Water Resources Security Evaluation Based on Matter Element Model in the Yellow River Basin

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Abstract

Water resource is a major limitation of human survival and development. Water security assessment is an important task in the environmental protection and control of water. The solution to assess the grade of water security in the Yellow River Basin is to study based on the theory of matter element of extension method. Considering the factors of water resources, water environment and social economic aspects, the assessment index system of water security is established . Based on the defining of assessment level, water security assessment based on matter element model is developed exerted both qualitative and quantitative analysis. According to the calculation of correlation degree in the matter element model, the assessment result is represented by the quantitative data that can reflect water security situation in the Yellow River Basin briefly.The result shows that: water security in Qinghai and Sichuan province is in security level, that in Henan province is in the relative security level, that in Shaanxi and Shandong province is in the security threshold level, that in Shanxi province is in the relative insecurity level and that in Gansu, Ningxia and Inner Mongolia province is in insecurity level. The result of matter element model is scientific and reasonable, simple and easy, and can meet the factual data. matter element model can be used in water security assessment and can reveal the complementary information of every single assessment index.

Keywords: Yellow River Basin; Water Security Assessment; Matter Element Model

1 Introduction

Many scholars focused on water security in response to climate change and human activities since the twentieth century (Xia et al., 2008; Cook et al., 2012; Allan et al., 2013). Water security is an important part of regional sustainable development (Brick et al., 2004; Deborah et al., 2007; Zhao et al., 2009). Water resources in the Yellow River Basin affect and constrain population growing, industrial, agricultural and economic development, and may even the national security (Grey et al., 2007; Xiao et al., 2008; Nazif et al., 2013). The issue of water security defined as an acceptable level of water-related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livehoods, national security human health, and ecosystem services (Bakker et al., 2012). Sustained climate change and intensive human activities have had an increasing impact on water security in northern and westward China (Xia et al., 2007). Problems of water shortage and environment deterioration are getting worse in the Yellow River Basin in recently years. It is because water resources are exposed to the combined effects of climate change; land-use change; increased water utilize and water pollution (Fuet et al., 2004). Water consumption by industry and agriculture increased dramatically and the contrast between upstream and downstream reaches become increasing apparently (Liu et al., 2004).

Ultimately, water security in the Yellow River Basin is severely threatened. Accordingly, to realize social-economic and environmental sustainable development, it is important to identify the major factors restricting water security, choose suitable assessment indexes, assess water security using appropriate assessment methods and put forward some countermeasures.

The research of water security assessment is still in the initial stage of qualitative analysis and lack of the operable quantitative analysis. The emphasis on regional water security assessment is how to determine the assessment indexes and the criteria of assessment grades, as well as how to establish an effective quantitative assessment model in uncertain conditions. Accordingly, water security assessment index is established on the foundation of theoretical analyses, expert consultation, and field investigation. The procedure of water security assessment is established by the matter element model. The advantage of matter element model is the correlation function that provides much differentiation information. The classical field of assessment index is defined in combination with some objective criterion when determine assessment grades, the status of single index is calculated by the correlation function of single index, and then the overall level of multi-index can be concluded by model integration. But now researches of water security assessment by the matter element model are rare.

In this study, the Yellow River Basin was chosen as an example to discuss the application of the matter element model in water security assessment, the differentiation information of every single assessment index was analyzed, and an exploration in field of water security assessment was made as well as some suggestions. Relevant water statistical data for 2006 in the Yellow River Basin were used to analyze water security. In addition, the major factors restricting water security were chosen based on expert consultation and field investigation in this basin. Assessment indexes were then selected and used for multi-factorial assessment of water security using matter element model. The goals of this study were to support optimized regulation of water in the Yellow River Basin, as well as provide scientific references for water security assessment in similar regions.

2 Materials and Methods

2.1 The Matter Element Method of water security

Every object has its own unique attributes in the objective world, which is the essence to distinguish different objects. Every object is the combination of many attributes of itself. Only by further study about the attributes, the assessment then can be precise and can provide scientific grounds in analyzing and making judgments. All the attribute is composed of the name and the corresponding value of it. matter element is a call for short to describe the basic element of things. one-dimensional matter element is represented by ordered triple $R=(P,c,x)$, in which P、c、and x represent the object, the feature of object and the value of object, respectively. P、c、and x are the basic three element in the concept of matter element.

2.1.1 Matter element theory in water security assessment

Water security P has a characteristic c and its value x. An ordered triple $R=(P,c,x)$ is the basic element to describe water security, and is called matter element for water security. Suppose water security P has more than one characteristic and can be described by n characteristics $c_1 \sim c_n$ and the corresponding values $x_1 \sim x_n$. Then matter element P is called n-dimensional matter-element, denoted as:

$$R=(P,c,x)=\begin{bmatrix} P & c_1 & x_1 \\ & c_2 & x_2 \\ & \cdots & \cdots \\ & c_n & x_n \end{bmatrix} \tag{1}$$

Where $R_i=(P,c_i,x_i)$ is called the sub-matter-element of R, $c=[c_1 \sim c_n]$ is the eigenvector, and $x=[x_1 \sim x_n]$ is the value of the eigenvector.

The idea of matter element assessment is that, firstly, assessment objects are divided into several grades according to existing data and the ranges of data at all levels are given by database or expert opinions. Then a multi-index is assessed through inducing the indexes of assessment objects into the set of each grade. The assessment results are compared according to the value of the correlation function. The greater the degree of correlation is, the better the degree of coincidence is.

2.1.2 Determine the classical field

Suppose:

$$R_0=\begin{bmatrix} P_0 & c_1 & x_{01} \\ & c_2 & x_{02} \\ & \cdots & \cdots \\ & c_n & x_{0n} \end{bmatrix}=\begin{bmatrix} P_0 & c_1 & \langle a_{01},b_{01}\rangle \\ & c_2 & \langle a_{02},b_{02}\rangle \\ & \cdots & \cdots \\ & c_n & \langle a_{0n},b_{0n}\rangle \end{bmatrix} \tag{2}$$

Where $x_{01} \sim x_{0n}$ are the value ranges of P_0 about $c_1 \sim c_n$ respectively, namely the classical field, and $x_{0i}=\langle a_{0i},b_{0i}\rangle (i=1\sim n)$.

2.1.3 Determine the controlled field

Suppose

$$R_p=(P,C,X_p)=\begin{bmatrix} p & c_1 & X_{p1} \\ & c_2 & X_{p2} \\ & \cdots & \cdots \\ & c_n & X_{pn} \end{bmatrix}=\begin{bmatrix} p & c_1 & \langle a_{p1},b_{p1}\rangle \\ & c_2 & \langle a_{p2},b_{p2}\rangle \\ & \cdots & \cdots \\ & c_n & \langle a_{pn},b_{pn}\rangle \end{bmatrix} \tag{3}$$

Where $X_{p1} \sim X_{pn}$ are the value ranges of P about $c_1 \sim c_n$ respectively, namely the controlled field of P. Set $X_{pi}=\langle a_{pi},b_{pi}\rangle (i=1\sim n)$, then $X_{0i} \in X_{pi} (i=1\sim n)$ obviously.

2.1.4 Determine the matter element formatted by the objects to be recognized.

To the assessment object P_0, the data or the analysis result expressed in format (4) by matter element.

$$R_0=(P,C,V)=\begin{bmatrix} p & c_1 & V_1 \\ & c_2 & V_2 \\ & \cdots & \cdots \\ & c_n & V_n \end{bmatrix} \tag{4}$$

Where P is the matter element to be assessed and V_i are the detected concrete data of P about C_i respectively, namely the specific data of assessment object.

2.1.5 Establish the correlation function

The values of the correlation function about each index of matter element to be assessed with each level are calculated by formula (5)

$$k_i(V_i)=\begin{cases}\dfrac{-\rho(V,X_{0i})}{|X_{0i}|}(V_i\in X_{0i})\\ \dfrac{\rho(V,X_{0i})}{\rho(V_i,X_{pi})-\rho(V_i,X_{0i})}(V_i\notin X_{0i})\end{cases} \tag{5}$$

Where $\rho(V_i,X_{0i})=\left|V_i-\frac{1}{2}(a_{0i}+b_{0i})\right|-\frac{1}{2}(b_{0i}-a_{0i})(i=1\sim n)$

$$\rho(V_i,X_{pi})=\left|V_i-\frac{1}{2}(a_{pi}+b_{pi})\right|-\frac{1}{2}(b_{pi}-a_{pi})(i=1\sim n)$$

Where $\rho(V_i,X_{0i})$ represents the distance of the $i\,th$ index V_i related to the corresponding classical field $X_{0i}=[a_{0i},b_{0i}]$; $\rho(V_i,X_{pi})$ represents the distance of the assessed matter element of the $i\,th$ index V_i to the controlled field $X_{pi}=[a_{pi},b_{pi}]$.

2.1.6 Calculate the correlation degree

Suppose:

$$K(p)=\sum_{i=1}^{n}\lambda_i K(v_i) \tag{6}$$

Where λ_i means the weighting of corresponding index $i\,th$, $K(p)$ means attributive degree of assessment object in all assessment levels, represents the degree of p belong to p_0, and ranges from $-\infty$ to $+\infty$.

If $K_{j_0}=\max(k_j(N_x))$ $(j=1\sim n)$,then the assessment object N_x belong to the j_0 level.

The value of correlation function $K(x)$ represents the membership degree of assessment unit that in accordance with some standard. $K(x)\geq 1$ means the assessment object that above the up limit of assessment standard. The bigger the value is, the greater the development potential is. $0\leq K(x)\leq 1$ represents the degree that assessment object accords with standard. The bigger the value is, the closer to the upper limit of the standard. $-1\leq K(x)\leq 0$ means the assessment object do not in accordance with the require of assessment standard, but it can turn to accord with assessment standard. The bigger the values is, easier to turn. $K(x)\leq -1$ represent the assessment object do not in accordance with the require of assessment standard, as well as cannot turn to the assessment standard.

2.2 Weight determination

Entropy is used to express the degree of uniformity of energy in space. Entropy method is a kind of objective weighting method and was widely used in the field of multi-element comprehensive evaluation (Tang et.al, 2006).

2.2.1 Standardization of index matrix

There are m evaluation objects and n evaluation indexes, composing the matrix $X = \left(x_{ij}\right)_{m\times n}$. Then we can get the standardize matrix using standardization method. The particular is as follows.

$$b_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}\left(i = 1 \sim m,\ j = 1 \sim n\right) \tag{7}$$

In this equation, $x_{\max}, x_{\min}$ means the most satisfied and the most dissatisfied ones with the index of different evaluation objects.

2.2.2 To determine the entropy for calculation each index according to the definition of entropy

The paper defines the entropy with j evaluation index as H_j.

$$H_j = \frac{\left(1+b_{ij}\right)}{-\ln m}\left(\sum_{i=1}^{m} f_{ij}\ln f_{ij}\right)\left(i = 1 \sim m;\ j = 1 \sim n\right) \tag{8}$$

Where, $f_{ij} = b_{ij} \Big/ \sum_{i=1}^{m} b_{ij}$ (9)

We modified f_{ij}, which is defined as follows:

$$f_{ij} = \frac{\left(1+b_{ij}\right)}{\sum_{i=1}^{m}\left(1+b_{ij}\right)} \tag{10}$$

2.2.3 To calculate the entropy weight of evaluation index

According to the defined entropy mentioned above, the paper defined the weight of entropy w_j as follows.

$$w_j = \frac{1-H_j}{n-\sum_{j=1}^{n} H_j},\ W = \left(w_j\right)_{1\times n},\ \sum_{j=1}^{n} w_j = 1 \tag{11}$$

2.3 The establishment of water security assessment index system and the classical field of matter element model

2.3.1 The index system of water security assessment

On the foundation of water security concept, the principle of available and operational of index data and the complex relationship of every factor in security assessment, as well as the related research achievements(Liu et al., 2014) for reference, the water security assessment index system is established as shown in table 1.

Table 1 Assessment Index System and Weight of Water Security

	Indexes	**weighting**
Water security	water producing coefficient	0.0782
	annual runoff	0.0725
	modulus index of groundwater resources	0.0979
	water producing index	0.0831
	water resources utilization index	0.0460
	development level of surface water	0.0786

	development level of ground water	0.0477
	water consumption per 10000 Yuan gross domestic product (GDP)	0.0475
	water consumption per unit output value of 10000 Yuan	0.0685
	pollution quantity of entering river	0.0723
	area proportion of over extraction of underground water	0.0600
	index of water resources supply-demand balance	0.0474
	average per capita water resources	0.0948
	population proportion of drinking water security in urban areas	0.0456
	population proportion of drinking water security in rural areas	0.0599

The index weighting used in this study is calculated by entropy method. According to formula (7) to (11), the result is shown in table 1.

2.3.2 The determination of classical field and controlled field

The determination of classical field (value ranges of assessment grade) is the foundation of matter element assessment. The difference between this research and other traditional water security assessment is that this study determines the classical field before assessment. According to the extension of water security assessment, five grades are divided into N_{01}~N_{05}, which can be described qualitatively as: security–relative security–security threshold–relative insecurity–insecurity. The determination of classical field mainly consults the national and international criterion, and yellow river basin average and so on. The classical field of matter element matrix R_{01}、R_{02}、R_{03}、R_{04}、R_{05} and the controlled field of matter element matrix R_p are shown as follows, respectively.

$$R_{01}=\left|\begin{matrix} N_{01} & c_1 & (0.3\quad 0.36) \\ & c_2 & (130\quad 170) \\ & c_3 & (5.5\quad 7) \\ & c_4 & (50\quad 62) \\ & c_5 & (0\quad 1) \\ & c_6 & (0\quad 30) \\ & c_7 & (0\quad 30) \\ & c_8 & (0\quad 100) \\ & c_9 & (0\quad 30) \\ & c_{10} & (0\quad 1) \\ & c_{11} & (0\quad 0.6) \\ & c_{12} & (0.6\quad 0.8) \\ & c_{13} & (1000\quad 32000) \\ & c_{14} & (99\quad 102) \\ & c_{15} & (85\quad 95) \end{matrix}\right| \quad R_{02}=\left|\begin{matrix} N_{02} & c_1 & (0.24\quad 0.3) \\ & c_2 & (90\quad 130) \\ & c_3 & (4\quad 5.5) \\ & c_4 & (38\quad 50) \\ & c_5 & (1\quad 2) \\ & c_6 & (30\quad 50) \\ & c_7 & (30\quad 50) \\ & c_8 & (100\quad 200) \\ & c_9 & (30\quad 60) \\ & c_{10} & (0.5\quad 1) \\ & c_{11} & (0.6\quad 1) \\ & c_{12} & (0.8\quad 1) \\ & c_{13} & (750\quad 1000) \\ & c_{14} & (96\quad 99) \\ & c_{15} & (75\quad 85) \end{matrix}\right| \quad R_{03}=\left|\begin{matrix} N_{03} & c_1 & (0.18\quad 0.24) \\ & c_2 & (50\quad 90) \\ & c_3 & (2.5\quad 4) \\ & c_4 & (16\quad 38) \\ & c_5 & (2\quad 3) \\ & c_6 & (50\quad 70) \\ & c_7 & (50\quad 70) \\ & c_8 & (200\quad 300) \\ & c_9 & (60\quad 90) \\ & c_{10} & (1\quad 1.5) \\ & c_{11} & (1\quad 1.4) \\ & c_{12} & (1\quad 1.4) \\ & c_{13} & (500\quad 750) \\ & c_{14} & (93\quad 96) \\ & c_{15} & (65\quad 75) \end{matrix}\right|$$

$$R_{04}=\begin{vmatrix} N_{04} & c_1 & (0.12 \quad 0.18) \\ & c_2 & (10 \quad 50) \\ & c_3 & (1 \quad 2.5) \\ & c_4 & (4 \quad 16) \\ & c_5 & (3 \quad 4) \\ & c_6 & (70 \quad 90) \\ & c_7 & (70 \quad 90) \\ & c_8 & (300 \quad 400) \\ & c_9 & (90 \quad 120) \\ & c_{10} & (1.5 \quad 2) \\ & c_{11} & (1.4 \quad 1.8) \\ & c_{12} & (1.4 \quad 1.8) \\ & c_{13} & (250 \quad 500) \\ & c_{14} & (90 \quad 93) \\ & c_{15} & (55 \quad 65) \end{vmatrix} \quad R_{05}=\begin{vmatrix} N_{05} & c_1 & (0.06 \quad 0.12) \\ & c_2 & (0 \quad 10) \\ & c_3 & (0 \quad 1) \\ & c_4 & (0 \quad 4) \\ & c_5 & (4 \quad 8) \\ & c_6 & (90 \quad 100) \\ & c_7 & (90 \quad 400) \\ & c_8 & (400 \quad 1200) \\ & c_9 & (120 \quad 320) \\ & c_{10} & (2 \quad 2.5) \\ & c_{11} & (1.8 \quad 2.2) \\ & c_{12} & (1.8 \quad 2.2) \\ & c_{13} & (0 \quad 250) \\ & c_{14} & (50 \quad 90) \\ & c_{15} & (40 \quad 55) \end{vmatrix} \quad R_p=\begin{vmatrix} N_p & c_1 & (0.06 \quad 0.36) \\ & c_2 & (0 \quad 170) \\ & c_3 & (0 \quad 7) \\ & c_4 & (0 \quad 62) \\ & c_5 & (0 \quad 8) \\ & c_6 & (0 \quad 1000) \\ & c_7 & (0 \quad 400) \\ & c_8 & (0 \quad 1200) \\ & c_9 & (0 \quad 320) \\ & c_{10} & (0 \quad 2.5) \\ & c_{11} & (0 \quad 2.2) \\ & c_{12} & (0.6 \quad 2.2) \\ & c_{13} & (0 \quad 32000) \\ & c_{14} & (50 \quad 102) \\ & c_{15} & (40 \quad 95) \end{vmatrix}$$

3 Water Security Assessments in the Yellow River Basin

3.1 Study Area

The Yellow River Basin ($32^{\circ}10' \sim 41^{\circ}50' N, 95^{\circ}53' \sim 119^{\circ}05' E$) is the second longest river in China, the fifth longest in the world. Accordingly, Yellow River Basin is extremely important to water security in China. Located across the east and west of China, the Yellow River Basin originates from the northern of Bayan Har Mountains in Qinghai, China, flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shannxi, Shanxi, Henan and Shandong provinces, respectively, from upstream to downstream and then flow into the Bohai Sea. The length of the trunk stream is $5464km$, the total area of the basin is $79.5\times10^4 km^2$. The outstanding characteristic of Yellow River Basin is different sources of sediment and water.

The annual runoff of yellow river is $534.8\times10^8 m^3$, just taking for 2% of the countrywide river runoff. The per capita water of yellow river is $473m^3$, taking for 23% of the countrywide per capita water. But this basin undertakes the water supply task of 15% of the country's farmland area and 12% population (Xue, 2011). The water security in the Yellow River Basin is very serious. The average annual precipitation of Yellow River Basin is 446mm. The rainfall distribution is uneven, from southeast to northwest gradually reduce under the effect of geographical location, topography, and terrain in this basin. The average annual air temperature in the river basin is $6.95^{o}C$, about range of $-8 \sim 14^{o}C$, the general trend is temperature in south higher than north and east higher than west, and seasonal variation of temperature is obvious.

3.2 The classical field, controlled field and assessment element

The assessment level, classical field and controlled field is determined according to the previous study. According to the magnitudes of every index in Qinghai (R_1), Sichuan (R_2), Gansu (R_3), Ningxia (R_4), Inner Mongolia (R_5), Shannxi (R_6), Shanxi (R_7), Henan (R_8) and Shandong (R_9) province, the assessment matter elements matrixes are shown as follows respectively.

$$R_1 = \begin{vmatrix} N_1 & c_1 & 0.28 \\ & c_2 & 114.73 \\ & c_3 & 0.08 \\ & c_4 & 11.55 \\ & c_5 & 0.12 \\ & c_6 & 9.28 \\ & c_7 & 339.02 \\ & c_8 & 441.77 \\ & c_9 & 312.00 \\ & c_{10} & 0.05 \\ & c_{11} & 0.00 \\ & c_{12} & 1.11 \\ & c_{13} & 3900.74 \\ & c_{14} & 96.00 \\ & c_{15} & 54.13 \end{vmatrix} R_2 = \begin{vmatrix} N_2 & c_1 & 0.30 \\ & c_2 & 164.59 \\ & c_3 & 0.00 \\ & c_4 & 16.46 \\ & c_5 & 0.01 \\ & c_6 & 0.79 \\ & c_7 & 100.00 \\ & c_8 & 134.08 \\ & c_9 & 182.00 \\ & c_{10} & 0.00 \\ & c_{11} & 0.00 \\ & c_{12} & 0.71 \\ & c_{13} & 31123.47 \\ & c_{14} & 100.00 \\ & c_{15} & 64.88 \end{vmatrix} R_3 = \begin{vmatrix} N_3 & c_1 & 0.15 \\ & c_2 & 63.19 \\ & c_3 & 0.28 \\ & c_4 & 6.60 \\ & c_5 & 0.46 \\ & c_6 & 42.58 \\ & c_7 & 163.19 \\ & c_8 & 304.19 \\ & c_9 & 235.00 \\ & c_{10} & 0.17 \\ & c_{11} & 0.00 \\ & c_{12} & 1.18 \\ & c_{13} & 518.24 \\ & c_{14} & 89.00 \\ & c_{15} & 58.54 \end{vmatrix} R_4 = \begin{vmatrix} N_4 & c_1 & 0.08 \\ & c_2 & 16.01 \\ & c_3 & 0.46 \\ & c_4 & 2.06 \\ & c_5 & 7.46 \\ & c_6 & 908.40 \\ & c_7 & 212.30 \\ & c_8 & 1128.89 \\ & c_9 & 228.00 \\ & c_{10} & 2.44 \\ & c_{11} & 0.97 \\ & c_{12} & 1.14 \\ & c_{13} & 175.58 \\ & c_{14} & 96.00 \\ & c_{15} & 44.37 \end{vmatrix} R_5 = \begin{vmatrix} N_5 & c_1 & 0.13 \\ & c_2 & 9.18 \\ & c_3 & 1.88 \\ & c_4 & 2.80 \\ & c_5 & 2.31 \\ & c_6 & 533.79 \\ & c_7 & 85.95 \\ & c_8 & 353.94 \\ & c_9 & 84.00 \\ & c_{10} & 2.16 \\ & c_{11} & 0.00 \\ & c_{12} & 1.09 \\ & c_{13} & 496.71 \\ & c_{14} & 54.00 \\ & c_{15} & 58.27 \end{vmatrix}$$

$$R_6 = \begin{vmatrix} N_6 & c_1 & 0.14 \\ & c_2 & 47.74 \\ & c_3 & 1.91 \\ & c_4 & 6.68 \\ & c_5 & 0.70 \\ & c_6 & 49.62 \\ & c_7 & 122.89 \\ & c_8 & 195.75 \\ & c_9 & 92.00 \\ & c_{10} & 0.75 \\ & c_{11} & 0.07 \\ & c_{12} & 1.24 \\ & c_{13} & 312.89 \\ & c_{14} & 94.00 \\ & c_{15} & 60.92 \end{vmatrix} R_7 = \begin{vmatrix} N_7 & c_1 & 0.11 \\ & c_2 & 31.51 \\ & c_3 & 2.43 \\ & c_4 & 5.58 \\ & c_5 & 0.74 \\ & c_6 & 48.21 \\ & c_7 & 108.92 \\ & c_8 & 133.50 \\ & c_9 & 67.00 \\ & c_{10} & 0.96 \\ & c_{11} & 2.19 \\ & c_{12} & 1.41 \\ & c_{13} & 245.96 \\ & c_{14} & 86.00 \\ & c_{15} & 46.75 \end{vmatrix} R_8 = \begin{vmatrix} N_8 & c_1 & 0.25 \\ & c_2 & 105.51 \\ & c_3 & 4.63 \\ & c_4 & 15.18 \\ & c_5 & 1.01 \\ & c_6 & 105.96 \\ & c_7 & 177.87 \\ & c_8 & 185.66 \\ & c_9 & 101.00 \\ & c_{10} & 0.46 \\ & c_{11} & 1.16 \\ & c_{12} & 0.97 \\ & c_{13} & 321.24 \\ & c_{14} & 90.00 \\ & c_{15} & 60.81 \end{vmatrix} R_9 = \begin{vmatrix} N_9 & c_1 & 0.21 \\ & c_2 & 78.31 \\ & c_3 & 5.04 \\ & c_4 & 12.88 \\ & c_5 & 1.13 \\ & c_6 & 763.57 \\ & c_7 & 150.58 \\ & c_8 & 153.68 \\ & c_9 & 71.00 \\ & c_{10} & 1.32 \\ & c_{11} & 0.00 \\ & c_{12} & 1.13 \\ & c_{13} & 218.17 \\ & c_{14} & 100.00 \\ & c_{15} & 70.87 \end{vmatrix}$$

4 Results and Discussion

Input the assessment element to the matter element model, the result can be calculated easily from the model. Let's take the water producing coefficient (v_1) in Qinghai province for example. Input $v_1 = 0.28$ to formula (1) to (5), the correlation degrees of this index those correspond to all the five assessment grades are respectively, $k_1(v_1) = -0.21$, $k_2(v_2) = 0.08$, $k_3(v_3) = -0.32$, $k_4(v_4) = -0.55$, $k_5(v_5) = -0.66$. So this index is in the range of grade N_{02}, namely the "relative security" level. And other related values of other indexes can be getting in the same way (table 2). Input the correlation grades of all the indexes that correspond to the five grades and the corresponding weights (table 1) to formula (6), then the comprehensive correlation degree of all the 15 indexes is in table 3.

Table 2 Correlation Degree of Water Security Assessment Indexes in the Yellow River Basin

	Qinghai	**Sichuan**	**Gansu**	**Ningxia**	**Inner mongolia**	**Shannxi**	**Shanxi**	**Henan**	**Shandong**
$k_1(v_1)$	Relative security	Security	Relative insecurity	Insecurity	Relative insecurity	Relative insecurity	Insecurity	Relative security	Security threshold
$k_2(v_2)$	Relative security	Security	Security threshold	Relative insecurity	Insecurity	Relative insecurity	Relative insecurity	Relative security	Security threshold
$k_3(v_3)$	Insecurity	Insecurity	Insecurity	Insecurity	Relative insecurity	Relative insecurity	Relative insecurity	Relative security	Relative security
$k_4(v_4)$	Relative insecurity	Security threshold	Relative insecurity	Insecurity	Insecurity	Relative insecurity	Relative insecurity	Relative insecurity	Relative insecurity
$k_5(v_5)$	Security	Security	Security	Insecurity	Security threshold	Security	Security	Relative security	Relative security
$k_6(v_6)$	Security	Security	Relative security	Insecurity	Insecurity	Relative security	Relative security	Insecurity	Insecurity
$k_7(v_7)$	Insecurity	Insecurity	Insecurity	Insecurity	Relative insecurity	Insecurity	Insecurity	Insecurity	Insecurity
$k_8(v_8)$	Insecurity	Relative security	Relative insecurity	Insecurity	Relative insecurity	Relative security	Relative security	Relative security	Relative security
$k_9(v_9)$	Insecurity	Insecurity	Insecurity	Insecurity	Security threshold	Relative insecurity	Security threshold	Relative insecurity	Security threshold
$k_{10}(v_{10})$	Security	Security	Security	Insecurity	Insecurity	Relative security	Relative security	security	Security threshold
$k_{11}(v_{11})$	Security	Security	Security	Relative security	Security	Security	Insecurity	Security threshold	Security
$k_{12}(v_{12})$	Security threshold	Security	Security threshold	Security threshold	Security threshold	Security threshold	Relative insecurity	Relative security	Security threshold
$k_{13}(v_{13})$	Security	Security	Security threshold	Insecurity	Relative insecurity	Relative insecurity	Insecurity	Relative insecurity	Insecurity
$k_{14}(v_{14})$	Relative security	Security	Insecurity	Relative security	Insecurity	Security threshold	Insecurity	Relative insecurity	Security
$k_{15}(v_{15})$	Insecurity	Security threshold	Relative insecurity	Insecurity	Relative insecurity	Relative insecurity	Insecurity	Relative insecurity	Security threshold

Table 3 Comparation of Water Security of Nine Provinces in the Yellow River Basin

Comprehensive correlation degree	N_{01}	N_{02}	N_{03}	N_{04}	N_{05}	**Level**
$k_j(v_1)$	-0.07	-0.56	-0.58	-0.57	-0.36	Security
$k_j(v_2)$	0.02	-0.65	-0.67	-0.70	-0.52	Security
$k_j(v_3)$	-0.30	-0.50	-0.38	-0.30	-0.22	Insecurity
$k_j(v_4)$	-0.78	-0.72	-0.66	-0.51	0.22	Insecurity
$k_j(v_5)$	-0.53	-0.55	-0.39	-0.17	-0.10	Insecurity
$k_j(v_6)$	-0.39	-0.38	-0.26	-0.09	-0.37	Threshold security
$k_j(v_7)$	-0.55	-0.44	-0.35	-0.18	-0.25	Relative insecurity
$k_j(v_8)$	-0.37	-0.19	-0.20	-0.23	-0.36	Relative security
$k_j(v_9)$	-0.34	-0.31	-0.25	-0.35	-0.37	Threshold security

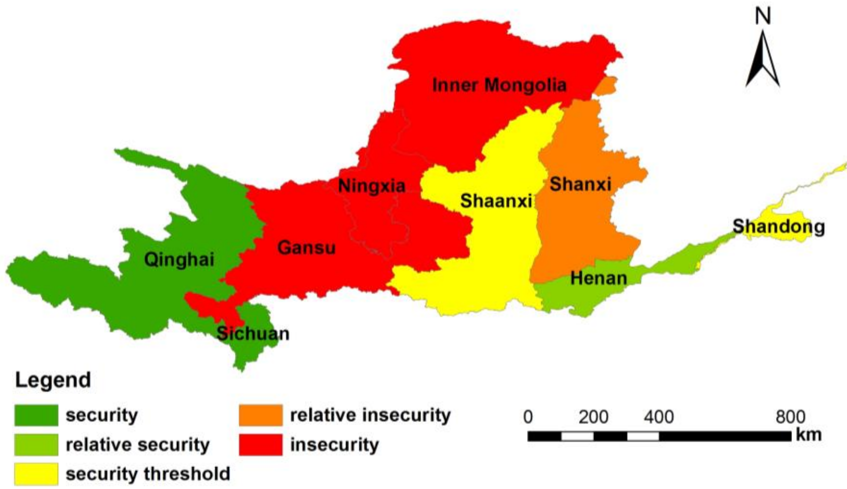

Figure 1. Compartment of Water Security in Yellow River Basin

From table 3 and figure 1, the water security level in Qinghai and Sichuan province is “security”, water security in Henan province “relative security”, water security in Shaanxi and Shandong province is “security threshold”, water security in Shanxi province is “relative insecurity” and water security in Gansu, Ningxia and Inner Mongolia is “insecurity”.

It can be seen from the overall regional spatial distribution that water security in provinces where the source of Yellow River Basin (e.g. Sichuan, Qinghai), the southern (e.g. Shannxi, Henan), and the developed province (e.g. Shandong) is better. It is because of the amount of water in source and southern of yellow river is enough, water condition better and the social economic in developed provinces better developed, make up the disadvantage of water condition. The provinces where water security is worse include Shanxi, Gansu, Inner Mongolia and Ningxia. These provinces are the important parts for Yellow River Basin management.

The assessment process described in this paper not only allowed us to compare various water security indexes in the nine provinces but also permits a diagnosis of water security. The results reveal both the strengths and weaknesses of water security and thus suggest the actions that can be carried out to improve water security. Increasing the level of water security and establishing a long-term strategic water security system based on sustainable use of the available resource could improve the region’s ecological environment and increase the likelihood of sustainable development in the basin. Given the rapid rate of development in the study area, it will be important to do such work based on the results of our study.

The scarcity and importance of water resources in the Yellow River Basin have heavily constrained the region’s socioeconomic development. The essential problem in this region is that economic development has been unsustainable, and has withdrawn water from the environment at a faster rate than the water can be recharged naturally. The driving forces behind this problem are the natural scarcity of water in the region and the spatial and temporal heterogeneity in the distribution of water resources. Moreover, the rapid population growth has placed extraordinary pressure on the fragile water resources. Therefore, it will be necessary to control regional population growth, improve public education, and develop a water security system for each of the provinces based on their unique characteristics and needs. For instance, careful planning should be devoted to reconsidering immigration into the study area and new land development in the Yellow River Basin. General principles apply to the management of water security in all nine provinces. First and foremost, development should not exceed the natural capacity of the water resources. Thus, water utilization should be constrained by government regulations and by limits placed on the development of new capacity so as to associate new development with the availability of water, and economic development should focus on sustainable water consumption. The constraints and carrying capacity of the water resources should also be fully considered and quantified in such a manner as to support policy-making and the construction of new enterprises.

5 Conclusions

According to the data of water resource, water environment and social-economic in the Yellow River Basin in 2006, the water security was assessed using the combination assessment model. The preliminary conclusions can be summarized as follows:

(1)The status of water security in the Yellow River Basin is extremely severe and requires more attention and observation in order to mitigate consequent losses. The water security level in Qinghai and Sichuan province is “security”, water security in Henan province “relative security”, water security in Shaanxi and Shandong province is “threshold security”, water security in Shanxi province is “relative insecurity” and water security in Gansu, Ningxia and Inner Mongolia is “insecurity”.

(2)Both the low utilization efficiency and low amounts of available water in the Yellow River Basin have resulted in a bottleneck that restricts water security in the Yellow River Basin. Some measures must be implemented to protect water resource and guarantee water security. For example, rapid development of water-saving technology and precision agriculture, further water resources management, control over irrigated areas and population growth should be implemented.

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