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FUZZY COMPREHENSIVE EVALUATION MODEL OF ECOLOGICAL DEMONSTRATION AREA

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ABSTRACT: Ecological demonstration area (EDA) is an authorized nomination, which should be assessed from several aspects, including ecological, social, environmental, economic ones and so on. It is difficult to advance an exact developing level index of EDA due to its indicator system's complexity and disequilibrium. In this paper, a framework of indicators was set to evaluate, monitor and examine the comprehensive level of ecological demonstration area (EDA). Fuzzy logic method was used to develop the fuzzy comprehensive evaluation model (FCEM), which could quantitatively reveal the developing degree of EDA. Huiji District of Zhengzhou, Henan Province, one of the 9th group of national EDAs, was taken as a study case. The framework of FCEM for the integrated system included six subsystems, which were social, economic, ecological, rural, urban and accessorial description ones. The research would be valuable in the comprehensive quantitative evaluation of EDA and would work as a guide in the construction practices of Huiji ecological demonstration area.

KEY WORDS: fuzzy comprehensive evaluation model (FCEM); ecological demonstration area (EDA); fuzzy logic; system dynamics; Huiji District of Zhengzhou

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1 INTRODUCTION

Ecological demonstration area (EDA) is an authoritative nomination by National Environmental Protection Administration of China, which first began its experimental construction of EDA in 1995 and was promulgated "National Examination Standard of EDA" in 2001. By now, nine groups of experimental EDAs have been confirmed, which included more than 500 regions and districts. Among them 166 EDAs achieved the authoritative designation.

In order to direct the regional planning of EDA, it is necessary not only to evaluate the temperate development level but also to anticipate the intending directions (CHENG *et al*., 2004). Recently there are considerable papers focusing on the methodologies of evaluating regional development level. Various methods are utilized, including ecological footprint (GE *et al*., 2005), sustainable development records audit (NILSSON *et al*., 1998), integrated impact assessment (BOND *et al*., 2001), and so on. Meanwhile, some case studies of EDAs have been reported by Chinese researchers. LIANG *et al*. (2003) defined a notion of sustainable development degree and applied it to Baota District, Yan'an City of Shaanxi Province. ZHU (2001) built an indicator framework to measure Wuxian City's sustainability with four subsystems: economy, environment, population and resources. WANG and CHEN (1998) evaluated EDA on the basic theory of combined ecological system of society, economy and nature.

These above papers mainly focused on summing the past or current level of sustainability while they did not forecast the regional development direction. NIJKAMP and VREEKER (2000) endeavored to judge the sustainability level of Songkhla/Hat Yai area in the southern Thailand with qualitative information through several development scenarios. Obviously this method is weak in quantifying. ZONG *et al*. (2005) built a system dynamic model to predict the future level of Pengzhou City, Sichuan Province. But the paper is weak in expatiating and calculating comprehensive level of the target years.

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It seems indispensable to establish a comprehensive evaluation method for measuring regional sustainability (PICCIOTTO, 2003). The main objective of this study is to construct a comprehensive evaluation model with fuzzy method for quantitatively calculating EDA's sustainability, which is called fuzzy comprehensive evaluation model (FCEM). The model would be effective and applicable, not only for EDA, but also for other regional sustainability evaluation (YU *et al*., 2005). Besides, the model would put forward both the current and future level of regional development.

2 METHODS

2.1 Construction of FCEM

2.1.1 Conceptual schema of FCEM

The process of constructing FCEM should include several steps, such as conceptual regulation, real-world data identification, model operation, and result output (Fig. 1). Among the steps, there is a kind of brain storm by expert participation, when the experts discriminate and select indicators from multitudinous candidate ones. After brain storm process, the indicator framework is determined.

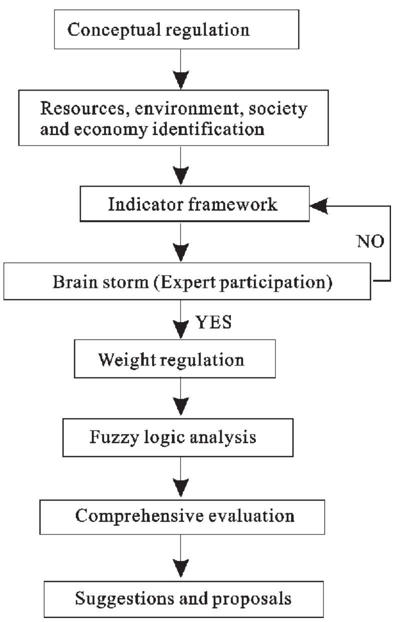


Fig.1 Conceptual schema of FCEM

The following step is to regulate the weight of each indicator. In this study, the Delphi-AHP method was utilized to calculate weights (SU, 2004; LI *et al*., 2005; CHEN *et al*., 2003). To be briefly, the intrinsic process of calculating weights through Delphi-AHP is not expatiated. Questionnaires and face-to-face interviews were used in the survey of suggestions and preferences of the public, local experts, authorities, planners and engineers, for getting the public to participate in the overall programming process. In our study, we invited experts from Environmental Protection Agency of Henan Province, Zhengzhou Bureau of Environmental Protection, Huiji Bureau of Environmental Protection, and some professors and researchers who were specialized in EDA programming.

2.1.2 Indicator system of EDA

EDA is a kind of officially authorized areas that is accredited by National Environmental Protection Administration of China. This organization released a copy of document in year 2001, which is named "National Criteria of Pilot Ecological Demonstration Area Construction".

The framework of FCEM for EDA includes six subsystems, which were social, economic (OSINSKI *et al*., 2003), ecological, rural, urban (MAY *et al*., 2000) and accessorial description ones.

2.2 Fuzzy Logic Application

2.2.1 Fuzzy sets construction

An indicator system of EDA was brought forward to determine the level of each indicator relative to Henan Province. The Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ degrees of each indicator are taken as excellent, good, eligible, medium and bad, respectively. Values between Ⅰ–Ⅱ, Ⅱ–Ⅲ, Ⅲ–Ⅳ, Ⅳ–Ⅴ, greater than Ⅴ or smaller than Ⅰ were translated to quantitative expressions through fuzzy sets theory (Table 1).

2.2.2 Fuzzy judgment matrix

We propose that the application of fuzzy set theory and fuzzy logic should be useful in deriving a model of an EDA's complex reality. Fuzzy set theory was originally developed in 1965 (BELLMAN and ZADEH, 1970) to represent how a domain can associate with a fuzzy set through a gradation of membership, instead of classifying them as either "true" or "false" or either "0" or "1", as in conventional Boolean (crisp) sets (GELDERMANN *et al*., 2000). At the same time, fuzzy logic also allows conclusions to be reached from premises with a gradation of truth (PETROVIC-LAZAREVIC *et al*., 2001). The memberships of a domain to one or more sets are defined by fuzzy membership functions (equations (1)–(5)). The explicit use of vagueness in fuzzy sets is very useful for handling the uncertainty inherent to EDA.

A fuzzy knowledge-based (expert) system, designed to mimic how expert solve problems, is based on heuristic rules that describe the available expert knowledge. The heuristic rules summarize the available expert knowl-

Table 1 Indicator system and their weights for evaluation of Huiji District's EDA

	Subsystem	Indicator	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Sub-weight	Weight
FCEM	Society (S)	S_1*	600	800	1200	1500	1800	0.2050	0.1634
		S_2*	2	3.5	5	8	10	0.1798	
		S_3	40	30	25	15	5	0.2366	
		S_4	10	8	6	4	2	0.1861	
		S_5	100	75	50	25	10	0.1925	
	Economic development (D)	D_1	10000	7500	5000	2000	1000	0.1800	0.1793
		D_2	20000	15000	10000	6000	4000	0.1914	
		D_3	4000	2000	1500	1000	800	0.1629	
		D_4	25000	15000	10000	8000	5000	0.1971	
		D_5	2.5	2.0	1.5	0.8	0.2	0.1457	
		D_6*	3.0	3.5	4.0	6.0	8.0	0.1229	
	Ecology and environment (E)	E_1	25	20	10	6	2	0.2140	0.1735
		E_2	100	80	60	40	20	0.2529	
		E_3	30	20	10	8	5	0.2296	
		E_4	100	80	60	40	20	0.1440	
		E_5*	2250	3000	3750	5250	6750	0.1595	
	Rural environment (R)	R_1	100	90	80	50	20	0.1984	0.1749
		R_2	100	95	90	70	50	0.1772	
		R_3*	100	200	280	350	450	0.1349	
		R_4*	1	2	3	8	10	0.1614	
		R_5	100	90	80	70	60	0.1455	
		R_6	100	95	85	75	60	0.1826	
	Urban environment (U)	U_1	5	4	3	2	1	0.1964	0.1833
		U_2	5	4	3	2	1	0.2447	
		U_3	5	4	3	2	1	0.2024	
		U_4	100	80	60	40	20	0.1722	
		U_5	20	15	8	5	2	0.1843	
	Accessorial description (A)	A_1	100	75	50	25	0	0.2037	0.1256
		A_2	100	85	75	50	25	0.2630	
		A_3	100	70	40	20	0	0.2407	
		A_4	100	95	90	75	50	0.2926	

Notes: 1. S_1, population density (person/km^2); S_2, population growth rate (‰); S_3, rate of non-agriculture population to total population (%); S_4, professional tutors per hundred school students; S_5, hospital beds per 10 000 people.

D_1, annual income of farmers per capita (yuan (RMB)); D_2, GDP per capita (yuan); D_3, local government's financial income per capita (yuan); D_4, annual income of urban people per capita (yuan); D_5, rate of environmental investment to GDP (%); D_6, water consumption of unit GDP (m^3/10^6 yuan).

E_1, forest cover rate (%); E_2, treatment rate of degraded land (%); E_3, rate of protected area to total area (%); E_4, recovery rate of mines and kilns (%); E_5, irrigation limitation of arable land (m^3/ ha).

R_1, integrated reuse rate of straws and stalks (%); R_2, treatment rate of livestock's manure (%); R_3, amount chemical fertilizer applied (kg/ha); R_4, amount of pesticide used (kg/ha); R_5, recycle rate of agricultural membranes (%); R_6, rate of protected arable land to total arable land (%).

U_1,urban atmospheric quality index; U_2, water quality index; U_3: urban noise index; U_4: treatment rate of urban solid wastes (%); U_5, urban public green space per capita (m^2).

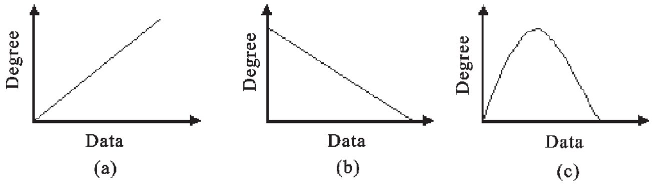
A_1, spread rate of sanitary toilets (%); A_2, urban gasification rate (%); A_3, treatment rate of municipal wastewater (%); A_4, eligibility rate of tourism sites (%).

2. *denotes negative indicators whose increasing values have negative impact on development; others are positive indicator whose increasing values have positive impact on development.

edge and take the IF-THEN form to mimic the whole process. Here a program group, including seven programs, based on MATLAB software (version 7.0.1), is executed.

According to their properties, different indicators could be classified as three types (Fig. 2), linear increasing, linear decreasing, and non-linear.

For a negative indicator (as type b), such as amount of pesticide used or water consumption per unit GDP, its subject degree function can be expressed by the fol-



(a) Linear increasing (b) Linear decreasing (c) Non-linear
Fig. 2 Three types of indicators

lowing equations (1)–(5).

$$\mu_{1j}(x_{ij})=\begin{cases}1 & x_{ij}\leqslant a_{i\,\mathrm{I}}\\ -(x_{ij}-a_{i\,\mathrm{II}})/(a_{i\,\mathrm{II}}-a_{i\,\mathrm{I}}) & a_{i\,\mathrm{II}}>x_{ij}>a_{i\,\mathrm{I}}\\ 0 & x_{ij}\geqslant a_{i\,\mathrm{II}}\end{cases} \quad (1)$$

$$\mu_{2j}(x_{ij})=\begin{cases}(x_{ij}-a_{i\,\mathrm{I}})/(a_{i\,\mathrm{II}}-a_{i\,\mathrm{I}}) & a_{i\,\mathrm{II}}>x_{ij}>a_{i\,\mathrm{I}}\\ -(x_{ij}-a_{i\,\mathrm{III}})/(a_{i\,\mathrm{III}}-a_{i\,\mathrm{II}}) & a_{i\,\mathrm{III}}>x_{ij}>a_{i\,\mathrm{II}}\\ 0 & x_{ij}\geqslant a_{i\,\mathrm{III}},\ x_{ij}\leqslant a_{i\,\mathrm{I}}\end{cases} \quad (2)$$

$$\mu_{3j}(x_{ij})=\begin{cases}(x_{ij}-a_{i\,\mathrm{II}})/(a_{i\,\mathrm{III}}-a_{i\,\mathrm{II}}) & a_{i\,\mathrm{III}}>x_{ij}>a_{i\,\mathrm{II}}\\ -(x_{ij}-a_{i\,\mathrm{IV}})/(a_{i\,\mathrm{IV}}-a_{i\,\mathrm{III}}) & a_{i\,\mathrm{IV}}>x_{ij}>a_{i\,\mathrm{II}}\\ 0 & x_{ij}\leqslant a_{i\,\mathrm{II}},\ x_{ij}\geqslant a_{i\,\mathrm{IV}}\end{cases} \quad (3)$$

$$\mu_{4j}(x_{ij})=\begin{cases}(x_{ij}-a_{i\,\mathrm{III}})/(a_{i\,\mathrm{IV}}-a_{i\,\mathrm{III}}) & a_{i\,\mathrm{IV}}>x_{ij}>a_{i\,\mathrm{III}}\\ -(x_{ij}-a_{i\,\mathrm{V}})/(a_{i\,\mathrm{V}}-a_{i\,\mathrm{IV}}) & a_{i\,\mathrm{V}}>x_{ij}>a_{i\,\mathrm{IV}}\\ 0 & x_{ij}\leqslant a_{i\,\mathrm{III}},\ x_{ij}\geqslant a_{i\,\mathrm{V}}\end{cases} \quad (4)$$

$$\mu_{5j}(x_{ij})=\begin{cases}1 & x_{ij}>a_{i\,\mathrm{V}}\\ -(x_{ij}-a_{i\,\mathrm{IV}})/(a_{i\,\mathrm{V}}-a_{i\,\mathrm{IV}}) & a_{i\,\mathrm{V}}>x_{ij}>a_{i\,\mathrm{IV}}\\ 0 & x_{ij}\leqslant a_{i\,\mathrm{IV}}\end{cases} \quad (5)$$

where μ_{1j}, μ_{2j}, μ_{3j}, μ_{4j}, μ_{5j} respectively represent the subject degree function values of indicator to Ⅰ, Ⅱ, Ⅲ, Ⅳ and Ⅴ degrees; j=2004, 2007 and 2013, referring the goal years of the EDA programming; x_{ij} represents the value of a certain indicator i at year j; $a_{i\mathrm{I}}$, $a_{i\mathrm{II}}$, $a_{i\mathrm{III}}$, $a_{i\mathrm{IV}}$, $a_{i\mathrm{V}}$ respectively represent the standard values of Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ degrees.

For a positive indicator (as type a), such as GDP per capita, or forest cover rate, its subject degree function is similar to the negative indicator (as type b) while the former ascends from V to I and the latter reverses. For a nonlinear indicator (as type c), its expression would be complicated. However, it is composed of numerous line segments while any single segment is linear. Thus the subject degree function of type c could be expressed as the analogical formula of type a or b.

2.2.3 Constructing FCEM

For an indicator j (j=1, 2, ..., m) in group i (i=1, 2, ..., n) in year k (k=2004, 2007 and 2013), the procedure of constructing FCEM could be described as follows:

1) Fuzzy matrix calculation of each group:

$$X_{ik}=\sum_{j=1}^{m} w_{ij}\times x_{ijk} \quad (6)$$

2) Fuzzy matrix calculation of a special year k:

$$X_{k}=\sum_{i=1}^{n} W_{i}\times X_{ik} \quad (7)$$

where X represents group types as S, D, E, R, U and A; w_{ij} represents sub-weight of indicator j in group i; and W_i is weight of group i.

Also, there must be:

$$\sum_{j=1}^{m} w_{ij}=1 \qquad (\text{for } i=1, 2, \cdots, n) \quad (8)$$

and

$$\sum_{i=1}^{n} W_i=1 \quad (9)$$

3 CASE STUDY

3.1 Description of Huiji District

Huiji District came into existence in 1987, when it was named Mangshan District. Its now-called name was confirmed in 2004. Huiji is one of the six districts of Zhengzhou City, which is the capital of Henan Province. Huiji is in the north part of Zhengzhou City and lies in the Huanghe River's south bank-side. It is about 17km wide from south to north, and 27km long from east to west. It covers an area of 232.8km^2, with a total population of about 160×10^3. Presently, 48.8km^2 in Huiji is urban area while others are rural area. Most part of Huiji is plain except its northwest part, which is skirt mountain of Loess Plateau, and is called Mangshan.

Huiji District was approved as one of the 9th group of national EDA pilot units by Environmental Protection Administration of China on October 26th, 2004. As designed by Huiji's EDA planning, its way on constructing EDA is composed of three periods, which are 2004–2007, 2008–2013 and after 2013.

3.2 Indicator Value Determination

In order to effectively reflect the dynamic characteristic of this system and provide more accurate data for the

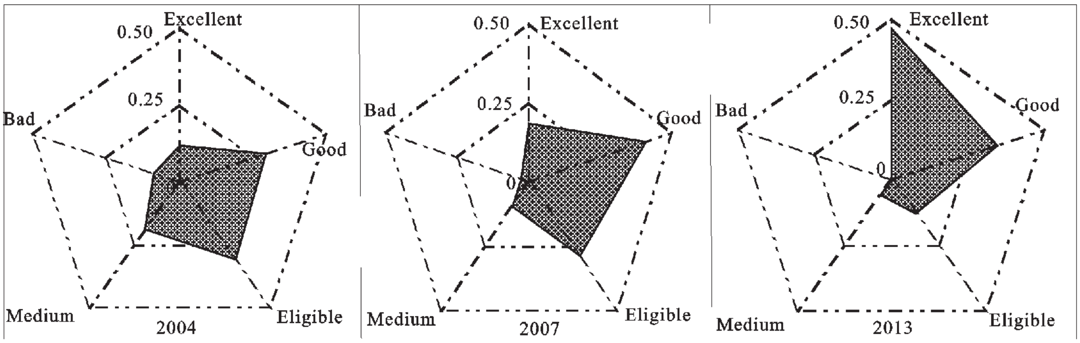


Fig. 3 FCEM of Huiji District' EDA in 2004, 2007 and 2013

FCEM, system dynamics (SD) approach was adopted to forecast some characteristic values of Huiji District in 2007 and 2013, such as population size, GDP, average annual income per farmer, forest cover area, and gross growth rate of population. Other values in the goal years were predicted or prescribed by the EDA construction programming of Huiji District.

The regional environmental quality for water, air, noise and municipal solid wastes were obtained by respective modeling studies in accordance with the national environmental quality standards announced by the Environmental Protection Agency of China.

3.3 Results and Discussion

FCEM was applied to Huiji District and the result was displayed in Fig. 3. Here three radar diagrams show the subject degree function in the three characteristic years and reveal a notable difference respectively.

As the FCEM was utilized in Huiji District, it showed an ascending trend on I degree and a descending trend on IV and V degrees. This means on the temporal dimension, according to our programming, the Huiji EDA will be propelled on the direction of "excellent". Also, on the spatial dimension, all the subject degrees of the six subsystems will be better from now to the coming future. The result shows that the Huiji District is in the degree of "eligible" in 2004, and in 2007 and 2013 it will be "good" and "excellent" if it follows the ecological and economic planning. But now it is preferable in ecology and environment and relatively delayed in society and economy. The model also proves that this area is gifted in social and economic development with the implement of the EDA programming.

This method of fuzzy comprehensive evaluation index comprises the EDA system's characteristics of complexity, hierarchy, and dynamics. And, the model proves to be capable in combining the temporal, spatial and serial characteristics of EDA' sustainable development. These above showed the FCEM in this article was proper, scientific and in point.

4 CONCLUSIONS

We propose a new concept of EDA's FCEM and its conceptual model in the viewpoints of ecological construction to evaluate the level of EDA development of a region with an agricultural-dominating economy. An indicator system and a fuzzy comprehensive evaluation model are presented, which involves six subsystems: society, economic development, ecology and environment, rural environment, urban environment and accessorial description. They are used to evaluate FCEM of Huiji District. The results show that the FCEM of Huiji will be improving in the future periods of EDA construction due to its EDA construction programming.

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