protection (EP) and availability of mineral resources. The modelling technique is based on the concept of fuzzy logic, which offers a convenient way of representing the relationships between the inputs and outputs of a system in the form of IF-THEN rules. The model indicates that the degree of sustainable development increases for increasing any of the input variables.

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