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Original Research Paper

Harmony Assessment Indicators and Methods for Water-Human System Based on Synthesis Model in Weihe Basin

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ABSTRACT

In response to a growing environmental crisis and to vast social inequalities in global development, we argue to adopt harmony development as a leading development model. The harmony assessment and harmony indicators can be powerful decision-supporting tools that foster harmonious development. In this paper, a set of evaluation indicators and models are proposed to assess the harmony level of the water-human system. Based on the concept of water-human harmony, authors established an index system with capacity to estimate water-human harmony, including 2 systems, 7 subsystems and 24 indicators. Employing Set Pair Analysis theory and Variable Fuzzy Set theory, the authors developed a model based on the variable weights (SPA-VFS-VW model) to describe the development degree of water-human system. The cooperative game theory was applied to set up a Cooperative Game Distance Coordination Degree model (CGDCD model). A novel harmony degree method (multi-criteria multiplicative synthesis model) was developed to assess the harmony degree. The derived models in this paper were applied to estimate the harmony degree of water-human system for a period of 10 years (2001 to 2010) in the Weihe basin. The results indicated that the values of harmony degree have a slightly decreasing trend ranging 0.597 to 0.696 in values. The assessing performance was compared with two assessment models to confirm the feasibility of the developed models and the reliability of the obtained results. This exploratory study also illustrates that the synthesis model presented in this paper can provide a practical and feasible approach to assess the water-human harmony. Assessment indicators and models provide the powerful decision-supporting tools for making environment strategies.

INTRODUCTION

The increasing demands for water in dry climates as a consequence of the population growth, urbanization, economic development and environmental requirements have been accelerated from year to year (Mohamad 2014, Francisco et al. 2014, Tom et al. 2014, Xianqi Zhang et al. 2014, Patil et al. 2014). The spatial and temporal variability of human induced hydrological changes in the basin is affecting the water quantity and water environment, which are converged to challenge the relation of water and human system (Mohamad 2014). Water environment problem, the shortage of water resources, serious water pollution have become a restricting factors for the regional economic and social sustainable development (Cashmore et al. 2007, Lenzen & Schaeffer 2004). An interdisciplinary approach is required to solve the current and future water scarcity and environment problems, and to minimize inequalities in the perspective of economic, social and environmental development (Francisco et al. 2014). The harmonious development of water and human system has gained broad acceptance amongst politician and other stakeholders in the society ever since deteriorating water environmental conditions in many parts of the world made it evident that water-human harmony may be at stake (Li 2010, Kang 2013). The harmony assessment and harmony indicators can be powerful decision-supporting tools for making water resources and environment strategies. This paper aims to contribute to the objective that frames assessment indicators and methods in the context of harmony development as a decision-making strategy.

Human society is a complex adaptive system embedded within the water system, on which it depends for support. Both of these systems coevolve in mutual interaction, and each of these systems consists of a myriad of subsystems that coevolve in mutual interaction with higher uncertainties. The evaluation for water-human harmony is a complex multi-objective issue with inherent uncertainties, and therefore various methods have been invented to effectively assess the uncertainties of these systems. Fuzzy analysis, stochastic analysis, matter-element analysis, and grey theory, among them, are powerful evaluation methods for the complex uncertainties systems (Li 2007, Matbouli et al. 2014, Mora et al. 2009, Wang 2004). Traditional approaches, however, usually produce fixed quantity indicators which only express a simple relation rather than detail construction of the complex systems (Wang et al. 2010). To reduce these biases, Zhao Keqin (1994) developed a new comprehensive integrated system analysis method, knows as Set Pair Analysis Method (SPA), which can reveal quantitatively and qualitatively degrees of identity, discrepancy and contrary for two pairs (Wang et al. 2010, Zhao 1994). The Variable Fuzzy Set Theory (VFS) mathematically describes the relativity and the dynamic variability of fuzzy systems (Chen 2005, Li et al. 2011). A combination of these two methods, SPA-VFS method, is a novel way to evaluate the development conditions of the complex systems.

Human system and water system develop in a coordinated track (Yang 2002, Tang et al. 2010). The models for evaluating coordination degree of the two systems, generally calculate the coordination degree by judging the distance of systems between actual development state and ideal development state (Tang et al. 2010). Therefore the "ideal development state" of a system is an important key. This paper analyses the "ideal development state" of systems by employing the cooperation game theory, and derives a Cooperation Game Distance Coordination Degree model (CGDCD) to assess the coordination degree of human system and water system.

This paper proposes a framework to evaluate water-human harmony that incorporates the following: (a) the conception of the water-human harmony, (b) a set of indicators with a capacity to assess water-human harmony, and (c) evaluation standards and assessment methods. Employing set pair analysis theory and variable fuzzy set theory, the authors derive Set Pair Analysis-Variable Fuzzy Set model based on variable weight (referred to as SPA-VFS-VW model) is developed to describe the development condition of the water-human system. Based on cooperative game theory, a cooperative game distance coordination (CGDCD) model is developed to describe the coordination degrees of the water-human system. Then a novel harmony degree method is proposed based on development degree and coordination degree of the water-human system. The derived methods are applied to assess harmony degree of the water-human system from the year 2001 to 2010 in the Weihe basin (located in Shaanxi province). This study tested the rationality and effectiveness of the devised modelling in the harmony assessment. The results indicated that the evaluation models developed in this paper can provide the practical and feasible methods for assessing the water-human harmony.

HARMONY ASSESSMENT INDICATORS

Harmony is defined as an accord or an agreement in action, opinion, or feeling (Dictionary.com 2014). The water-human harmony refers to congruity of subsystems to their parent systems or to one another (Kang 2013, Zuo 2012). These systems develop in a state of mutual interaction, and mutual adaptation, which promotes coordinated development of the whole water-human system.

Appropriate assessment indicators are required to identify whether the systems are on a path of water-human harmony. The water-human system is a complex system, will affect the sustainable development of water, society and environment. The sustainable development indicators will be taken as the reference to identify the harmony indicators (Rinne et al. 2013, Leontina 2013). The water system alone is composed of 4 subsystems, including water resources, water environment, water disaster, and water management which involve all characteristics of water as natural resources. The human system comprises society, economy and technology as its subsystems. The water-human harmony is a key point to judge the sustainable development of the society and economy. In an arid watershed, factors such as pollution, population growth, and the overall inefficient use of water resources, contribute to deteriorate the harmony. The Weihe watershed is a typical basin in the northwest arid area where significant deterioration of the water system is an issue of grave concern. According to the characteristics of the water system and the human system in the Weihe basin, the authors selected a set of assessment indicators, and established assessment standard grades of indicators for assessing the water-human harmony in the Weihe basin as given in Table 1.

SPA-VFS-VW DEVELOPMENT DEGREE MODEL

SPA assessment theory: An assessed sample $A_l(l=1,2,...,m)$ with m number of indicators, and the kth grade standard $B_k(k=1,2,...,K)$ construct a set pair $H=(A_l,B_k)$ (Wang et al. 2010, Li et al. 2011). The connexion degree $\mu_{A_l \square B_k}$ of the set pair $H=(A_l,B_k)$ can be expressed as:

$$\mu_{A_l \square B_k} = \frac{S}{m} + \frac{F_1}{m} I_1 + \frac{F_2}{m} I_2 + ... \frac{F_{K-2}}{m} I_{K-2} + \frac{P}{m} J \quad ...(1)$$

where, $S + F_1 + F_2 + ... + F_{K-2} + P = m$: in this expression, S denotes the identity degree of $H=(A_l,B_k)$, $F_1, F_2 ... F_{K-2}$ denote discrepancy degrees of $H=(A_l,B_k)$, and P denotes the identity degree of $H=(A_l,B_k)$. $I_j(j=1,2,...,K-2) \in [-1,1]$ are coefficients of discrepancy; J is a coefficient of the contrary, $J=-1$. The relation of A_l and B_k approaches to the identity as the ratio *S/m* reaches closer to 1. If the ratio *P/m* reaches closer to 1, their relation approaches to contrary. Otherwise the relation tends to be discrepancy.

VFS theory: Assuming a pair of opposite fuzzy conceptions $\tilde{A}$ denoting the property of attraction and $\tilde{A}_c$ denoting that of repulsion in the interval *U*, (for any element $u, u \in U$), the relative membership degree of u to $\tilde{A}_c$ can be described as , $\mu_{\tilde{A}}(u)$, and the relative membership degree of u to $\tilde{A}_c$ is described as $\mu_{\tilde{A}_c}(u)$, this gives $\mu_{\tilde{A}}(u) + \mu_{\tilde{A}_c}(u) = 1$. The relative difference degree of u to $\tilde{A}$ is defined as:

$$D_{\tilde{A}}(u) = \mu_{\tilde{A}}(u) - \mu_{\tilde{A}c}(u) \quad ...(2)$$

By substituting $\mu_{\tilde{A}_c}$ we get the following equation,

$$D_{\tilde{A}}(u) = 2\mu_{\tilde{A}}(u) - 1 \quad ...(3)$$

Entropy weight: Given a matrix $X_{ij}(i = 1, 2, ..., m; j = 1, 2, ..., n)$, where *m* is the number of indicators, and *n* is the number of the samples, the entropy of the *i*th indicator is:

$$E_i = -\sum_{j=1}^{n} P(x_{ij}) \ln[P(x_{ij})] / \ln n \quad (i = 1, 2, ..., m;\ j = 1, 2, ..., n) \quad ...(4)$$

Where E_i is the entropy of *i*th indicator, $E_i \in [0,\ 1]$, and $P(x_{ij})$ is the corresponding probabilities of each sample with the condition $\sum_{j=1}^{n} P(x_{ij}) = 1$.

The entropy weight of the *i*th indicator is defined as

$$W_i = (1 - E_i) / (m - \sum_{i=1}^{m} E_i) \quad ...(5)$$

Where, $0 \le W_i \le 1, \quad \sum_{i=1}^{m} W_i = 1$

Variable weight: The variable weight, which is calculated by modifying the basic weights, such as entropy weight and AHP weight, varies with the size of the assessed sample (Li et al. 2013).

Let us assume a group of indicators $(x_1, x_2, ..., x_n)$, and calculate the variable weight using the following the expressions.

$$w_i(x_1, x_2, ..., x_n) = \lambda_i(x_i^{'}) / \sum_{j=1}^{n} \lambda_j(x_j^{'}) \quad (i = 1, 2, ..., n) \quad ...(6)$$

$$\lambda_i(x_i^{'}) = \frac{\lambda_{\neg i}^{*} \lambda_{0i}}{\lambda^{*} \exp\left[\frac{1}{1-k_i} \left(\frac{x_i^{'}}{x_{im}^{'}}\right)^{1-k_i}\right]} \quad ...(7)$$

$$\lambda_{0i} = \frac{w_{0i} \sum_{j \ne i} w_{bj}}{1 - w_{0i}}; \quad \lambda^{*} = \sum_{i=1}^{n} \lambda_{0i}; \quad \lambda_{\neg i}^{*} = \sum_{j \ne i}^{n} \lambda_{0j}; \quad k_i = 1 - \frac{1}{\ln \frac{\lambda_{0i}(\lambda_{\neg i}^{*} + w_{bi})}{\lambda^{*} w_{bi}}} \quad ...(8)$$

$$w_{0i} = \frac{w_{bi}}{\min_{1 \le j \le n} w_{bj} + \max_{1 \le j \le n} w_{bj}}; \quad (i = 1, 2, ..., n;\ j = 1, 2, ..., n) \quad ...(9)$$

Where, $w_i(x_i) \in [0,1]$ is the variable weight, $\lambda_i(x_i^{'})$ is the introduced function, w_0 is the upper weigh, and w_b is the basic weight.

The variable weight is very sensitive to the abnormal indicators, which could accurately describe the importance level of indicators.

SPA-VFS-VW model: The procedures of the SPA-VFS-VW model can be described as the following.

Step1: Establish assessment indicators set $A_l (l = 1, 2, ..., m)$ and the standards set $B_k(k = 1, 2, ..., K)$.

Step 2: Calculate the connexion coefficient of A_l and B_k . If $s_1, s_2, ...s_{K-1}$ divide the interval of grade standards into *K* blocks, each block corresponds to a grade, the connexion coefficient is:

$$\mu_{A_l \sim B_k} = \begin{cases} 1 - \left| \frac{2(s_{k-1} - x_l)}{s_{k-1} - s_{k-2}} \right| & x_l \in \text{grade}(k-1) \\ 1 & x_l \in \text{grade}(k) \\ 1 - \left| \frac{2(x_l - s_k)}{s_{k+1} - s_k} \right| & x_l \in \text{grade}(k+1) \\ -1 & x_l \in \text{grade(others)} \end{cases} \quad ...(10)$$

Step 3: Calculate the relative membership degrees $v_{x_l \sim B_k}$. It is well known that $\mu_{x_l \sim B_k} \in [-1, 1]$. As the identity value of A_l and B_k increases, the value of $\mu_{x_l \sim B_k}$ approaches close to 1 and A_l tends to be more affiliated with the *k*th grade standard. On the contrary, as the identity value of A_l and B_k reduces, A_l tends to be less affiliated with the *k*th grade standard. It is obvious that $\mu_{x_l \sim B_k}$ is a kind of relative difference degree of the fuzzy set "assessment grade *k*". Therefore the relative membership degree v_k of A_l with the fuzzy set "assessment grade *k*" is expressed as:

$$v_{x_l \sim B_k} = (1 + \mu_{x_l \sim B_k}) / 2 \quad ...(11)$$

Step 4: Calculate the comprehensive membership degree $\bar{v}_k$ of each subsystem to 5 grades using the following equation,

$$\bar{v}_k = 1 / \left(1 + \left(\frac{d_k(P_l, x_i)}{d_k(x_i, P_r)}\right)^{\alpha}\right) \quad ...(12)$$

$$d_k(P_l, x_i) = \left\{ \sum_{i=1}^{m} [w_i(1 - v_{ik}(x_i))]^p \right\}^{1/p} \quad ...(13)$$

$$d_k(x_i, P_r) = \left\{ \sum_{i=1}^{m} [w_i(1 - v_{i(k+1)}(x_i))]^p \right\}^{1/p} \quad ...(14)$$

Table 1: Water-human harmony assessment index system and standards in the Weihe basin.

System	Subsystem		Assessment indicators	Assessment standards				
				Grade1	Grade 2	Grade 3	Grade 4	Grade 5
	Water resources	x_1	Water resources per capita (m^3/person)	<500	500-1000	1000-1700	1700-10000	>10000
		x_2	Annual Runoff (mm)	<10	10-50	50-200	200-900	>900
		x_3	Ratio of water resources utilization (%)	>50	30-50	20-30	10-20	<10
		x_4	Proportion of irrigation water to total water resources (%)	>90	73-90	55-73	40-55	<40
Water system	Water environment	x_5	Forest coverage (%)	<10	10-30	30-50	50-60	>60
		x_6	Compliance ratio of industrial wastewater (%)	<40	40-50	50-80	80-95	>95
		x_7	Ratio of polluted water in river (%)	>50	30-50	10-30	5-10	<5
	Water disaster	x_8	Proportion of flood disaster (%)	>20	10-20	5-10	2-5	<2
		x_9	Proportion of drought disaster (%)	>20	10-20	5-10	2-5	<2
	Water management	x_{10}	Perfection of water resources laws (%)	0-20	20-40	40-60	60-80	80-100
		x_{11}	Public awareness on river protection (%)	0-20	20-40	40-60	60-80	80-100
	Society	x_{12}	Population density (person /km^2)	>300	100-300	50-100	20-50	<20
		x_{13}	Cultivated area per capita (ha/ person)	<0.05	0.05-0.08	0.08-0.8	0.8-1	>1
		x_{14}	Water consumption per capita (m^3/person)	>1100	1000-1100	800-1000	510-800	<510
		x_{15}	Proportion of urbanization (%)	<20	20-40	40-60	60-80	>80
		x_{16}	Basic social security coverage (%)	<50	50-65	65-80	80-90	>90
	Economy	x_{17}	GDP per capita (yuan/ person)	<3000	3000-6600	6600-25000	25000-77400	>77400
Human system		x_{18}	Proportion of agricultural output to GDP (%)	>30	15-30	12-15	3-12	<3
		x_{19}	Proportion of tertiary industry to GDP (%)	<20	20-40	40-50	50-60	>60
		x_{20}	Gink coefficient	>0.5	0.4-0.5	0.3-0.4	0.2-0.3	<0.2
		x_{21}	Engel coefficient	>0.6	0.55-0.6	0.4-0.55	0.3-0.4	<0.3
	Technology	x_{22}	Water Consumption per 10,000RMB of GDP (m^3/10,000RMB)	>1060	610-1060	140-610	24-140	<24
		x_{23}	Water consumption per unit irrigation area (%)	<0.3	0.3-0.4	0.4-0.5	0.5-0.6	>0.6
		x_{24}	Recycling rate of industrial water (%)	<30	30-40	40-70	70-90	>90

Where α is model parameter, $\alpha = 1$ or $\alpha = 2$; p is distance parameter, $p = 1$ or $p = 2$.

When $\alpha = 1$, $p = 1$, equation (12) will be modified as

$$\bar{v}_k = \sum_{i=1}^{m} w_i v_{ik}(x_i) \quad ...(15)$$

Step 5: Judge development state of A_i. The development state H is defined as,

$$H = \sum_{k=1}^{K} k\left[\bar{v}_k / \sum_{j=1}^{K} \bar{v}_j\right] = \sum_{k=1}^{K} k\bar{v}'_k \quad ...(16)$$

Step 6: Calculate the development degree (DD). Normalize development state to the interval [0,1], that is,

$$DD = H / n \quad ...(17)$$

Where n is the highest grade.

CGDCD MODEL

Distance coordination degree model: The coordination degree describes a coordination level of two systems, or of the subsystems to their systems (Kang 2013, Yang 2002, Tang 2010). In the water-human harmony assessment, coordination degree reflects a level of the actual development state of assessed systems close to the ideal development state. The coordination degree is measured by the distance coordination degree model incorporating, the weighted absolute distance formula as the following,

$$d = \sum_{i=1}^{N} w_i \times \left|H_i - H^*\right| \quad ...(18)$$

Where d is the distance between the actual state and the ideal state. H_i is the actual development state of ith system. H_i^* is the ideal development state of ith system. w_i is the weight of water system or human system.

As usual, the smaller values of d indicates a larger coordination degree. Therefore, the coordination degree DCD is described as,

$$DCD = 1 - d = 1 - \sum_{i=1}^{N} w_i \times \left|H_i - H^*\right| \quad ...(19)$$

The ideal development state: The water-human system is characterized by interdependent, self-sustaining and dynamic processes, rather than by a static state. There is a kind of pulling force among subsystems, drawing a subsystem to develop into the track of the others subsystem, till they arrive at an ideal development state. In order to analyse the ideal development state, the paper employs the idea of the cooperative game theory. The essence of the cooperative game theory is to search for the coordination or compromise among different competitors with their conflicting interests.

Human and water system evolve in mutual coordination, mutual competition and mutual compromise, and which eventually arrive at an ideal development state. The two systems are visualized as two persons in a cooperative game theory who both are competing and coordinating in order to achieve a "win-win and coexistence" (Chi et al. 2008).

Let us assume that $r_i (i = 1, 2)$ is the contribution rate of water system or human system to the ideal state in a cooperative game. The ideal development state is given by,

$$H^* = \sum_{i=1}^{2} r_i H_i \qquad ...(20)$$

One of the key steps in this model is to identify the contribution rate. To eliminate the biases and subjectivity of any one method, authors compute values of contribution rate in a variety of ways. However the contribution rates from different methods probably conflict on certain level.

Optimal contribution rate: Assume vectors of the contribution rate $r_p = \{r_1, r_2, ...r_L\}, p = 1, 2, ...L$, where L is the number of the vectors. The possible vectors are,

$$r = \sum_{p=1}^{L} a_p \times r_p^T \qquad (a_p > 0) \qquad ...(21)$$

In order to find the optimal contribution rate r^*, we shall minimize the differences of r and r_p, that is, $\min \left\| \sum_{p=1}^{L} a_p \times r_p^T - r_p \right\|$. According to differential properties of matrix, the optimum first derivative condition is converted into the following linear equation.

$$\sum_{p=1}^{L} a_p \times r_q \times r_p^T = r_q \times r_q^T \qquad q = 1, 2, ..., L \qquad ...(22)$$

We can get the optimized solution as $a^*_p = (a_1, a_2, ..., a_L)$, and then we can get contribution rate r_p^* given in equation (21).

HARMONY DEGREE MODEL

As per the conception of water-human harmony, the development degree is no less important than coordination degree (Kang 2013). This paper assigns the two systems the same weights. The harmony degree is assessed by employing multiplicity synthesis modelling and is introduced as,

$$HD = [DD \times DCD]^{\frac{1}{2}} \qquad ...(23)$$

In view of common assessment standards for harmony and sustainability of water resources (Kang 2013, Yang 2002), harmony degree is divided into five grades within an interval of (0, 1) as given in Table 2.

APPLICATION

The proposed models are applied to assess the water-human harmony degree in the Weihe basin from year 2001 to 2010. First, the development degree is assessed by using the SPA-VFS-VW model and the coordination degree is assessed by using the CGDCD model. Then the harmony degree is estimated based on the obtained development degree and coordination degree.

Development degree assessment: Collect data of the indicators in the Weihe basin, establish assessment indicators system, and rank the grade standards of the indicators as depicted in Table 1.

To explain clearly the proposed models, we take the water resources subsystem in 2010 as an example. The data of indicators are x_1 = 339.3m^3/person, x_2 = 118.17mm, x_3 = 59.43%, and x_4 = 65.66%, respectively.

Establish set pair, where A is (x_1, x_2, x_3, x_4) and B is the grade standards of the indicators as given in Table 1.

Calculate the connexion coefficient $\mu_{x_i \sim B_k}$ of the set pair $H = (A_l, B_k)$ and relative membership degree $v_{x_l \sim B_k}$. The results are listed in Table 3.

Calculate the basic weights of indicators by using entropy weight method, and the entropy weight are (0.334, 0.337, 0.321, 0.008). Calculate the variable weight based on the equations (6)-(9). The obtained results are given in Table 4.

The Comprehensive relative membership $\bar{v}_k$ is calculated by using the equations (12) -(15), and the obtained result is $\bar{v}_k = (0.366, 0.449, 0.149, 0.036, 0)$.

Compute the development degree of water resources subsystem in year 2010 by using the equation (16). The value of the development state and the development degree are obtained as 1.854 and 0.559 respectively. Calculate the development degrees of others subsystems as calculated above. The results are given in Table 5.

Calculate the weights of water system and human system based on the AHP method, which are 0.545 and 0.455 respectively. Finally we get the development degrees of the water- human system as given in Table 5.

The development degrees show increasing trends for all the three systems, with their values ranging between 0.491

Table 2: Grades standards of harmony degree in the water-human harmony system.

Grade	1 No harmony	2 Critical harmony	3 Weak harmony	4 Medium harmony	5 Strong harmony
Degree	<0.6	0.6~07	0.7~0.8	0.8~0.9	0.9~1

Table 3: $\mu_{x_l \sim B_k}$ and $v_{x_l \sim B_k}$ of the water resources subsystem in the Weihe basin in 2010.

	$\mu_{x_l \sim B_k}$					$v_{x_l \sim B_k}$				
Indicators	I	II	III	IV	V	I	II	III	IV	V
x_1	1	0.357	-1	-1	-1	1	0.679	0	0	0
x_2	-1	0.091	1	-0.091	-1	0	0.546	1	0.454	0
x_3	1	0.997	-1	-1	-1	1	0.998	0	0	0
x_4	-1	0.185	1	-0.185	-1	0	0.592	1	0.408	0

Table 4: Variable weights of the indicators in the water resources subsystem.

Indicators	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
x_1	0.400	0.332	0.249	0.398	0.329	0.392	0.350	0.396	0.366	0.321
x_2	0.407	0.336	0.251	0.400	0.330	0.392	0.348	0.393	0.363	0.309
x_3	0.188	0.327	0.494	0.196	0.335	0.211	0.297	0.206	0.265	0.363
x_4	0.005	0.006	0.007	0.006	0.007	0.005	0.006	0.005	0.006	0.006

Table 5: The development degrees in the Weihe basin in 2001 to 2010.

System	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Water	0.491	0.492	0.516	0.515	0.534	0.535	0.551	0.555	0.555	0.559
Human	0.509	0.531	0.551	0.552	0.599	0.610	0.630	0.680	0.701	0.736
Water-human	0.499	0.510	0.532	0.532	0.564	0.569	0.587	0.612	0.621	0.640

Table 6: The harmony degrees of water-human system in the Weihe basin.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DD	0.499	0.510	0.532	0.532	0.564	0.569	0.587	0.612	0.621	0.640
DCD	0.954	0.902	0.911	0.909	0.837	0.813	0.802	0.688	0.634	0.557
HD	0.690	0.678	0.696	0.695	0.687	0.680	0.686	0.649	0.628	0.597
Grade	II	II	II	II	II	II	II	II	II	I
FCE model	II	II	II	II	II	II	II	II	II	I
ANN model	III	II	III	III	II	II	II	II	II	II

and 0.736 (Table 5). The results also reveal that the development level of the water system is lower than that of the human system in the period 2001-2010. The human system was developing more rapidly than the water system. There was a steady development in the water-human system.

Coordination degree assessment: The equations (21)-(22) are applied to compute the optimal contribution rate. The equation (20) is applied to compute the ideal development state, which are (2.496, 2.548, 2.659, 2.658, 2.818, 2.844, 2.932, 3.057, 3.105, 3.195). The coordination degree of the water-human system is computed by using equations (18)-(19). The obtained values are given in Table 6.

Harmony degree assessment: The harmony degree of water-human system is computed by using the equation (23). The results are given in Table 6.

The values of the coordination degree are decreasing with the increase of the water system. The results indicate the imbalance development state of the human system and the water system in the period of recent 10 year. The harmony degrees of water-human system locate the grade II (critical harmony) or the grade I (no harmony) except 2010. Meanwhile the proposed model achieves the similar results except few years by comparing with the FCE model and ANN model. However, the difference between the models is justified, as these values are close to the boundary of the two grades which might be identified into anyone of two adjacent grades in the different models. It leads us to conclude that the proposed models from this paper are satisfactory in evaluations.

DISCUSSION AND CONCLUSION

A novel method to assess the harmony degrees of the water-human system was investigated. The SPA-VFS-VW model integrated variable fuzzy set theory and variable weight into set pair analysis method to analyse the development level of the system. The authors developed a coordination model based on the game theory to estimate the coordination level of the system. Taking the Weihe basin as an example, the proposed models were verified satisfactory. It also demonstrated that the proposed model in this paper can provide a new, reliable and convenient way to measure the harmony level of the water-human systems.

To coordinate the relation of water and human society is one of the important ways to solve the water environment problems. Judging the harmony level of the water-human system not only provides a decision-making basis for water environment protection and environment management, but also is of great significance for optimizing water environment, and realizing the sustainable development of water, society, economy and environment.

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