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Set Pair Analysis for Rural Drinking Water Quality

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Abstract—**A large number of uncertain problems existing in rural drinking water safety system, it is of great significances to apply Set Pair Analysis(SPA) theory to analyze and study these uncertain problems in rural drinking water safety system. This study applies SPA theory to conduct an integrated evaluation of water quality to rural drinking water safety in Ya'an City, based on classification values of Sanitary Standard for Drinking Water（GB5749-85）. This study has worked efficiently in practice. Compared with the same kind of methods which have been found, this paper has the outstanding results for the uncertain problems of health risk assessment of the rural drinking water safety.**

Key words-Set Pair Analysis; Rural Drinking Water Quality;Connection Degree; Ya'an, Sichuan

I. INTRODUCTION

At present, there are more qualitative researches on rural water safety. However, systematic and quantitative researches are fallen short. Therefore, it is necessary to establish an integral theoretical system of water security, from respects such as water safety evaluation, measurement of water safety and water safety security system.

SPA can specifically describe a large number of certain and uncertain issues in the objective world. SPA, proposed by Keqin Zhao in 1989, is a modified uncertainty theory with both certainties and uncertainties considered as an integrated certain–uncertain system and depicting the certainty and uncertainty systematically from three aspects as identity, discrepancy and contrary [1,2,3]. Its core idea is to regard certain and uncertain problems as a certain-uncertain system. In this certain-uncertain system, certainty and uncertainty are interrelated, mutual influenced, mutual constrained, besides, they can be mutually transformed under given conditions. And sorts of uncertainties can be comprehensively described with a certainty-uncertainty formula that can express its idea to the most extend, so as to transfer dialectical understanding of uncertainties into a specific mathematical tool.

SPA is a comprehensive evaluation method of uncertainty, which has been extensively demonstrated.

Shao Jinhua, et al. [4], established an evaluation model on the degree of regional water resources development and utilization, and applied this model to conduct an integrated evaluation on the degree of water resources development and utilization in Hanzhong Basin. Through comparative analysis of fuzzy pattern recognition, fuzzy integrated evaluation, attribute identification method, artificial neural network method, the results came out that the SPA model was not only theoretical strict and of easy method, but also of accurate evaluation results, so as to demonstrate the rationality and feasibility of this method. Men Baohui, et al. [5], established an evaluation model on the degree of water resources development and utilization in evaluated areas by means of the SPA method, and applied it to evaluate the degree of water resources development and utilization in Xi'an City and urban areas around it. The same results as attribute identification method and fuzzy integrated evaluation method were gotten and then the method was considered more operable. Guo Wenxian, et al. [6] evaluated regional rainwater resources development and utilization by means of SPA, and verified it with fuzzy evaluation method. Jirong Yang, et al. [7], based on the principles of SPA, established a set pair integrated evaluation model on parts and materials selection, which mainly considers how to select the best one in a variety of materials reasonably in the process of parts design. This mathematical model made the qualitative evaluation of materials selection quantified, refined, clarified, and improved the feasibility and scientific rationality of evaluation work. At the same time, they put forward that the principles of set pair integrated evaluation model, with a wide application prospect, could be also used in a range of issues such as optimization of machining cutting parameters, optimization of processing plan, product quality evaluation. Xujie, et al. [8], on the basis of analysis on the principles that supplier evaluation indicator system should follow, established a general indicator system of supplier evaluation, structure evaluation model for supplier selection based on the SPA Method. Furthermore, he elaborated on supplier selection and evaluation process, which were based on the SPA.

Practices have proved that, the SPA theory is a relatively new soft computing to effectively analyze and deal with uncertain issues. In recent years, it has attracted much more attention by academic community day by day and has been applied to many areas successfully including decision-making, forecasting, data fusion, uncertainty reasoning, product design, network planning, and integrated evaluation, etc.

Since the substance of rural drinking water safety degree is a process of analysis, which combines evaluation indicators of certainty and evaluation criteria with evaluation factors of uncertainty and changes of its content. Hence, this study tries to apply the SPA method to make an integrated evaluation on rural drinking water safety in Ya'an City.

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II. MATERIAL AND METHOD

A. *Overview of the Study Area*

Ya'an City locates in the western part of Sichuan Province and belongs to mountainous region of western margin in Sichuan Basin. It is a transitional area between Sichuan Basin and Qinghai-Tibetan Plateau with seven counties and one district. With industrial and agricultural development and effect of human activities, water pollution of Qingyi watershed in Ya'an City is getting worse day by day. There are two types of water pollution in rural areas of Ya'an: one is the schistosome-affected areas in Lushan County and Tianquan County, where water source is polluted by oncomelania; the other is river pollution caused by the aggravation of human activities, by the forest devastation and by the fertilizer and pesticide abuse in agricultural production, which will affect human life and drinking water quality. According to the investigation and statistics, 580,200 residents didn't get safe drinking water, accounting for 46.77% of agricultural population. Among them, about 321,600 residents drank water that didn't reach the quality standard, 23,800 residents lived with water exceeding the standard fluoride content, 15,700 residents suffered from brackish water, 31,100 residents lived with IV-level or beyond IV-level untreated surface water, 171,400 residents intook untreated surface water that bacteriological indicator seriously exceeded the standard, 10,400 residents suffered from untreated underground water of heavy pollutant. There were 69,600 residents who drank water of other quality indicator exceeding the standards (mainly includes Glauber's salt, Fe, Mn and mineral), among which, 51,000 residents suffered from water shortage. 61,000 residents were affected because the water source guaranteed rate is below the standard.

B. *Models*

Basic Principles of SPA

For a given set pair of two aggregates $H=(A,B)$, under specific circumstance (set W), after analysis on features of set pair H, N features are obtained, among which, S features are commonly owned by two aggregates A and B of the set pair H; there are P features opposed to each other in aggregate A and B. The rest $F=N-S-P$ features are neither against each other, nor commonly owned by the two aggregates, as:

$$u=\frac{S}{N}+\frac{F}{N}i+\frac{P}{N}j \qquad (1)$$

Where, S/N, F/N, P/N are respectively the degree of identity, the degree of discrepancy and the degree of opposition, which all reflect the measured degree of identity, discrepancy and opposition; μ is the connection degree, which is used to portray a certain number.

Suppose that, $a=S/N$, $b=F/N$, $c=P/N$, then formula (1) can be abbreviated as follows:

$$u=a+bi+cj \quad (a+b+c=1) \qquad (2)$$

Where, i is the coefficient of the degree of discrepancy, $i\in$[-1,1], its value is uncertain; j is the coefficient of the degree of opposition, j=-1.

Through formula (1) and (2), the connection degree expression shows the connection, influence and transformation of the identity, the discrepancy and the opposition. When i equals 1, the degree of uncertainty transfers to the degree of identity; when i is -1,then the degree of uncertainty transfers to the degree of discrepancy; when i is gotten in interval (-1,1), it reflects respective proportions of certainty and uncertainty.

The connection degree μ and the degree of discrepancy i make up the core of the SPA theory, which contains random, fuzzy, incomplete information (grey) and other common uncertainties.

Calculation Method of Connection Degree

When evaluation of drinking water safety in a given region by means of SPA is conducted, drinking water safety evaluation indicators and evaluation criteria of the region should be made to be a set pair firstly. Suppose that there are N evaluation indicators, in which, there are S indicators superior than I-level indicator, P indicators inferior than III-level indicator, and F indicators between I-level indicators and III-level indicators; then the connection degree μ between indicators and evaluation criteria is evaluated via the basic formula (1) of SPA.

However, the calculation results are not definite by means of formula (1).Even if drinking water safety degree differs in various regions, similar results may also be obtained due to the uncertainty of evaluation method and indicators. Therefore, quantitative relationship between values of indicators and graded indicators of drinking water safety degree should be further analyzed. Comprehensive analysis of identity, discrepancy and opposition are conducted continually, based on graded standards, so as to work out the average connection degree $\overline{u}$ of different regions. The belonged levels of the degree of drinking water safety in to-be-evaluated regions are gotten via values of the degree of identity, the uncertain degree of discrepancy and the degree of opposition. However, from calculation results of the connection degree formula (1), drinking water safety degree in different regions is evaluated and sorted on the basis of the degree of identity, the uncertain degree of discrepancy and the degree of opposition.

Drinking water safety evaluation indicators generally consist of beneficial indicators and cost-oriented indicators. Their connection degrees are calculated as follows:

Beneficial indicators:

$$u=\begin{cases} 1+0i+0j & x\in[S_I,+\infty] \\ \dfrac{x-S_{II}}{S_{II}-S_I}+\dfrac{S_I-x}{S_{II}-S_I}i+0j & x\in[S_{II},S_I] \\ 0+\dfrac{x-S_{III}}{S_{III}-S_{II}}i+\dfrac{S_{II}-x}{S_{III}-S_{II}}j & x\in[S_{III},S_{II}] \\ 0+0i+1j & x\in[0,S_{III}] \end{cases} \qquad (3)$$

Cost-oriented indicators：

$$u=\begin{cases} 1+0i+0j & x\in[0,S_I] \\ \dfrac{S_{II}-x}{S_{II}-S_I}+\dfrac{x-S_I}{S_{II}-S_I}i+0j & x\in[S_I,S_{II}] \\ 0+\dfrac{S_{III}-x}{S_{III}-S_{II}}i+\dfrac{x-S_{II}}{S_{III}-S_{II}}j & x\in[S_{II},S_{III}] \\ 0+0i+1j & x\in[S_{III},+\infty] \end{cases} \quad (4)$$

Where, S_I , S_{II} , S_{III} are I-level, II-level and III-level thresholds of evaluation criteria respectively; x are indicators of drinking water safety degree in different to-be-evaluated regions.

C. *Samples Investigation*

In 2005, on the basis of investigation about fundamental state and making full use of rural drinking water quality statistical data in recent two years by Department of Health, sampling inspection of water system was divided into two categories according to topography, geomorphology, geology, hydrology, water systems and drinking water sources, distribution of water-borne diseases and water supply project types. Department of Health acted in concert with Ministry of Water Resources to collect samples of source water, peripheral water of centralized water supply projects, well water, reservoir water and pond water, and then to carry out laboratory test and detection on water quality in related townships. Thereby, the distribution areas, where the water quality was below the standard, and the number of people living in those areas, were obtained according to different water quality. 221 water samples were collected (see in Fig.1)

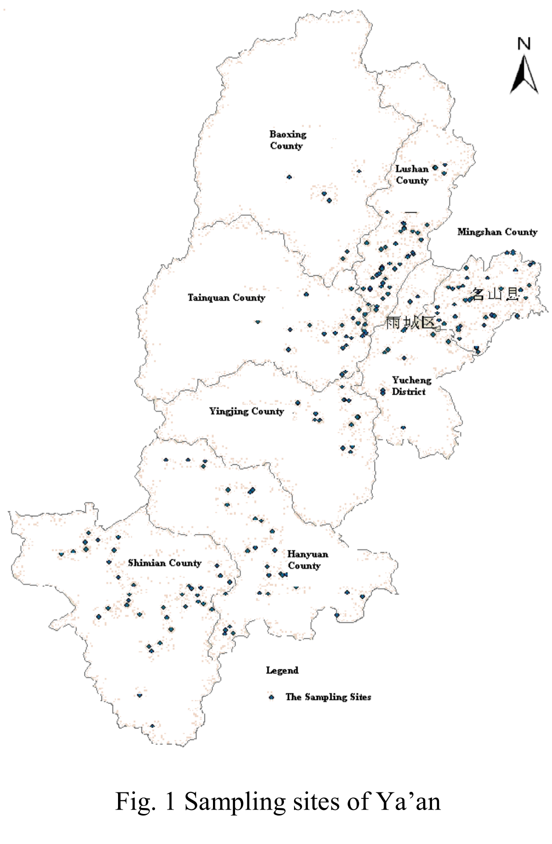

Fig. 1 Sampling sites of Ya'an

and 21 water quality indices were under detection, including physical water quality index (color, turbidity degree, offensive odor, visible materials by bare eye), hydrochemical index (PH, COD, total hardness, total dissolved solid, chloride, sulfate), toxicology index (Fe, Mn, Fluoride, As, Hg, Cd, Cr, Pb, Nitrate) and bacteriology index (faecal coliforms, total coliforms), etc.

III. RESULTS AND DISCUSSIONS

A. *Evaluation of the SPA method Applied in Rural Drinking Water Safety of Yucheng District, Ya'an City*

Water quality in different countries of different counties and districts was tested in 2005, taking Yucheng District for example in calculation.

The connection degrees of drinking water safety degree in Yucheng District are calculated via formula (1), calculation results are shown in table 1.

Table 1 Connection degree

Connection degree	a	b	c
μ_1	0.83	0.06	0.11
μ_2	0.89	0.05	0.06
μ_3	0.78	0.11	0.11
μ_4	0.94	0.06	0.00
μ_5	0.83	0.17	0.00
μ_6	0.78	0.06	0.17
μ_7	0.89	0.05	0.06
μ_8	0.67	0.16	0.17
μ_9	0.83	0.11	0.06
μ_{10}	0.78	0.06	0.17
μ_{11}	0.83	0.00	0.17
μ_{12}	0.67	0.22	0.11

The water quality safety situation in evaluated regions can be sorted through table 1; the sorted results, according to unsafety degree, are gotten in descending order as follows:

8>12>10>6>11>3>1>9>5>7>2>4.

The connection degrees and their average values of each evaluation indicator appointed to drinking water quality safety degree in each to-be-evaluated region are obtained via formulas (3) and (4).

Drinking water quality safety degree in to-be-evaluated regions are classified according to evaluation indicators in those regions, and then towns of unsafe drinking water quality are obtained, which is listed as follows:Xianghua village, Xianghua town (6); Liuliang village, Fengming town (8); Zhanggou village, Zhongli town (10); Boshu village, Bifengxia(12).

B. *Summary and Analysis of Results*

After use of the same method to have calculation and evaluation analysis of rural drinking water quality status in other districts of Ya'an City, the results show that, integrated evaluation of drinking water quality in some districts, counties, villages and towns are unsafe or basically safe. Therefore, statistical tables are divided into 2 kinds. One is villages and towns of unsafe rural drinking water quality in Ya'an City and the other is districts and counties of relatively unsafe rural drinking water quality. The calculation results are shown in table 2 and 3.With the principle of "first to urgency, first to emphasis, focused, step by step", priority should be given to solve problems of rural drinking water safety existed in these villages and towns.

TABLE 2. VILLAGES AND TOWNS OF UNSAFE RURAL DRINKING WATER QUALITY IN YA'AN CITY

Location of sampling sites		Representative population of water samples	Connection degree	Major factors that affect water quality to be up to below the standards
Yucheng District	Liuliang village	35402	0.4706	Total bacteria and total coliform bacteria exceed the standard. There are visible objects.
	Boshu village	1517	0.4942	Total coliform bacteria exceed the standard. There are visible objects.
	Zhanggou village	15743	0.5471	Total bacteria and total coliform bacteria exceed the standard. Sulfate content exceeds the standard.
	Xianghua village	15743	0.5816	Total bacteria and total coliform bacteria exceed the standard. Sulfate content exceeds the standard.
Minshan County	Gucheng,Xindian, pit water	1700	0.4835	Total coliform bacteria exceed the standard. Chromaticity exceeds the standard.
	Shiqiao,Xindian, pond water	1108	0.5028	Total bacteria and total coliform bacteria exceed the standard.
	Shuiyue,pit water	1642	0.5344	Total bacteria and total coliform bacteria exceed the standard, Nitrate exceeds the standard.
	Shigang,Zhongfeng, Yuxi River	5475	0.5384	Total bacteria and total coliform bacteria exceed the standard. Turbidity degree exceeds the standard.
	Yongxing, Huacheng, well water	5762	0.5554	Total coliform bacteria exceeds the standard.
	Weigan village in southern city, water of Minshan River	1600	0.5616	Chromaticity exceeds the standard.
Hanyuan County	Huangmu,pond water	1959	0.2143	Total bacteria and total coliform bacteria exceed the standard.
	Huangmu,weir water	1960	0.2571	Total bacteria and total coliform bacteria exceed the standard.
	Downstream water of Liusha River	4527	0.4286	Total bacteria and total coliform bacteria exceed the standard.
	Upstream water of Liusha River	4527	0.5625	Total coliform bacteria exceeds the standard.
	Xianfeng, the 4th team in Saijing town.	519	0.5714	Total coliform bacteria exceeds the standard.

TABL 3. DISTRICTS AND COUNTIES OF RELATIVELY UNSAFE RURAL DRINKING WATER QUALITY

Location of sample points		Representative population of water samples	Connection degree	Major factors that affect water quality to be up to below the standards.
Yingjing County	Mixi village,Shiqiao town	200	0.6764	Nitrate exceeds the standard.
Shimian County	Songlin River,Xianfeng town	16038	0.7778	Total bacteria and total coliform bacteria exceed the standard.
Tianquan County	Ganhe village,Yuquan town	2600	0.7722	Fluoride content exceeds the standard. Total coliform bacteria exceed the standard.
	Huzhu village,Dahe town	5100	0.7778	Fluoride content exceeds the standard. Total coliform bacteria exceed the standard.
Lushan County	Caoping village，Siyan town	1965	0.8095	Total coliform bacteria exceed the standard.
Baoxing County	Dayu groove of Dayu village,Lingguan town	1590	0.8315	Total coliform bacteria exceed the standard.

IV. CONCLUSIONS

Based on research results, this study points out that the SPA theory has yet to be further explored in the following fields:

①Determining the connection degree is the key to evaluation results, a , b , c in the formulae of connection degree are estimated based on provided information. Criterions of this paper are: it is considered identical when the evaluation factors are in the same level; it is considered contrary when the evaluation factors are in the separated levels; it is considered discrepant when the evaluation factors are in the adjacent levels. According to the principles of SPA, j =-1, therefore, the key to calculation of μ is how to get i .Theoretically, i is between [-1, 1]. However, actually, different angles, issues of different natures and different perspectives have an impact on values of i . This paper selects i = 0, i.e., the discrepant part is not taken into account in calculation of μ .

② Set Pair Analysis, as an integrated evaluation method, is able to objectively reflect the overall state of things. However, it is easy to neglect some case-by-case and prominent indicators of things, which mainly manifests in:

When a majority of indicators in a county are in the safe range, however, only with unsafety degree of one or two indicators being prominent, it is unideal to sort the drinking water quality unsafety degree by means of the SPA method;

When data of some villages are not adequate, the results are also unideal. For example, 10 indicators are tested in the first village, 2 being unsafe and 1 being basically safe; 17 indicators are tested in the second village, 3 being unsafe and 1 being basically safe. Under normal circumstances, the second village is safer than the first village by means of the SPA method. But that is not the case.

Nevertheless, as a brand-new theory and method of uncertainty, SPA is of clear concept, concise calculation and richness of content. Based on analysis and theory about SPA, this paper conducts an integrated evaluation of rural drinking water quality in Ya'an City, so as to provide scientific decisions and rational basis for the analysis of water resources development and utilization in Ya'an; it helps the public to access information, which can not only improve supervision but also impel government to carry out constructions of infrastructural facilities and perfect ability of management policies and reformation. At the same time, it provides an important reference for rural drinking water quality evaluation in other regions.

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