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A fuzzy two element rule feature extraction method based on Hierarchical Theory

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Abstract. In order to improve the accuracy of analysis on dynamic coupling mechanism of ecological–agricultural system in Erhai Lake Basin, an analytical method based on hierarchical fuzzy meta-association rule for dynamic coupling mechanism of ecological–agricultural system in Erhai Lake Basin is proposed. Firstly, use ecological environment subsystem, economic development subsystem, and social progress subsystem to build dynamic coupling mechanism model of ecological–agricultural system in Erhai Lake Basin; secondly, propose a fuzzy meta-association rule method based on hierarchy theory, and use similar structure of stored data of each independent influence factor branch to carry out meta-rule and binary fusion and extraction; in which, there is no need to handle the entire dataset, and it is allowed to obtain result/mode from a single database, thus reducing the time for rule mining; finally, the effectiveness of the algorithm is verified through simulation experiment.

Key words. Hierarchical model, Meta-association rule, Coupling mechanism, Erhai Lake Basin.

1. Introduction

With the advance of industrial civilization and development of social economy, more and more defects in traditional development patterns are exposed, the leading function of human in ecological system is strengthening, and economic behaviors have become an important factor which influences and disturbs ecological environment. Therefore, attention in modern ecological science shall be paid to research on relation between creatures and environment under the effect of human activities for the purpose of discovering and mastering the mechanism and rule which can make harmonious development among human beings, creatures, and environment possible. As pointed out by Odum “thought of ecological system: human is an indivisible part

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of the complicated biogeochemical cycle" is the basic conception of modern ecology, and it is an idea which is vital to human life. Ecological civilization is built on the basis of industrial civilization; it pays attention to constant coordination and sustainability of ecological system, and emphasizes the fully use of various functions of ecological system and the development of its functions for the good of human beings through optimization and adjustment under the premise of maintaining coordination of ecological environment system. This is also the implication of coordinate coexistence of regional system for man-land relationship.

Ecological-economic system coupling is one of the frontier research fields in ecological economics; the root for decline of ecological carrying capacity is the serious imbalance in man-land relationship, namely, human's social and economic activities go beyond the carrying capacity of ecological system. Therefore, the research on regional ecological-economic coupling mechanism and mode as well as the realization of balance in ecological system and economic system during development are main fields for sustainable development of human society, and they are also within the "Five-in-One" strategy which is implementing in China, and they are important questions of reality in constructing "ecological civilization". The coordinated ecological-economic system coupling is an important standard for judging sustainable development, and therefore the methods, measure, driving force, mode, and mechanism of ecological-economic system coupling have been research focuses of scholars in all countries.

In the Thesis, an analytical method based on hierarchical fuzzy meta-association rule for dynamic coupling mechanism of ecological–agricultural system in Erhai Lake Basin is proposed; a dynamic coupling mechanism model of ecological–agricultural system in Erhai Lake Basin is built; a fuzzy meta-association rule method based on hierarchical theory is proposed for meta-rule and binary fusion and extraction, in which there is no need to handle the entire dataset, thus reducing the time for rule mining.

2. Overall indicators

Regional ecological civilization consists of ecological environment subsystem, economic development subsystem, and social progress subsystem among which the coordinated development is the objective of ecological civilization construction. The overall standard of ecological civilization construction is the general requirement for this combined system. All system elements shall be sound and reasonably allocated; the structure of elements shall be reasonable; their functions shall be complete; besides, they shall be linked up with the general objective of ecological civilization construction so as to make regional ecosystem balance continue, and also to realize virtuous circle of the entire compound ecological system. By combining the concept, characteristics, implementation subject, affecting object, governance level, and coordination degree of ecological civilization, in the Thesis, the idea is that consideration shall be given to both natural ecology and human civilization, implementation subject and affecting object, governance level and coordination degree during the construction of indicator system. On this basis, a performance appraising system for ecological civilization construction containing three subsystems which are natural ecological environment subsystem, economic development subsystem, and social progress subsystem and covering five aspects which are nature, economy, society, politics, and culture is constructed; the system is divided into four core inspection fields which are ecological economy, environmental quality, social development, and coordination degree.

(1) Standard of ecological environment subsystem. Ecological environment is a basic condition for ecological civilization construction, and it is an indicator for regional ecological environment evaluation; it covers two aspects: I, by changing regional ecological environment elements and on the basis of maintaining necessary natural features and landscape for settlement, construct cultural settlement landscape according to local conditions, bring the environmental pollution under control, realize inherent self-organization, self-adjustment, self-purification, and self-renewal abilities of ecological environment system, and also maintain favorable operation, balance and harmony of ecological system. II, reasonably develop and use as well as practically protect regional resources and environment; follow spatial and temporal distribution characteristics of natural resource elements such as regional landscape cover, geological structure, hydrologic process, weather conditions, land features, forest and green space, and so on; on this basis, plan and optimize regional space distribution as well as protect and improve landscape pattern, as shown in Table 1.

Table 1. Construction indicator system for ecological environment subsystem

Ecological environment subsystem	Air quality	Atmosphere background value
		Rainfall pH value
		Dust treatment rate
	Landscape cover	Vegetation abundance
		Green land area per capita
	Quality in watershed	Total organic carbon (TOC)
		Dissolved oxygen (DO)
		Chemical oxygen demand (COD)
	Settlement evolution	Construction land area
		Cultivated land area
		Population density

(2) Standard of industrial development subsystem. Ecological civilization shall be supported by advanced economy and strong comprehensive strength. In aspect of industrial structure optimization, attention shall be paid to development of ecological economy industry and ecological service industry so as to meet market demand for green products; as to production mode, using high and new technology to change economic growth mode and also to improve use ratio of resources and energy so as to form ecological and environmental protection economy system and ecological industry chain with features of ecological economy; in aspect of industrial space layout, it is required to realize optimal distribution of resources and rational distribution of

productivity in accordance with the requirements of eco-economic functional regionalization; see Table 2.

Table 2. Construction indicator system for industrial development subsystem

Industrial development subsystem	Industrial development	Added value of agriculture
		Added value of secondary industry
		Added value of service industry
	Economic sustainability	GDP consumption per unit
		R&D investment
		Structure of tertiary industry
	Production emission	Sewage treatment rate
		Solid waste treatment rate
		CO_2emission
	Cyclic utilization	Tail gas recovery rate
		Utilization rate of heat energy
		Utilization rate of reclaimed water

3. Fuzzy meta-association rule based on hierarchical theory

3.1. Related definitions

Given $I = \{i_1, i_2, \cdots, i_m\}$ being a finite set of ecological-agricultural label items; fuzzy matters are defined as non-void fuzzy subset–$\tau \subseteq I$; in τ, $i \in I$ is satisfied with unit interval membership, for example, $\tau(i) \in [0,1]$. Through extension, if A is a subset of i, the membership of fuzzy trade item τ to A can be defined as $\tau(A) = \min\limits_{i\in A} \tau(i)$. Then, giving a set $\tilde{D}$ of fuzzy matters; in $\tau \in \tilde{D}$, when and only when $\tau(A) \leq \tau(B)$, the fuzzy association rule $A \to B$ in $\tilde{D}$ is workable.

In hierarchical theory, considering item $i \in I$ and general item set $A \subset I$; defining hierarchy (Λ_A, ρ_A) in fuzzy set $\tilde{D}$; in it, $\Lambda_A = \{\alpha_1, \alpha_2, \cdots, \alpha_m\}$; predefining hierarchical set as $1 = \alpha_1 > \alpha_2 > \cdots > \alpha_m > 0$; $\alpha \in \Lambda_A$ can be clearly represented in hierarchy by using the following function$\rho_A(\alpha) = \left\{\tau \in \tilde{D} : \tau(A) \geq \alpha\right\}$.

For random item set A and item set B in $\tilde{D}$, considering their hierarchy association rules–$A = (\Lambda_A, \rho_A)$ and $B = (\Lambda_B, \rho_B)$. Defining the form of fourfold table as $\mathcal{M}_{\alpha_i}\left(A, B, \tilde{D}\right)$ which includes cardinality[10] of hierarchy α_i related $\tilde{D}$:

$$\mathcal{M}_{\alpha_i}\left(A, B, \tilde{D}\right) = \begin{bmatrix} \mathcal{M}_{\alpha_i} & B & \neg B \\ A & a_i & b_i \\ \neg A & c_i & d_i \end{bmatrix}. \tag{1}$$

Where, a_i, b_i, c_i and d_i are nonnegative integers; and $a_i = \left|\rho_{A\wedge B(\alpha_i)}\right|$, $b_i = \left|\rho_{A\wedge\neg B(\alpha_i)}\right|$; the definitions of c_i and d_i are similar. In order to evaluate the effectiveness of fuzzy association rules, the following basic probability distribution[11] is defined:

$$\text{Prob}\,(Y) = \sum_{\alpha_i \in \Lambda : Y = \rho(\alpha_i)} \alpha_i - \alpha_{i+1}\,. \tag{2}$$

Where, there shall be at least one preimage–$\alpha \in \Lambda$ which can be cleared through setting $\Lambda = 1$:

$$FSupp(A \to B) = \sum_{\alpha_i \in \Lambda_A \cup \Lambda_B} (\alpha_i - \alpha_{i+1})(\frac{a_i}{a_i + b_i + i_i + d_i})\,. \tag{3}$$

$$FConf(A \to B) = \sum_{\alpha_i \in \Lambda_A \cup \Lambda_B} (\alpha_i - \alpha_{i+1})(\frac{a_i}{a_i + b_i})\,. \tag{4}$$

$$FCF(A \to B) = \sum_{\alpha_i \in \Lambda_A \cup \Lambda_B} (\alpha_i - \alpha_{i+1}) \cdot \begin{cases} \dfrac{a_i d_i - b_i c_i}{(a_i + b_i)(b_i + d_i)}, \; if \; a_i d_i > b_i c_i \\ 0, \; if \; a_i d_i = b_i c_i\,, \\ \dfrac{a_i d_i - b_i c_i}{(a_i + b_i)(b_i + c_i)}, \; if \; a_i d_i < b_i c_i\,. \end{cases} \tag{5}$$

When $|\rho_A(\alpha_i)| = 0$, there may be indeterminate form–0/0 in confidence coefficient calculation, which is not allowed. Therefore, in order to guarantee the definition of fuzzy rule, the above indeterminate condition is set as 1.

3.2. Meta-rule extraction

The aim of Meta-association rule is to obtain location distribution or horizontal partition storage of data from database; under these two conditions, it is expected to extract possible association from one set of association rules in each main dataset. This treatment method is effective for ecological-agricultural datasets which are large-scale, complex, and isomerous.

Here examples are used to explain; it is assumed that one multi-branch system like ecological-agricultural label has many branches which spread all over the network. In this case, data stored in each independent ecological-agricultural branch will have similar structure. There are certain advantages in knowledge which is fused and extracted by using meta-rule: (1) there is no need to handle the entire dataset, for the calculation efficiency of algorithm will be reduced. (2) It allows result/mode to be obtained from a single database, which can reduce time required for rule mining.

Refer to Fig.1 for general structure suggested by us which mainly includes two main steps. (1) Obtain association rule which can be represented as D_i from each database at regular intervals; (2) generate associative fusion in the form of meta-association rule. The new database built with collected rules in the first step is named as metadatabase $\mathcal{D}$ which can be represented in the form of fuzzy form or Boolean form, as shown in Table 3; it depends on user application or the accuracy of rules extracted in the first step.

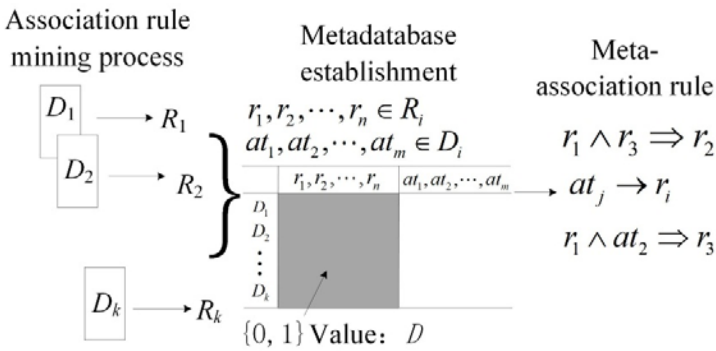


Fig. 1. From Original dataset to final meta-association rule

Table 3. Boolean (upper) metadatabase and fuzzy (lower) metadatabase

$\mathcal{D}$	r_1	$\cdots$	r_n	at_1	$\cdots$	at_m
D_1	1	$\cdots$	0	1	$\cdots$	1
D_2	0	$\cdots$	0	0	$\cdots$	1
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
D_k	1	$\cdots$	1	1	$\cdots$	0
$\tilde{\mathcal{D}}$	r_1	$\cdots$	r_n	at_1	$\cdots$	at_m
D_1	0.2	$\cdots$	1	0.9	$\cdots$	1
D_2	0	$\cdots$	0.6	0	$\cdots$	0.2
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
D_k	0.9	$\cdots$	0.5	1	$\cdots$	0.1

Then, we can differentiate fuzzy meta-association rules or clear meta-association rules; steps are as follows:

Step 1: Order $\{D_1, D_2, \cdots, D_k\}$ as an attribute-sharing database. Use rules to extract program; a different association rule R_i can be extracted from each database for each D_i. These discovered association rules and their evaluated values can be represented as sets $R_1, R_2, \cdots, R_k$; there are many repeated rules, but the generality is not lost; it is assumed that minimum support with same threshold value and same certainty factors are used for dataset processing.

Step 2: Collect data through step 1; establish structurized metadatabase $\mathcal{D}$; all r_j rules shall at least belong to one set R_i. Another characteristic of $\mathcal{D}$ is that it can utilize rich data to describe D_i in detail by using methods of $at_1, at_2, \cdots, at_m$. At last, metadatabase is taken as input of meta-rule extraction process.

3.3. Meta-association rule fusion of fuzzy hierarchy

Refer to algorithm 1 for mining process of meta-association rule. Refer to codes in No.16 to No.12 lines in algorithm 1 for the so-called item calculation process of frequent item set or candidate set. These rules are extracted by using threshold values higher than those defined by users; see codes in No.13 to No.15 lines in algorithm. Calculations required for step 1 is the most complex; different heuristic strategies are proposed to reduce time required for rule mining. In the mentioned algorithm, binary bit string is used to represent items, which can speed up the calculation of conjunctions; besides, items shown in the way of binary representation occupy small memory, thus reducing memory requirements for system.

Algorithm 1 meta-association rules

Input: $D_2, \cdots, D_k, at_1, at_2, \cdots, at_m, minsupp, minCF$;
Output: $R_1, R_2, \cdots, R_k$;
1: **for** ***all*** D_i **do**
2:   $\#D_i$pretreatment
3:   Read D_i, and store item I;
4:   . Convert D_i into Boolean database;
5:   # Association rule mining6.
6:   **if** $Supp(X) \geq minsupp$ **then**
7:     $X \in C$ $\#C$ is candidate set
8:   **end if**
9:   **for** ***all*** $X, Y \in C; X \cap Y = \emptyset$ **do**
10:     **if** $Supp(X \to Y) \geq minsupp$ **then**
11:       $X \wedge Y \in C$ and $X \to Y$ are frequent;
12:     **end if**
13:     **if** $CF(X \to Y) \geq minCF$ **then**
14:       $X \to Y \in R_i$ and $X \to Y$ are determined;
15:     **end if**
16:   **end for**
17: **end for**
18: # Establish metadatabase $\mathcal{D}$
19: Compile all different rules $R_1, R_2, \cdots, R_k$;
20: Establish $\mathcal{D}$ by using compiling rule and additive attribute
21: # Meta-rule mining
22: Repeatedly carry out step 2 to step 16 by using $\mathcal{D}$;

In algorithm 1, after requirements for support and certainty factors of each metadatabase $\{D_1, D_2, \cdots, D_k\}$ are met, carry out mining of association rules. Then, establish metadatabase $\mathcal{D}$ or fuzzy metadatabase $\tilde{\mathcal{D}}$. In this step, supplementary information can be taken as additive attribute of metadatabase. The attribute of fuzzy metadatabase $\tilde{\mathcal{D}}$ can be modeled into a fuzzy set. At last, clear or fuzzy meta-association rules can be extracted respectively. Obviously, in case initial dataset is not applicable, meta-rule extraction will be carried out in step 18. In case fuzzy metadatabase is applicable, step 22 will be started, which enables us to mine algorithms by using any fuzzy rules. In detail, when carrying out step 2 to step 16, we take metadatabase $\mathcal{D}$ as input and the obtained fuzzy meta-association rule as output.

Then, the fusion algorithm of meta-association rule based on hierarchical theory can be seen in algorithm 2. In parallel level set, FSupp and FCF of equation (7) and equation (9) are used to carry out fuzzy evaluation. Especially, in step 9, for each $\alpha \in \Lambda$, certainty factor and definition support can be calculated independently; besides, weighting and calculation of calculation result of equation (7) and equation (9) can be carried out.

Algorithm 2 fuzzy association rule mining

Input: Λ, fuzzy set $\tilde{\mathcal{D}}$, $minsupp$,$minCF$;
Output: FR, # fuzzy association rule set
1: #$\tilde{\mathcal{D}}$ pretreatment
2: Read D_i and store item I;
3: Convert $\tilde{\mathcal{D}}$ into Boolean database p; #$p$is the hierarchy number of Λ
4: Code the database into a binary vector$p$;
5: # Association rule mining
6: **for *all*** $\alpha_i \in \Lambda$ **do**
7: Repeatedly carry out step6 to step 16 of algorithm1; obtain clear rule set from each hierarchy;
8: Read all discovered rules in hierarchy α_i;
9: Use equations (2) and (4) to calculate $FSupp$ and FCF;
10: **end for**
11: Collect rules meeting requirements of $FSupp$ and FCF;

3.4. Calculation complexity analysis

As mentioned above, association rule mining algorithm usually includes two steps. The calculation complexity of the algorithm is represented as $O(|D|\,2^{|I|})$. In the method proposed by us, since the original D_i can realize parallel treatment, there is a same calculation complexity $-O(|D|\,2^{|I|})$ with that of algorithm in stage I of line 1 to line 17 in the algorithm; calculation complexity, initial database scale k, number m of additive attributes, and the number of different rules obtained in step 1 are related to it. According to this, its calculation complexity can be obtained as $O(k2^{m+r})$, since the calculation process shown in algorithm 2 is concurrently carried out in respect of $\alpha \in \Lambda$.

4. Experimental analysis

4.1. Overview of research area

Erhai is an important freshwater lake in China, and it is also the second largest plateau lake in the Yunnan-Guizhou Plateau, with a basin area of 2565KM3; it has cultivated the history of human civilization in Dali area for about 4000 years. Erhai is the core area of "National Nature Reserve in Cangshan Mountain and Erhai Lake"; it is like a bright plateau pearl of suburb lakes in China which has obtained good protection and thus survived; in addition to its ecological conservation value, Erhai still has other seven main functions which are drinking water supply for the basin, agricultural irrigation, power generation with water, climate adjusting, fishery, shipping as well as tour and sightseeing. In recent years, with concentration of population in the basin and rapid development of regional economic society, the threat to carrying capacity of ecological environment in Erhai is increasingly serious; the water quality in the lake tends to worsen from Class II to Class III and from moderate nutrition state to eutrophication; now, the water is in the initial stage of eutrophication. Under the background of scientific outlook on development and ecological civilization construction, local government proposes the development idea of "Clear Erhai, Prosperous Dali"; besides, it carries out a series of work aiming at prevention and control of water pollution in plateau lakes, and conducts ecosystem-economy comprehensive treatment and protection for Erhai Lake Basin, which preliminarily contains the worsening trend of water pollution, and starts new stage for "ecological civilization" construction in Erhai Lake Basin. Refer to Fig.2 for terrain and landform of Erhai Lake Basin.

4.2. Current situation analysis of economic development

(1) Agricultural development level. The total value of agricultural output in 2013 was 3.4 billion yuan which is 19.50% more than that of last year. In it, the output value of planting industry was 1.380 billion yuan; the output value of forestry was 37 million yuan; that of animal husbandry was 184.2 thousand yuan, and that of fishery was 121 million yuan. At the end of the year, the area of common cultivated land in Dali City was 11839 hectares, with effective irrigation area of 11090 hectares; total grain output reached 170 thousand tons; oil output was 1905 tons; flue-cured tobacco output was 3882 tons; vegetable yield was 160 thousand tons, with an increase of 1.75%; and the fruits output was 19 thousand tons. The agricultural economy is relatively advanced; the animal husbandry focused on cow breeding has strong driving force in increasing farmers' income; the amount of cow inventory and meat, milk, and eggs increases rapidly; in 2013, the amount of cows on hand reached 34470, and the production of milk reached 190 thousand tons, as shown in Fig.3.

(2) Industrial development level. The total industrial output value in 2013 was 30.09718 billion yuan, 22.84% higher than that of last year, in which 15.92949 billion yuan was realized at the corresponding level of the city, and 14.16769 billion yuan was realized by innovative industrial parks; the industrial added value was 10.58966

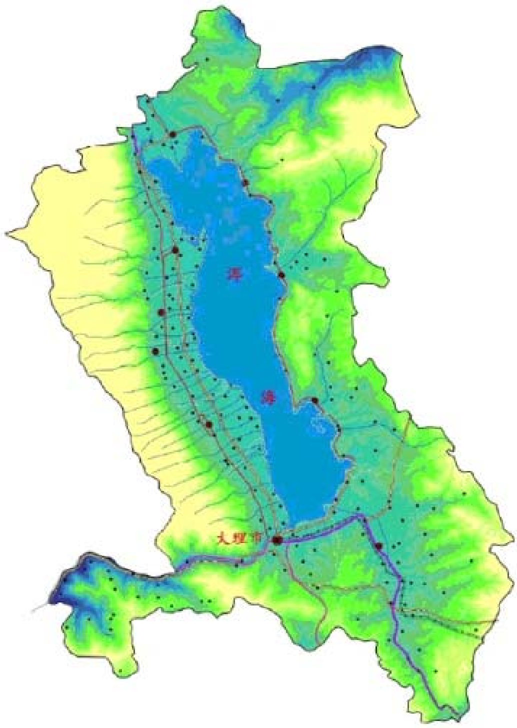
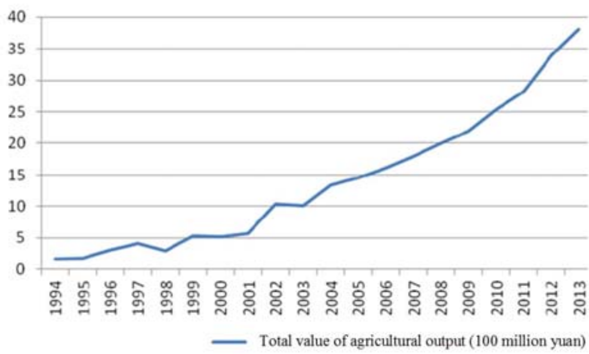


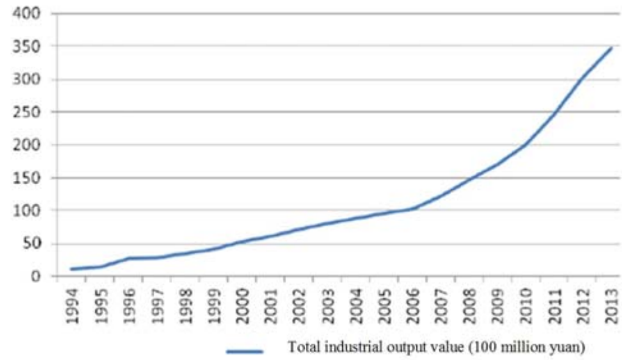
Fig. 2. Figure of terrain and landform of Erhai Lake Basin



Total value of agricultural output (100 million yuan)

Fig. 3. Agricultural development trend

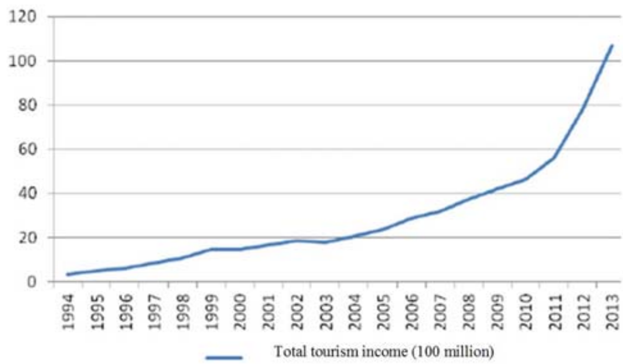
billion yuan, 15% (comparable) higher than that of last year. Industrial enterprises above designated size realized output value of 23.61577 billion yuan, 24.33% higher than that of last year; and they have realized industrial added value of 8.46994 billion yuan, 17.7% higher than that of last year; total amount of profits and taxes was 6.47320 billion yuan, with an increase of 20.28%; the total amount of profit and taxess was 2.50313 billion yuan, with an increase of 21.47%, as shown in Fig.4.



Total industrial output value (100 million yuan)

Fig. 4. Agricultural development trend

(2) Tourism development level. In 2013, 7.2014 million-person-time domestic and overseas tourists were received (12.83% higher than that of last year); among them, overseas tourists are of 413.1 thousand person-time, with an increase of 21.32%; total tourism income was 7.789 billion yuan which is 39.24% higher than that of last year; in it, total foreign exchange earnings from tourism was 123.3285 million dollars which is 21.32% higher than that of last year; total domestic tourism income was 6.987 billion yuan which is 41.64% higher than that of last year, as shown in Fig.5.



Total tourism income (100 million)

Fig. 5. Tourism development trend

4.3. Development index of ecological-economic system in Erhai

On the basis of weight of each index in coupling measurement index system of ecological-economic system in Erhai, multiply by nondimensionalized value of each index in corresponding year, and then obtain the comprehensive indexes of ecological system and economic system in each year.

As shown in Fig.6, it can be known that the ecological subsystem in Erhai Lake

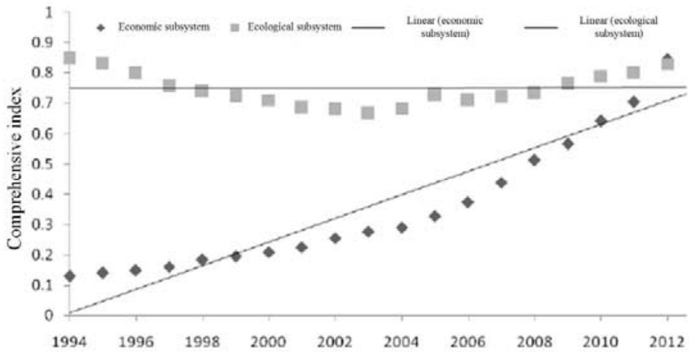


Fig. 6. Changes in comprehensive indexes of ecological system and economic system in Erhai Lake Basin

Basin experienced a "descending first and rising latter" process generally; a inflection point occurred in 2003; in 2005 and 2013, reverse-trend fluctuation occurred. The economic subsystem in Erhai Lake Basin shows a rising trend; according to growth range, the growth rate has constantly increased since 2001. From 1994 to 2013, in general, the ecological development index was larger than economic development index in Erhai Lake Basin, which indicates that the economic development in the basin did not cause large damage to water environment quality; in 2012, economic subsystem index was approaching ecological subsystem index, indicating that the sensitivity of ecological system in the basin to economic development increased, and therefore higher requirements were put forward for ecologicalization of economic development mode. In addition, between the year of 2005 and 2013, with the rapid increase of economic development index, a reverse was shown in the trend line of ecological system indexes in the basin; the interannual fluctuation is not obvious, which indicates that there is a disconnection between economic activity and ecological environment, and economy no longer grows at the cost of ecological environment, and aslo verifies the policy effect of development mode transformation in Erhai Lake Basin under ecological civilization construction.

5. Conclusion

In the paper, an analytical method based on hierarchical fuzzy meta-association rule for dynamic coupling mechanism of ecological–agricultural system in Erhai Lake Basin is proposed; a dynamic coupling mechanism model of ecological–agricultural system in Erhai Lake Basin is built; a fuzzy meta-association rule method based on hierarchical theory is proposed; and it is allowed to obtain result/mode from a single database, which can reduce the time for rule mining. There is certain universality in the algorithm in the Thesis; in the next step, results of analyses on more local ecological—agricultural coupling mechanisms through the algorithm will be verified.

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