

# Research on Evaluation Method and Application of Water-saving Society Building Based on Chen Shouyu Fuzzy Set

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**Abstract.** According to the basic theories of fuzzy set theory and the evaluation calculation methods proposed by Prof. Chen Shouyu of Dalian University of Technology, combined with the commonly used evaluation index system in current water-saving society building in China, a fuzzy comprehensive evaluation model for water-saving society is built based on the evaluation of the water resources background and water consumption characteristics of the research area. By taking Shanxi Province located on Loess Plateau of China as an example, the development level of the water-saving society building in the region is obtained and the corresponding water-saving society building ideas are proposed to further promote the development of water-saving society.

## 1. Introduction

As an important aspect of solving the water shortage problem, water saving has obtained certain research progress in recent years. Water-saving society building has reached consensus in many countries. At present, foreign countries do not have complete and mature cases. Only Israel, Japan, South Africa and other countries carried out partial research and attempts in water rights and water demand management. However, China has comprehensively promoted the building of water-saving society from the national level. Domestic and foreign experts believe that China's water-saving society building theory and practice will explore a new path for many countries to deal with water shortages.

Wang Hao et al. proposed an evaluation index system for the water-saving society pilot in Zhangye area (Wang Hao et al, 2007); Wu Jisong proposed a target system of ecological water-saving society in the pilot city (Wu Jisong, 2004); Zhang Xiaojie proposed evaluation index system on the water saving in urban area (Zhang Xiaojie, 2001); Chen Ying et al. studied the water-saving social evaluation index system and put forward the evaluation index system of "water saving evaluation index, ecosystem evaluation index, and economic development reference index" (Chen Ying et al, 2005), and gradually deepened and developed water-saving society evaluation methods and systems on this basis (Chen Ying et al, 2004; 2012; 2004; 2003); Shi Jun et al. under the index system proposed by Chen Ying and others, carried out a water-saving society evaluation research in a county (Shi Jun et al, 2006); Zhang Xingfang made use of system dynamics method to evaluate the level of urban water-saving (Zhang Xingfang, 2000); Huang Qian et al. used a fuzzy matter-element model based on entropy weights for water-saving social evaluation (Huang Qian et al, 2007).

Chen Shouyu's fuzzy set was proposed by Prof. Chen Shouyu, the expert of China's hydrology and water resources and has been developing from the initial engineering fuzzy set and variable fuzzy set to the current variable fuzzy clear hybrid set (abbreviated as variable set). This method has been



widely used in the fields of water resources, water environment, water ecology and other areas except for water resources at home and abroad (Chen shouyu, 2009; Chen shouyu and xue zhichun et al, 2013a, 2013b; Peng yong et al, 2017), such as transportation, civil engineering, and geological engineering. The scientific effectiveness and excellence of the method have been gradually verified in continuous engineering applications and have been accepted by a large number of researchers at home and abroad.

This paper adopts the method of fuzzy grading and fully considers two important attributes of “fuzziness” and “variability” in the evaluation process. It selects and uses a relatively mature evaluation index system to evaluate the current level of water-saving society building level in the most serious soil erosion area in the Loess Plateau region of Shanxi Province. Through the evaluation results, the advantages and disadvantages as well as strengths and weaknesses in the building of a water-saving society in the Loess Plateau can be drawn, so as to make corresponding adjustment in the next stage of water-saving society building, thereby realizing the goal of building a water-saving society better, faster, and more efficiently and providing reliable water resources protection for China's comprehensive building of a green and beautiful and harmonious society.

## 2. Water-saving society evaluation index system

According to the research of Chen Ying, et al., the evaluation index system established by them has been widely recognized and applied by peer experts. It is a relatively universally recognized evaluation index. This article quotes the water-saving social evaluation index system of Chen Ying and others and combines with the actual situation in the target area to make proper adjustment for evaluation and application.

It is basically divided into three levels including 2 first-level indexes, 6 second-level indexes, and 26 third-level indexes. Two of the first-level indexes are water-saving social development systems (B1) and water-saving social security systems (B2), 6 secondary indexes are integrated water resources (C1), industrial water-saving (C2), agricultural water-saving (C3), life water-saving (C4), ecosystem building (C5) and socio-economic development (C6). The evaluation system index system is shown in the figure below.

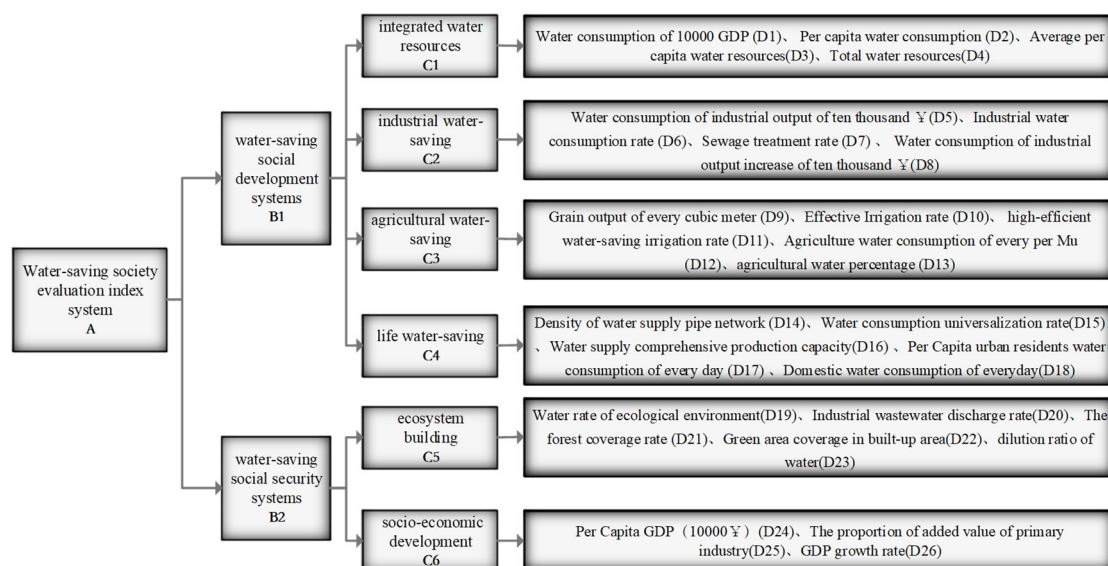


Fig1. Water-saving society evaluation index system

## 3. Water-saving society evaluation method

### 3.1. Membership calculation

In order to ensure the authenticity and reliability of the data, statistical data are used in this study. Since the individual index data has different properties, in order to eliminate the dimension effect, the original data is standardized. The standardization method has been proposed (Chen shouyu, 2009):

1. For larger and better index, the standardized formula is:  $Z_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$
2. For smaller and better index, the standardized formula is:  $Z_i = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}}$

$X_i$  is the statistical value,  $X_{\max}$  is the maximum value of the grading index, and  $X_{\min}$  is the minimum value of the grading index. After the above-mentioned standardization process, the standardized result of the index value is obtained. When the index value is smaller than the minimum value of the grading index or greater than the maximum value of the grading index, the evaluation formula of the evaluation index to the superior degree of membership is:

$$\mu_i = \begin{cases} Z_i & (0 < Z_i < 1) \\ 0 & (Z_i < 0) \\ 1 & (Z_i > 1) \end{cases} \quad (1)$$

### 3.2. Weight determination

This paper selects the binary comparison fuzzy decision analysis method proposed by Prof. Chen to determine the weight of index at all levels. The basic principles are as follows.

The set of index for which importance is to be compared is  $O = \{o_1, o_2, o_3, \dots, o_m\}$ , where  $o_i$  is the total number of index of system index concentrated target  $i = 1, 2, \dots, m; m$ . The elements of the index set  $O$  are qualitatively sorted by the degree of importance of the binary comparisons to determine the index weights.

The element  $o_k$  of the index set  $O$  are compared with  $o_l$  ( $k = 1, 2, \dots, m, l = 1, 2, \dots, m$ ) for the binary comparison. If: (1)  $o_k$  is more important than  $o_l$ , the sorting scale  $0.5 < \beta_{kl} \leq 1$ ; (2) if  $o_k$  and  $o_l$  are equally important, the sorting scale  $\beta_{kl} = 0.5$ ; (3) if  $o_l$  is more important than  $o_k$ , the sorting scale  $0 < \beta_{kl} \leq 0.5$ . The  $\beta_{kl}$  is relative importance fuzzy scale value of  $o_k$  and  $o_l$ .

According to the relationship table of tone operator and fuzzy scale value, the value of  $\beta_{kl}$  can be obtained to come out with the relative importance fuzzy scale matrix:

$$\beta = \begin{bmatrix} \beta_{11} & \beta_{12} & \cdots & \beta_{1m} \\ \beta_{21} & \beta_{22} & \cdots & \beta_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \beta_{m1} & \beta_{m2} & \cdots & \beta_{mm} \end{bmatrix} = (\beta_{kl}) \quad (2)$$

Where,  $k, l = 1, 2, \dots, m$ .

Relative importance fuzzy scale matrix  $\beta$  has the following characteristics:

- (1) The diagonal elements of the matrix are 0.5, that is  $\beta_{kk} = 0.5$ ;
- (2) Each element in the lower triangular matrix can be obtained from the elements in the upper triangular matrix, that is  $\beta_{kl} = 1 - \beta_{lk}$ , the sum of the fuzzy scale values  $\beta_{kl}$  per row of the square matrix  $\beta$  (without comparing the 0.5 fuzzy scale values with itself), that is

$\omega'_k = \sum_{l=1}^m \beta_{kl}, k \neq l, k = 1, 2, \dots, m$ .  $\omega'_k$  represents that after comparing the relative importance of the

index  $o_k$  with other index, the sum of relative importance fuzzy scale value with  $o_k$  as baseline, or the relative importance of the index set  $O$  is represented by the vector  $\varpi' = (\omega'_1, \omega'_2, \dots, \omega'_m)$ , i.e.,

$$\varpi' = (\omega'_1, \omega'_2, \dots, \omega'_m) = \left( \sum_{l=1}^m \beta_{1l}, \sum_{l=1}^m \beta_{2l}, \dots, \sum_{l=1}^m \beta_{ml} \right) \quad (3)$$

Normalize  $\varpi'$  to get the weight vector  $\varpi$  of the index set  $O$

$$\begin{aligned} \varpi = (\omega_1, \omega_2, \dots, \omega_m) &= \left( \omega'_1 / \sum_{k=1}^m \omega'_k, \omega'_2 / \sum_{k=1}^m \omega'_k, \dots, \omega'_m / \sum_{k=1}^m \omega'_k \right) \\ &= \left( \frac{\sum_{l=1}^m \beta_{1l}}{\sum_{k=1}^m \sum_{l=1}^m \beta_{kl}}, \frac{\sum_{l=1}^m \beta_{2l}}{\sum_{k=1}^m \sum_{l=1}^m \beta_{kl}}, \dots, \frac{\sum_{l=1}^m \beta_{ml}}{\sum_{k=1}^m \sum_{l=1}^m \beta_{kl}} \right) \end{aligned} \quad (4)$$

### 3.3. Evaluation system calculation model

Through the setting and analysis of the above index system, the above fuzzy membership degree method calculates the fuzzy relative membership degree of each level of index. Then through the following node calculation model, the results of water-saving society evaluation can be obtained. The model consists of the water-saving society target model (system model), the water-saving society development sub-model ( $G_t$ ) and the water-saving society security system sub-model ( $E_t$ ).

#### 3.3.1 The target model

The general model of water-saving society consists of a development sub-model and a safeguard sub-model:  $EM = W_1 G_t + W_2 E_t$ , where  $t$  is the time period,  $G_t$  and  $E_t$  are water-saving society development subsystems and water-saving society security subsystems respectively;  $W_1$  and  $W_2$  are the system weight.

#### 3.3.2 Development level subsystem model

The development subsystem model includes comprehensive evaluation, industrial water-saving evaluation, agricultural water-saving evaluation and life water-saving evaluation:

$$G_t = \sum_{i=1}^4 w_{1i} \mu_{1i} + \sum_{i=1}^4 w_{12} \mu_{2i} + \sum_{i=1}^5 w_{13} \mu_{3i} + \sum_{i=1}^5 w_{14} \mu_{4i} \quad (5)$$

Where:  $W_{11}, W_{12}, W_{13}, W_{14}$  are the secondary subsystem index weights of the development subsystem and  $\mu_{1i}, \mu_{2i}, \mu_{3i}, \mu_{4i}$  are the degrees of membership of the secondary subsystems of the development subsystem.

#### 3.3.3 Security level subsystem model

The security subsystem model includes two subsystems of ecosystem building and economic development. The system assessment model is as follows:

$$E_t = \sum_{i=1}^5 w_{21} \mu_{5i} + \sum_{i=1}^3 w_{22} \mu_{6i} \quad (6)$$

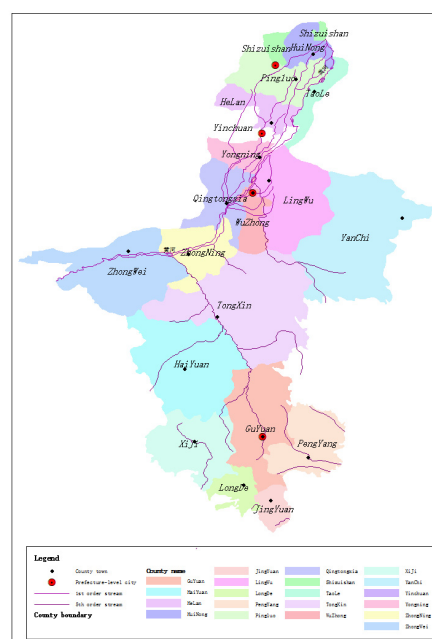
Where:  $W_{21}$  and  $W_{22}$  are the secondary subsystem index weights of the security system,  $\mu_{5i}, \mu_{6i}$  are the degrees of membership of the secondary subsystems.

According to the above model, it is possible to calculate the degree of membership of the level of development of water-saving society to the degree of fineness, so that the development level and gap of each index and evaluation target can be qualitatively and quantitatively determined and analysis can be made to compare the degree of membership of each index and come up with suggestions in a targeted way, which provides important practical guidance for strengthening the building of a water-saving society.

#### 4. Evaluation of Ningxia water-saving society building

##### 4.1. Research background

Ningxia is a province with a severe shortage of water resources, and the outstanding feature of water resources is the small quantity and poor quality. The total water resources of the region is 1.163 billion m<sup>3</sup>, and the per capita local water resources occupy 185 m<sup>3</sup>, which is only 1/3 of the Yellow River Basin and 1/12 of the national total. The water supply in Ningxia mainly depends on transiting Yellow River, hence one of the most water-short province in the country. The average supply and consumption of water in Ningxia from 2010 to 2013 was 7.185 billion m<sup>3</sup>, and the average water consumption in the entire region was 3.50 billion m<sup>3</sup>. In 2013, the total supply of water in the region was 7.213 billion m<sup>3</sup>.



**Figure 2. General map of study area**

The distribution of water resources in Ningxia varies greatly and the problem of water shortage in the central and southern regions is particularly prominent. Land desertification is serious in the region and it is difficult for people and livestock to drink water. The area of the southern Loess Hilly Region covers an area of 14,500 km<sup>2</sup>, accounting for 22% of the region. The average annual rainfall is 472mm and the local available Yellow River tributaries provide 249 million m<sup>3</sup> of water resources. With the Yellow River mainstream allocation indicators, the available water resources are 296 million m<sup>3</sup> and the per capita water resources utilization is only 243 m<sup>3</sup>; the mountain height in the region is high and water height is low, water conservancy facilities are insufficient, and agricultural production is low and unsteady. It is a poverty-stricken area supported by the state with prominent water and soil erosion problems and frequent natural disasters.

In order to solve the bottleneck of water resources shortage, the Party Committee and People's Government of Ningxia Autonomous Region proposed to build a provincial water-saving society in

2004 and planned to use it for about 15 years to initially build a water-saving society. In 2012, the "Administrative Measures for the Building of a Water-saving Society in Ningxia Hui Autonomous Region" was issued, becoming the first provincial local government regulation for the building and management of a water-saving society; in 2013, the "Circular on Issuing the Most Stringent Water Resources Management System Assessment Method of General Office of the People's Government of the People's Republic of China" further strengthened the management assessment including the task of building a water-saving society; it has successively issued the "Implementation Opinions on Further Promoting the Building of a Provincial-level Demonstration Zone in Ningxia Water-saving Society" and "Action Plan on Issuing the Ningxia Water-saving County(district) Standard Building" and "Circular on the Implementation of Water Conservation-type Units Building for Public Institutions in the Region" to promote the building of water-saving standards and water-saving carriers for county-level administrative regions, and effectively implement the building of a water-saving society. The relevant measures and notices have laid a solid foundation for guiding the building of a water-saving society and effectively promoting and strengthening organization management and assessment of water-saving society building.

#### 4.2. Index weights

In each water-saving society evaluation index of the primary election, the degree of influence of a single index on the secondary index and the overall goal is not consistent. This paper uses the fuzzy binary comparison method proposed by Prof. Chen Shouyu to determine the grading indicators hierarchically. Finally, the weights of indicators at each level are shown in the following table:

Table 1. Index Weights

<b>B1</b> (0.78)	<b>C1</b> 0.195	<b>D1</b> 0.325	<b>D2</b> 0.264	<b>D3</b> 0.217	<b>D4</b> 0.195	
	<b>C2</b> 0.195	<b>D5</b> 0.394	<b>D6</b> 0.263	<b>D7</b> 0.212	<b>D8</b> 0.131	
	<b>C3</b> 0.195	<b>D9</b> 0.319	<b>D10</b> 0.171	<b>D11</b> 0.213	<b>D12</b> 0.106	<b>D13</b> 0.191
	<b>C4</b> 0.195	<b>D14</b> 0.313	<b>D15</b> 0.254	<b>D16</b> 0.168	<b>D17</b> 0.188	<b>D18</b> 0.078
<b>B2</b> (0.22)	<b>C5</b> 0.135	<b>D19</b> 0.271	<b>D20</b> 0.22	<b>D21</b> 0.181	<b>D22</b> 0.181	<b>D23</b> 0.146
	<b>C6</b> 0.085	<b>D24</b> 0.446	<b>D25</b> 0.362	<b>D26</b> 0.191		

#### 4.3. Evaluation results and analysis

Based on the above-mentioned evaluation index system, according to the progress made since the construction of a water-saving social pilot project in Ningxia Autonomous Region and the availability of major statistical data, from the "2014 China Statistical Yearbook" and "2014 Ningxia Statistical Yearbook" "2014 Ningxia Water Resources Bulletin" and other relevant data were used to find the statistical data required for each index. The above evaluation model is used to calculate and obtain the results of the water-saving society evaluation in Ningxia Autonomous Region as shown in the following table.

Table 2. Results of water-saving society evaluation in 2014 in Ningxia Autonomous Region

Evaluation index				Evaluation result		
First-level	Second-level	Third-level	Eigen value	Third-level evaluation results	Second-level evaluation results	First-level evaluation results
B1	C1	D1	281	0.3231014	0.042	0.748
		D2	1103	0.0000000		
		D3	168	0.0012062		
		D4	11.4	0.0000552		
	C2	D5	396.1	0.0995589	0.032	
		D6	59	0.0981481		
		D7	52.8	0.0001051		
		D8	57.76	0.0489455		
	C3	D9	5.74	0.0000140	0.02	
		D10	33	0.0000824		
		D11	20	0.0000582		
		D12	383	0.0440091		
		D13	90.2	0.1133000		
	C4	D14	5.03	0.1095508	0.025	
		D15	96.51	0.0002109		
		D16	145.1	0.0002120		
		D17	144.7	0.0574302		
		D18	28.8	0.0267092		
B2	C5	D19	3	0.0000000	0.017	0.252
		D20	95	0.1164624		
		D21	11.89	0.0092588		
		D22	37.9	0.0363479		
		D23	41	0.0319236		
	C6	D24	39420	0.2235880	0.023	
		D25	11	0.1804905		
		D26	10	0.0000170		

Based on the results of the above evaluation indicators, the excellency degree  $EM(2014)=0.639$  of the water-saving social assessment in the Ningxia Autonomous Region in 2014 can be obtained through the formula  $EM=W1Gt+W2Et$ , according to the evaluation criteria in Table 3 below, the evaluation results are determined:

Table 3. Water-saving society index system evaluation criterion

$0 < \mu_i \leq 0.2$	Starting-level
$0.2 < \mu_i \leq 0.4$	Primary-level
$0.4 < \mu_i \leq 0.6$	Medium-level
$0.6 < \mu_i \leq 0.8$	Good
$0.8 < \mu_i \leq 1$	Excellent



Judging from the above evaluation results, the building of a water-saving society in Ningxia is generally in a good state. It is in line with Ningxia's achievements in the field of water-saving society building over the years and it is also consistent with the implementation of the national water-saving society Ningxia demonstration area. From the statistical indicators of the national and provincial governments, we can see that in recent years, local governments have gradually changed the traditional thinking of production first and treatment second and introduced advanced technologies and development concepts, advocated environmental protection and energy conservation and vigorously promoted the building of a conservation-minded society. While developing sustainable economy, it also carried out afforestation and returning farmland to forests which resulted in rapid development of water-saving society in recent years and its evaluation results are in line with reality in all aspects of social building and development.

From the evaluation results of six secondary evaluation indicators, it can also be seen that the overall secondary indicators are all below the medium level. From a separate perspective, the advantages in social and economic development are obvious and the comprehensive evaluation of water resources has been improved. Industrial water saving, agricultural water saving building are most backward and there is still room for improvement in both water-saving and ecosystem.

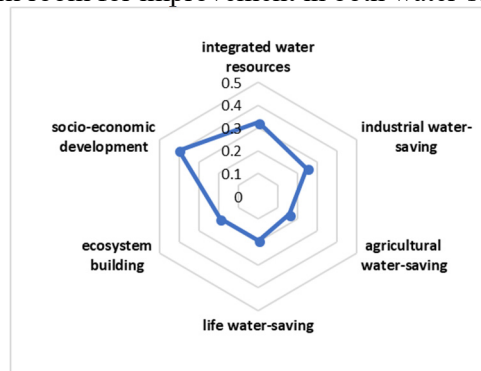


Fig3. Results of water-saving society evaluation of Ningxia second-level index

Through the building of a water-saving society during the pilot period, the transformation of the economic development mode and the optimization of industrial structure are vigorously enhanced. The ratio of living, industrial and agricultural industries has been adjusted from 11:49:40 in 2005 to 8.7:49:3:42.0 in 2013. The water resources management system combining total volume control and quota management has been continuously improved and the total amount of water used has been effectively controlled. The “zero growth” or even “negative growth” of water consumption has been initially implemented to support the sustained and rapid economic and social development, and has driven the entire region’s ecological civilization construction with significant achievements made in natural ecology and urban water ecological development. The water ecological environment has gradually recovered and the main stream of the Yellow River Ningxia Section has maintained good water quality above Class III.

While solving its own water problems and enhancing regional water security, the building of a water-saving society in Ningxia also explores the experiences of some arid and semi-arid regions in northwest China in building water-saving society in a wider range and in more fields. First, strict management of the entire water use process is the fundamental measure for achieving total control of regional water use. Second, the overall water rights conversion is crucial for water-shortage regions to realize industrial back-feeding agriculture and development industrialization and agricultural modernization. Third, the building of water-saving society in northwest region focuses on accelerating the transformation of economic development methods and strategic adjustment of the industrial structure. Fourth, the all-round organization and management model is an important organizational guarantee for promoting the building of a water-saving society.



## 5. Conclusion

Through the above evaluation results, it's known that at present, the overall level of water-saving society building in Ningxia is at a good level, but most of the indicators are below the medium level, only a few indicators such as GDP growth rate achieves a good level above medium, which also sufficiently shows that the development of Ningxia, which is located in the western region some time ago and even at the moment, is aimed at "focusing on economic development", "stabilizing the economy and ensuring growth." The evaluation results fully reflect the unique development characteristics of the inland region in the overall and internal structure of the Northwest China and can reasonably reflect the current situation of the building of a water-saving society in the region. Through the evaluation, shortcomings are revealed, so that planning and construction in the future can be carried out in a targeted way.

The building of a water-saving society not only needs to improve the utilization of water resources from the technical point of view, but also needs to guide people to form a water-saving culture or consciousness. The current low level of development is far from the goal. With the correct understanding of the connotation of water conservation and the proper implementation of various measures taken by government, the level of social water saving will inevitably embrace great improvement.

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