Assessment of the Tarim River basin water resources sustainable utilization based on entropy weight set pair theory

Shibao Lu, Yizi Shang and Wei Li

ABSTRACT

Scientific assessment provides important tools for the sustainable use of water resources. This paper applies the set pair theory of entropy weight to evaluate the uncertainty involved. A preliminary classification of samples is conducted by calculating the connection degree of each evaluation index, and then uniform, differential and confrontational analyses of set pairs are carried out on the samples to identify their level. In identifying the weight of each evaluation index, the entropy value theory of information theory is introduced into the model. Combined with Tarim 2004 to 2007 water resource data, an evaluation of the sustainable water resource utilization in this region is made from the social and economic, water resource and ecological environmental water resource evaluation index system. The results show that the development and utilization of water resources in the Sanyuanliu region of Tarim are saturated, and the utilization of water resources in the Hotan region (III), Aksu region (III) and Kashgar region (III) appears to be unsustainable. After a comparison with other methods, it is concluded that the evaluation result provided by the method is reasonable and objective.

Key words | entropy weight method, evaluation index, set pair analysis, water resource utilization

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INTRODUCTION

Water, an important natural resource and the most important component of the natural environment, is an indispensably valuable resource for human survival and development as well as major a strategic economic resource. With China's rapid socio-economic development, the difference between the demand for water and its supply is increasing significantly (Asefa *et al.* 2014; Dessu *et al.* 2014). Water resources have become the important factor in social and economic development. Therefore, the scientific assessment and rational development of water resources constitute an important step in guaranteeing sustainable socio-economic development through sustainable water resource use.

Since the middle of the last century, with the increase in worldwide population and socio-economic development, as well as the increase in water withdrawal and drainage for production and people's daily lives (Nazemi & Wheater 2014), numerous countries have suffered different levels of water scarcity, aggravated by aquatic ecological degeneration and water pollution and other water-associated problems. This has led to the consideration of practical ways to achieve the sustainable use of water. Water resource assessment, as a fundamental task in water resource planning and management, is attracting increasing attention in various countries around the world.

In 1999, China's Ministry of Water Resources published *A Guide to Water Resources Assessment* (SL/T 238-1999) comprising industrial standards for making specific rules on the content, techniques and methods for systematically assessing water resources for the first national water assessment survey. *A Guide to Water Resources Assessment* (SL/T

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238-1999) (Department of Water Resources and Hydrology) introduced the contents and the requirements for the analysis and investigation of the utilization of water resources, the existing problems, the influence of the development and utilization of water resources on the environment, and comprehensive evaluation of water resources. In 2001, further modifications and improvement were made during the national water resources planning process.

The main evaluation methods in the Guide include the main composition method, grey clustering method, fuzzy comprehensive evaluation method and the fuzzy variable model method (External Evaluation of UNESCO's Contribution to the World Water Assessment Programme; Meng & Hu 2009; Lu *et al.* 2017). Of the evaluations reported, Wang *et al.* use a theoretical assessment method based on a binary water circulation mode at the beginning of the 21st century (Wang *et al.* 2004) to gauge the effect of human interference on the natural circulation system;

Liu (Liu *et al.* 2010) analyzes water supply and demand and potential for development and utilization in Greece's Aegean Islands; Ni's research (Ni *et al.* 2012) includes water quantity and quality, with the quantity evaluation covering surface water, groundwater and the total amount of water resources, while the quality evaluation involves surface water and groundwater; Shivanita (Umapathi *et al.* 2013) evaluates water resources, precipitation, surface water, groundwater, the total quantity of water resources and the combination and conversion relationships between each component and their impact; and Huang (Huang *et al.* 2012) establishes a hydrogeological conceptual model and corresponding mathematical model of the groundwater system to calculate the exploitable amount of groundwater under different conditions using numerical simulation based on finite differences. The Guide's assessment also provides important tools for the sustainable use of water resources.

Some progress in water assessment has been made in various countries, although there are still a number of problems to be solved in current analysis research, including the following.

Assessment foundation

The method of measurement-restoration-modification is often used in water resource assessment by taking the influence of human activities as its starting point, then restoring the water circulation flux to its natural state to evaluate the volume of water. However, with the increasing amount of human activities, the volumetric ratio of water resources to be restored and modified is becoming greater (Shang *et al.* 2016), rendering such a unitary static assessment approach inappropriate in most situations.

Assessment mode

Some countries always use surface/ground water and water quantity/quality separation modes of assessment (Singh 2014). However, these assessment modes separate the complex transformation relationship between surface water and ground water, and cannot reflect the influence of water quality on water resources, which is detrimental to the system's allocation, integrated scheduling and comprehensive management.

Assessment method

Statistical methods are mainly used in contemporary water assessment. However, these cannot cope with more complex and changeable environments. Some studies (Ni *et al.* 2012; Xie *et al.* 2013) have tried to introduce a distributed hydrological model into water resource assessment by considering it as the main content where, with the physical mechanism, the model will constitute an important tool, as it is for the further 3S development and computer technologies.

Set pair theory overcomes many of these assessment problems (Xie *et al.* 2013). This theory accommodates the uncertainty, combines quantitative with qualitative analysis, integrates objective and subjective assessments and analyzes the overall and partial aspects of the interrelationships between the various objects involved. Based on the analysis of system uncertainty in the sustainable use of water resources, the evaluation indicators and criteria can be paired to constitute a set of anti-relational links to analyze commonalities and differences. The numerous indicators in the system can then be entirely expressed in an element connection number that can measure the overall sustainable level of water resource use.

Information entropy is a systematic disordering measurement in which entropy can be used to balance the volume of effective information and reflect the relative significance of various assessment factors. Therefore, the weights of these factors, through entropy, can effectively avoid human subjectivity by considering their differences. Hence, the calculation of the information entropy-based indicator weights can be objectively applied to the water resource assessment process (Sigh & Oh 2015; Xu *et al.* 2015).

In this paper, information entropy is combined with set pair theory, a set pair analysis (SPA) model is constructed and evaluated by the basic entropy weight method and applied to make an actual assessment during the water resource assessment process. A mathematical analysis method is adopted for the certainties and uncertainties contained in each system and element. Additionally, taking a specific district in northwest China as a case study, an evaluation index system for sustainable water resource utilization is established in combination with 2004 to 2007 water resource utilization data. The SPA method is used by taking the objective influence of each index into full consideration, to evaluate the sustainable utilization of water resources in the region (Liu *et al.* 2010). The method enriches water resource sustainable utilization and provides new theoretical guidance for water resource protection, development and utilization.

BASIC THEORY OF SET PAIR ANALYSIS

SPA is a new method of analyzing uncertain relationships that was first put forward by Chinese scholar Zhao Keqin in a national system theory and regional planning conference. Its core concept is to take certainties and uncertainties as a mutually connecting, restricting, interpenetrating and interchangeable certain and uncertain system (Su *et al.* 2009a, 2011b). Basic SPA theory involves constructing a set pair H(A,B) according to given collections A and B, and conduct an IDC quantitative analysis and comparison of the features of the two collections. Suppose there are N features, among which there are S common features, P independent features and F features that are neither uniform nor opposite. Therefore, the connection degree μ is:

$$\mu = \frac{S}{N} + \frac{F}{N} i + \frac{P}{N} j \tag{1}$$

where i is the difference coefficient, whose value depends on different situations within the interval [−1, 1]and may sometimes serve as a differential mark; j is contrary degree coefficient, which is usually set as −1 and may sometimes serve as contrary mark. μ is the connection degree of set pair H(A,B). Normally, a = S/N, b = F/N, c = P/N, in which case (−1,1) is changed to

$$\mu = a + bi + cj \tag{2}$$

where a, b and c are components of the connection degree, and a + b + c = 1. a, b and c are called the identical degree, difference degree and contrary degree (Su *et al.* 2009a, 2009b) respectively of H(X,Y).

SET PAIR ANALYSIS FOR SUSTAINABLE WATER RESOURCE EVALUATION

Sustainable water resource evaluation is an analytical process with a certainty evaluation index and a standard, as well as an uncertainty, evaluation factor. The sustainable water resource evaluation in SPA involves joining a selectable plan and an ideal plan into a pair of plans. An IDC decision analysis is then carried out on the pair to find the plan 'closest' to the ideal plan by ranking feasible plans according to their order of superiority. In such an evaluation, suppose there are N evaluation indices, among which there are S evaluation indices that are superior to the standard and P evaluation indexes inferior to the standard. In addition, there are F unevaluated or un-compared evaluation indices. The connection degree of each evaluation index can be calculated by comparing a, b and c. For water resource utilization of the same level in different regions, while there is a different value of evaluation index, identical, differential and contrast set pair analyses are needed to grade standard. Depending on the features of the evaluation indices, these can be divided into the-smaller-the-better types and the-bigger-the-better types. The connection degree of the former index is

$$\mu_{sk}\begin{cases} 1+0i+0j & x\in[0,\mathrm{S}_1] \\ \frac{S_2-\mathrm{x}}{S_2-S_1}+\frac{\mathrm{x}-S_2}{S_2-S_1}\mathrm{i}+0\mathrm{j} & x\in(\mathrm{S}_1,\mathrm{S}_2] \\ 0+\frac{S_3-\mathrm{x}}{S_3-S_2}+\frac{\mathrm{x}-S_2}{S_3-S_2}\mathrm{i} & x\in(\mathrm{S}_2,\mathrm{S}_3] \\ 0+0i+0j & x\in(\mathrm{S}_3,\infty] \end{cases} \quad (3)$$

while the connection degree of the-bigger-the-better index is

$$\mu_{sk}\begin{cases} 1+0i+0j & x\in[\mathrm{S}_1,\infty] \\ \frac{S_2-\mathrm{x}}{S_2-S_1}+\frac{\mathrm{x}-S_2}{S_2-S_1}\mathrm{i}+0\mathrm{j} & x\in[\mathrm{S}_2,\mathrm{S}_1) \\ 0+\frac{S_3-\mathrm{x}}{S_3-S_2}+\frac{\mathrm{x}-S_2}{S_3-S_2}\mathrm{i} & x\in[\mathrm{S}_3,\mathrm{S}_2) \\ 0+0i+0j & x\in[0,\mathrm{S}_3) \end{cases} \quad (4)$$

The S_1, S_2 and S_3 in (3) and (4) are the respective standard values of the evaluation index; k is the No. k evaluation index; S is the No. S point to be evaluated; and x is the measured value of the No. k evaluation index at evaluation point S.

DETERMINATION OF THE WEIGHT COEFFICIENT BY THE ENTROPY WEIGHT METHOD

In the evaluation of water resources based on SPA, each evaluation index has an equal weight, which fails to take into account the different indices and will therefore produce inaccurate results. In information theory, the entropy value can reflect the degree of disorder in information as well as the amount of information itself (Lu *et al.* 2016a, 2016b, 2016c). More information in a certain index indicates a bigger influence, while a smaller entropy value denotes less degree of disorder in the system. Therefore, the degree of information and its effect on the evaluation by information entropy (the weight of each evaluation index determined by the matrix formed by the evaluation index value), can reflect the evaluation features of the water resources. The main calculation steps follow.

CALCULATION USING THE ENTROPY WEIGHT METHOD

(1) Suppose an index system formed by m indices is used to compare n plans, and the feature value of the No. i index in the No. j plan is x_{ij}, the matrix of feature values of the indices is

$$X=(x_{ij})m\times n \quad (5)$$

When the system is in a different condition, the probability of each condition is P_i $(i=1,\ldots,n)$, and the entropy of the system is defined for a specific index x_i, the information entropy is

$$E=-\sum\nolimits_{i=1}^{n}\mathrm{d_i}\ln d_i \quad (6)$$

According to (2), entropy with the following conditions can be used:

$$E=-\sum_{i=1}^{m}\frac{d_{ij}}{d_i}\ln\frac{d_{ij}}{d_i} \quad (7)$$

According to the *extremum* property, when $d_{ij}/d_i(k=1,2,\ldots,m)$ is close to the equality condition, the entropy increases, and when $d_{ij}/d_i(k=1,2,\ldots,m)$ reaches the equality condition, the conditional entropy reaches maximal value, namely $E_{\max}=\ln m$.

(2) Normalize the indices. The dependence level in fuzzy mathematics as the normalization process is used to solve the comparison problem due to the different index dimensions. $E_{\max}$ is used to normalize (3), and therefore the entropy to evaluate decision importance is

$$\mathrm{e(d_i)}=-\frac{1}{1nm}\sum\nolimits_{i=1}^{m}\frac{\mathrm{d}_{ij}}{d_i}\ln\frac{d_{ij}}{d_i} \quad (8)$$

(3) Determine the entropy weight. After normalization, the objective weight is obtained by

$$\theta_i=\frac{1}{n-E_e}[1-e(d_i)] \quad (9)$$

of which

$$E_e = \sum_1^n e(d_i),\ 0 \le \theta \le 1 且 \sum_1^n \theta_i = 1$$

CASE STUDY

Located in an arid area of west China, the Tarim River has a total area of 1.02 million km^2 and, with a 1,321 km long main stream, it is the longest continental river in China. In the Tarim basin, the average participation rainfall in many years is 105.5 billion m^3, while the total amount of water resource is 44.61 billion m^3, with 41.88 billion m^3 surface water, 36.955 billion m^3 underground water resource and 49.95 billion m^3 total surface runoff (Huang & Pang 2010; Tan et al. 2011; Xiao et al. 2012). In the past 50 years, with the high-intensity economic and social activities featuring the development and utilization of water resources in the Tarim river, its natural ecological process has undergone significant changes, intensified desertification, an expanded area, severely damaged biological diversity and disastrous weather such as increased airborne dust and dust storms, resulting in a daily deterioration in the ecological environment. All these are posing a severe threat to the area's ecological safety and healthy socio-economic development.

Establishment of the evaluation standard

A sustainable water resource utilization system is a complex compound system. The evaluation index system must be comprehensive and avoid excessive detail or information overlap. The water resource system is a comprehensive system, and has a complex sub-system structure intersected with the society, economy and environment systems (Lu et al. 2016a, 2016b, 2016c; Ma et al. 2013). Therefore, the selection of the water resource evaluation index system must consider the regional features of sustainable development objects in the evaluation, social and economic development and the development and utilization of water resources, etc. Twelve indices are selected from three systems according to the contribution of water resources to social development, including social development, water resource conditions and the ecological environment in four regions, so as to establish an evaluation index system of three standard evaluation levels. According to the level of sustainable water resource development in this region, water resource sustainability is divided into four levels – sustainable (level I), sub-sustainable (level II), bad-sustainable (level III) and non-sustainable (level IV). The I, II and III levels are relatively clear. For the difference between level III and level IV, consider the input-output benefit ratio of the water resources. For the input index, suppose the upper limit value of the level IV standard is two times than that of the level III standard; while, for the output index, suppose the upper limit of the level IV standard is half that of the level III-standard, as shown in Table 1.

Determination of entropy weight

For each evaluation factor, the weight is decided by the plan used for water resource evaluation (Lu et al. 2015). Different plans have different weights, which is called objective information. The entropy weight method can fully extract information in the original data, and therefore the result is relatively objective (Sun et al. 2013). In addition, some studies use the probabilistic method, hierarchical method and Delphi method to determine the subjective weights (Zheng et al. 2011; Huang et al. 2012; Hsueh 2015; Lu et al. 2016a, 2016b, 2016c). To avoid influence from subjective factors and reflect the accuracy of the complementary entropy weight method in the water resource evaluation, the connection degree is first calculated by SPA of three regions according to the identical, differential and contrary values in (1), (3) and (4), and the grade of water resource evaluation determined according to the standards as shown in Table 3. Then the weight of each evaluation factor is calculated according to (5)–(9), as shown in Table 2.

Analysis and discussion of evaluation results

From several important indices for water resource evaluation in Table 2, the drought levels denote Kashgar > Aksu > Hotan, with respective values of 39.35, 21.04 and 20.5. As for development and utilization of water resources, the levels denote Kashgar > Aksu > Hotan, with respective values of 133.7%, 130.9% and 38.7% while, for per capita

Table 1 | Evaluation indices and classification standard

System (code)	Index (code)	I	II	III	IV
Social economy (C_1)	Natural population growth rate (%) (p_1)	2	6	12	24
	Population density (people/km²) (p_2)	20	60	100	200
	GDP growth rate (%) (p_3)	8	6	4	2
	Per capita GDP (CNY/people) (p_4)	10000	6000	3000	1500
Water resource (C_2)	Per capita water resource amount (m³/people) (p_5)	7000	5000	3500	1750
	Per capita water supply (m³/people) (p_6)	4500	3500	2500	1250
	Per capital daily domestic water (people/day) (p_7)	130	100	70	35
	Water supply modulus (10^4 m³/km²) (p_8)	10	35	60	120
	Utilization rate of water resource (%) (p_9)	50	62	75	150
	Degree of water resource development (%) (p_{10})	30	50	70	140
	Diversion rate of surface water (%) (p_{11})	30	50	70	140
	Exploitation rate of underground water (%) (p_{12})	20	35	50	100
	Elasticity of water consumption (p_{13})	0.1	0.3	0.5	1
	Arable land rate (%) (p_{14})	6.7	16.7	26.7	53.4
	Arable land irrigation rate (%) (p_{15})	20	40	60	120
	Water conservation irrigation rate (%) (p_{16})	80	50	20	10
	Water conservation investment ratio (%) (p_{17})	5	3.5	2	1
Ecological environment (C_3)	Ecological water consumption rate (%) (p_{18})	25	20	15	7.5
	Water and soil loss rate (%) (p_{19})	10	20	30	60
	Arable land salinization rate (%) (p_{20})	10	20	30	60
	Drought index (p_{21})	10	25	40	80

Table 2 | Evaluation indices, weights and dependence levels at the sources of the Tarim River

	Aksu		Kashgar		Hotan		Sanyuanliu		
Index	Actual value	Dependence level	Actual value	Dependence level	Actual value	Dependence level	Actual value	Dependence level	Weight
P1	12.10	IV	11.63	III	11.86	III	11.81	III	0.0708
P2	12.98	I	19.40	I	11.50	I	15.54	I	0.0870
P3	8,190.00	II	4,508.14	III	2,891.75	IV	5,197.88	III	0.0783
P4	3,420.25	IV	2,180.75	IV	5,975.50	II	3,389.01	IV	0.0806
P5	4,423.50	II	2,834.25	III	2,233.75	IV	3,137.64	III	0.0804
P6	69.15	IV	57.56	IV	38.77	IV	63.03	IV	0.0702
P7	44.18	III	56.83	III	24.88	II	38.72	III	0.0742
P8	130.92	IV	133.72	IV	38.70	II	93.83	IV	0.1055
P9	15.84	II	25.04	III	10.65	II	15.10	II	0.0708
P10	92.89	IV	100.25	IV	93.77	IV	96.42	IV	0.0791
P11	0.06	Bad IV	1.15	IV	7.28	I	1.71	IV	0.0967
P12	20.50	II	21.04	II	39.35	III	26.96	III	0.1064

Note: the main data source is from the Xinjiang Statistical Yearbook in 2005, 2006, 2007 and 2008 and the literature.

water resources, Hotan > Aksu > Kashgar, with respective values of 5,975.5 m^3, 3,420.25 m^3 and 2,180.75 m^3. Therefore, the level of development and utilization of water resources in Aksu and Kashgar is higher while their availability is lower, which is a saturated condition for water resource development. However, the level in Hotan is only 38.7%, indicating that there is still some potential for development.

Table 3 | Degrees of contrary in the sources of Tarim River

Region	System	$\mu 1$	$\mu 2$	$\mu 3$	$\mu 4$	μ	Grade
Aksu	C1	0.0851	0.0689	0.0340	−0.0945	$\mu 1$	I
	C2	−0.3333	−0.1213	0.4123	0.2336	$\mu 3$	III
	C3	−0.0954	0.0097	0.0001	−0.0097	$\mu 2$	II
	C	−0.3436	−0.0427	0.4465	0.1295	$\mu 3$	III
Kashgar	C1	−0.0620	0.0988	0.0620	0.0267	$\mu 2$	II
	C2	−0.5608	−0.2171	0.3845	0.5505	$\mu 4$	IV
	C3	−0.1011	0.0097	0.1344	−0.0097	$\mu 3$	III
	C	−0.7239	−0.1086	0.5809	0.5676	$\mu 3$	III
Hotan	C1	−0.0620	−0.0048	0.0618	0.0620	$\mu 4$	IV
	C2	−0.1237	0.0528	0.4168	−0.0964	$\mu 3$	III
	C3	−0.0097	0.1100	0.0097	0.0095	$\mu 2$	II
	C	−0.1954	0.1580	0.4883	−0.0249	$\mu 3$	III

Table 3 shows that the sustainable water resource utilization in each area has reached a near-non-sustainable condition. The level of sustainable water resource utilization in the three regions is ranked Hotan > Aksu > Kashgar, all of which meet the practical condition. From Table 2, the top six indices in the selected 12 evaluation index weights are drought index $p_{12,}$ water resource development and utilization rate p_8, ecological water consumption rate p_{11}, GDP growth rate p_2, per capita water resource p_4 and per capita water supply p_5, all of which are important water resource utilization constraints.

Using the relative dependence level formula in the evaluation of water resources in this region, the evaluation grades and other index values change the index data value of the evaluation matrix (Sharma & Meher 2014; Dunn *et al.* 2015). The variations in the comprehensive index in Table 2 indicate that the potential for sustainable water resource utilization from 2004 to 2007 is decreasing and, the change in the comprehensive index in Table 3 indicates that it has now reached level III (bad-sustainable). The main reason for this is the huge evaporation that has taken place in the arid west region, backward water conservancy facilities, high quotas for agricultural irrigation, an increasing demand for water resources for economic growth, and 'engineering' water shortage in some regions, where water conservancy engineering facilities have been constructed. Of the areas involved, the sustainable water resource utilization rates in Aksu and Hotan are 130.92% and 133.72% respectively. This denotes super-high saturated development, having far exceeded the upper limit for the development and utilization of water resource in arid regions. The sustainable water resource utilization rate in the Hotan region is 38.7%, however, which still has some potential for development.

The sequence of sub-systems in socio-economic development is Aksu (I) > Kashgar region (II) > Hotan region (IV). As for GDP, the GDP growth rate and other indices, the Aksu water resource is the foundation for sustainable socio-economic development. For the sustainable water resource utilization sub-system, Table 2 indicates that the sequence in three regions of the whole compound system is Hotan region (III) > Aksu region (III) > Kashgar region (IV). As for the water resource sub-system, it is the core for sustainable water resource utilization. Therefore, it is essential to improve the development and utilization rate of water resources and save water. Sustainable development in the Hotan region is more likely than that of the Asku and Kashgar regions, which are mainly reflected in the arable land rate, water supply modulus, per capita water consumption and water resource development and utilization rate.

For the sub-system of ecological environment, the sustainable development order is Hotan (II) > Aksu (II) > Kashgar (III). The Kashgar region is at a 'relatively bad' level, which is also the reason for the lowest sustainable utilization degree of the compound system of water resources in this region. Meanwhile, since the ecological water consumption rate arid index and other index data values are respectively 0.06 and 20.50, 1.15 and 21.04, it is clear that the ecological environment in this region is very vulnerable.

Table 4 | Summary of three evaluation methods

	Property identification method		Comprehensive evaluation method		Fuzzy matter element method	
Region	Dependence	Grade order	Dependence	Grade order	Dependence	Grade order
Aksu	III	2	III	2	III	3
Kashgar	III	4	IV	4	III	4
Hotan	III	1	III	1	III	1

Table 4 compares the results with the property identification method, comprehensive evaluation method and fuzzy matter element method, which shows they are quite similar.

CONCLUSION

Utilizing water resources to promote harmonious socio-economic development is one of the most important features for regional sustainability in the future. There are many factors involved, and scientific evaluation can help promote their sustainability and regional sustainable development (Huang *et al.* 2012).

The comprehensive evaluation and entropy weight method adopted in this paper does this by organically integrating the subjective and objective indicators. An evaluation model for sustainable water resource utilization is established using the SPA method and 12 indexes are selected from the socio-economic system, water resource system, and ecological environment system to establish the evaluation indices. This simplifies the calculation of the weights involved to overcome the lack of a uniform standard for evaluation indices and reduces subjectivity in the evaluation process as far as possible – effectively solving the superior and inferior ordering problem of the indicators for sustainable water resource utilization and objectively reflecting the contribution of the evaluation indicators.

The application of the method to a case study of the Tarim river head indicates its sustainable water resource utilization to be basically in a weak-non-sustainable condition in the order of the Hotan region (III) > Aksu region (III) > Kashgar region (III). Of the three sub-systems for sustainable water resource utilization, the socio-economic sub-system ranks Aksu (I) > Kashgar (II) > Hotan (IV); with the water resource sub-system being Hotan (III) > Aksu (III) > Kashgar (IV); and ecological environment sub-system Hotan (II) > Aksu (II) > Kashgar (III). In addition, the comparison of these evaluation results with those of the property identification method, comprehensive evaluation method and fuzzy matter element method confirms the validity of the method. However, the method remains to be further developed and tested so it can further determine the effectiveness of entropy weight SPA to evaluate the sustainable utilization of water resources (Yue *et al.* 2014).

For the case study, achieving the economic basis and important targets in sustainable water utilization involves trying to improve existing social and economic conditions in the Hotan region and further optimize social and economic conditions in Asku and Kashgar regions on the basis of maintaining current economic and social conditions so as to realize rapid and successful economic and social development. The ecological environment is the basic resource for current and future society, and will influence overall sustainable development of the whole region. Hence, it is of profound and far-reaching significance to protect the ecological environment. The water resource sub-system is the core for sustainable utilization, and it is imperative to conserve water and improve water resource utilization efficiency. A good ecological environment is the basic condition for people's life and development, and the foundation for economic and social development, and thus needs to be protected.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests in this work.

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