Evaluation of the Influence of Ningxi Water Supply Project on Economy, Society and Environment of Ningxia

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Abstract: Ningxi Water Supply Project (here in after referred to as “the Project”) undertakes many important tasks, such as supporting the industrial development of Yinchuan City, providing ecological protection for Ningxia Yellow River irrigation area and Yinchuan City, and developing the dominant agricultural industry in the eastern foothills of Helan Mountain. Therefore, it is important to carry out the evaluation of the influence of the Project on the economy, society and environment of Ningxia, such evaluation and analysis can help us make a clearer and more comprehensive understanding of the role of the Project of Ningxia, and then take further corresponding measures to promote the normal performance of the Project to support and guarantee the healthy, sustainable economic and social development of Ningxia.

1. Introduction
The Project is a newly-formed river reservoir with Shapotou Water Control Project as water supply source, based on the existing Meli Canal, the reconstructed Yuejin Canal and the newly-constructed Xixia Canal and Xixia Reservoir, and connected to the Yellow River Diversion Project. The Project covers six cities and counties including Yinchuan City, Zhongwei City, Zhongning County, Qingtongxia City, Yongning County and Helan County in Ningxia, and will provide water source after its completion, significantly important to guarantee the social and economic development of the central and northern Ningxia, the implementation of the “Greater Yinchuan” strategy and the integrated regional water supply management. Currently, there exist some problems in the construction and operation management of the Project, such as the delay in the expansion and reconstruction of the Yuejin Canal, the lack of harmony between the canal systems under the Xixia Canal, the insufficient water supply capacity of the Xixia Reservoir, etc, which render the economic, social and eco-environmental benefits impossible to be fully utilized and the drinking water safety difficult to be guaranteed in the water-receiving areas. Therefore, it is important to carry out the evaluation of the influence of the Project on the economy, society and environment of Ningxia, and comprehensively evaluate and analyze the economic, social and eco-environmental benefits of the Project. Such evaluation and analysis can help us make a clearer and more comprehensive understanding of the role of the Project after its completion in the economy, society and environment of Ningxia and then take further corresponding measures to promote the normal performance of the Project to support and guarantee the healthy, sustainable economic and social development of Ningxia.
2. Establish an evaluation index system
The comprehensive evaluation of the influence of the Project on the economy, society and environment of Ningxia is a regional comprehensive evaluation, which used to determine the degree of the influence of the Project on various economic, social and eco-environmental aspects within the water supply scope and to translate these influences into objective calculated values. The evaluation index system consists of a target layer, a criteria layer and an index layer.

2.1 Target layer
The first layer is the target layer. The Project can provide all-round and multi-level water resource guarantee for the sustainable economic and social development of Ningxia. The comprehensive indexes – i.e. the indexes of the influence of the Project on the economy, society and environment of Ningxia – are established to measure the degree of the comprehensive influence of the Project on the social and economic development and the eco-environment of the water supply areas.

2.2 Criteria layer
The second layer is the criteria layer. The layer adopts quantitative indexes, called sub-indexes, which can comprehensively reflect the factors of the influence of the Project on various economic, social and environmental aspects of Ningxia and do not overlap each other. There are three sub-indexes in the criteria layer, namely the economic influence index, the social influence index and the environmental influence index.

The first sub-index is the economic influence index. It is used to evaluate the economic benefits supported by the Project and can directly reflect the influence of the Project on the economic development within the water supply scope, embodying the important role of the Project.

The second sub-index is the social influence index. It reflects the degree of the guarantee of the Project for the population, industry, agriculture and eco-environmental water use in the economic and social development of Ningxia Project, serving as an important index to measure the sustainable economic and social development of Ningxia.

The third sub-index is the environmental influence index. It is mainly used to judge the situation of the water eco-environment in the project area, reflecting the degree of the harmony between the economic and social development and the water eco-environment of Ningxia and to judge whether the operation of the Project is conducive to promoting the harmony and consistency between the economic and social development and the water resources of Ningxia.

2.3 Index layer
The third layer is the index layer. It contains specific indexes to evaluate the influence of the Project on the economy, society and environment and can reflect a specific aspect of the influence of the Project on the economy, society and environment of Ningxia.

Based on the sub-indexes of the criteria layer, the indexes are selected for the index layer and the evaluation index system is established and improved after several times of modification upon experts’ advice. The comprehensive evaluation index system contains one index in the target layer, three indexes in the criteria layer and nine indexes in the index layer, as shown in Table 1, in which the project area refers to the water supply area of the Project and the administrative area refers to the general administrative area where the Project is located.
3. Construct a fuzzy clustering loop iterative model
Because of the evaluation of the influence of the Project on the economy, society and environment is fuzzy to some extent, the author combined fuzzy comprehensive evaluation method and loop iterative algorithm for the evaluation, constructed a fuzzy clustering loop iterative model and sorted the different evaluation samples by calculating the weights of evaluation indexes to obtain the comprehensive results after aggregation calculation. The fuzzy clustering loop iterative model is to use a mathematical statistical method for all the index values reflecting the influence of the Project on various economic, social and eco-environmental aspects within the water supply scope to set one general index to reflect the general influence degree and set n comprehensive indexes to reflect the degree of the influence on specific economic, social and eco-environmental aspects. The algorithm is detailed as below:

In the comprehensive evaluation of the influence of the Project on the economy, society and environment of Ningxia, the author classified the evaluation samples into c grades according evaluation criteria and then carried out clustering evaluation of them. The evaluation index set is composed of n samples, expressed by \( X = \{ x_1, x_2, \ldots, x_n \} \). Each sample has m index eigenvalue vectors, expressed by \( x_j = \{ x_{1j}, x_{2j}, \ldots, x_{mj} \} \). An eigenvalue matrix is composed of n samples, expressed by \( X = (x_i) \) where \( X \) is the eigenvalue matrix; \( x_i \) is the index eigenvalue of sample \( i; i = 1, 2, \ldots, m \); \( j = 1, 2, \ldots, n^{[1-2]} \). Set \( Y = (y_{ih})_{m \times c} \) as standard sample set eigenmatrix, where \( y_{ih} \) is the standard limit of the corresponding index \( x_i \) (\( i = 1, 2, \ldots, m \)). Due to the different evaluation eigenvalue vectors of samples, normalize the evaluation index eigenvalue vectors by [0, 1] to facilitate the comparison of the index eigenvalues. The index eigenvalue matrix after normalization by [0, 1] is \( R = (r_{ij}) \), where \( r_{ij} \) is the normalized index eigenvalue; \( 0 \leq r_{ij} \leq 1; i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \).
When the bigger $x_{ij}$ is, the better the result is:

$$r_{ij} = \frac{x_{ij} - y_{ic}}{y_{il} - y_{ic}}$$

(2)

When the smaller $x_{ij}$ is, the better the result is:

$$r_{ij} = \frac{y_{il} - x_{ij}}{y_{il} - y_{ic}}$$

(3)

When the closer to a certain middle value $x_{ij}$ is, the better the result is:

$$r_{ij} = \begin{cases} 
1 - \frac{x_{ij} - y_{imid}}{y_{il} - y_{ic}}, & y_{imid} < x_{ij} < y_{il} \\
1 - \frac{y_{imid} - x_{ij}}{y_{il} - y_{ic}}, & y_{ic} < x_{ij} < y_{imid} 
\end{cases}$$

(4)

Cluster the sample index eigenvalues by $c$ categories and obtain the fuzzy clustering matrix $U=(u_{hj})$, where $u_{hj}$ is the relative membership degree of sample $j$ belonging to category $h$; $h = 1, 2, \ldots, c; j = 1, 2, \ldots, n$. It meets the conditions:

$$\sum_{h=1}^{c} u_{hj} = 1$$

$$\sum_{j=1}^{n} u_{hj} > 0$$

$$0 \leq u_{hj} \leq 1$$

(5)

Set $m$ normalized index eigenvalues of category $h$ as clustering center of category $h$, then the clustering center of $c$ categories is $m \times c$ order fuzzy clustering center matrix:

$$S = (s_{ih})$$

(6)

Where $0 \leq s_{ih} \leq 1; i = 1, 2, \ldots, m; h = 1, 2, \ldots, c$.

The $m$ normalized index eigenvalues of sample $j$ is expressed by vector $r_j$:

$$r_j = (r_{1j}, r_{2j}, \ldots, r_{mj})^T$$

(7)

The normalized clustering center of category $h$ is expressed by vector $s_h$:

$$s_h = (s_{1h}, s_{2h}, \ldots, s_{mh})^T$$

(8)

$$s = \left(1, \frac{c-2}{c-1}, \frac{c-3}{c-1}, \ldots, \frac{1}{c-1}, 0\right)$$

(9)

As different evaluation indexes have different effects on clustering, set index weight vector as $\omega_i$:

$$\omega_i = (\omega_1, \omega_2, \ldots, \omega_m), \; i = 1, 2, \ldots, m$$

(10)

Meet:
The difference between sample \( j \) and category \( h \) is expressed by general weighted Euclidean distance \( D_{hj} \).

\[
D_{hj} = \sqrt{\sum_{i=1}^{m}[\omega_i(r_{ui} - s_{ui})]^2}
\]

Establish an objective function:

\[
\min \{ F(u_{hj}) = \sum_{h=1}^{c} u_{hj}^2 D_{hj}^2 \}
\]

The comprehensive trade-off metric for the difference between sample \( j \) and \( c \) categories can be expressed as:

\[
f_j(u \cdot s \cdot \omega) = \sum_{h=1}^{c} |u_{hj}|^2 \sum_{i=1}^{m} \omega_i (r_{ui} - s_{ui})^2 \]

Establish an objective function:

\[
\min \{ f(u \cdot s \cdot \omega) = [f_1(u_1 \cdot s \cdot \omega), f_2(u_2 \cdot s \cdot \omega), \ldots, f_n(u_n \cdot s \cdot \omega)] \}
\]

Use equal-weight linear weighted average method to transform the objective function into a single objective optimization problem and, by constructing the Lagrangian function and making calculation, obtain:

\[
\omega_l = \sum_{i=1}^{m} \left[ \frac{\sum_{h=1}^{c} |u_{hj}|^2 (r_{ui} - s_{ui})^2}{\sum_{h=1}^{c} |u_{hj}|^2 (r_{ui} - s_{ui})^2} \right]^{-1} \cdot \omega_l
\]

\[
u_{hj} = \begin{cases}
0, & D_{hj} = 0, k \neq h \\
\left[ \frac{\sum_{i=1}^{m} |\omega_i| (r_{ui} - s_{ui})^2}{\sum_{i=1}^{m} |\omega_i| (r_{ui} - s_{ui})^2} \right]^{-1}, & D_{hj} \neq 0 \\
1, & D_{hj} = 0
\end{cases}
\]

The solving steps of the fuzzy clustering loop iterative model are as follows:\[3-4]\:

**Step 1:** give values to the number of clusters \( c \) and the accuracy of iterative calculation \( \varepsilon_1 \) and \( \varepsilon_2 \);

**Step 2:** Set the initial weight vector as \( \omega_l^0 \), the initial fuzzy clustering matrix as \( u_{hj}^0 \), and \( l=0 \);

**Step 3:** calculate \( \omega_l^{l+1} \) and \( u_{hj}^{l+1} \) respectively;

**Step 4:** if they meet

\[
\max |\omega_{ij}^{l+1} - \omega_{ij}^l| \leq \varepsilon_1, \quad \max |u_{hj}^{l+1} - u_{hj}^l| \leq \varepsilon_2
\]

the iteration ends, and \( \omega_l^{l+1} \) and \( u_{hj}^{l+1} \) can be used as the optimal index weight vector \( \omega^* \) and the optimal fuzzy clustering matrix \( u_{hj}^* \) respectively which meet the calculation accuracy requirements; otherwise, \( l=l+1 \), and the iterative calculation continues.

**Step 5:** multiply the weight of each index by the relative membership degree of each index in the corresponding sample and then add them up to obtain the comprehensive evaluation results of each sample.
4. Evaluation results

The Project focuses on industrial water supply, giving priority to meeting the industrial water demand of Xixia District of Yinchuan City and creating favorable water resource conditions for the industrial development of Qingtongxia Dam Power Plant and Qingtongxia Aluminum Plant. After the implementation of the Project, the overall goal is to basically ease the tension between the water resource demand and supply in the project area from 2010 to 2020, basically eliminate the bottleneck affecting the economic and social development of Ningxia, basically curb the deterioration of the eco-environment in the eastern foot of the Helan Mountain caused by excessive exploitation of groundwater, and promote the society and economy of the project area to gradually embark on a civilized development with healthy production, affluent life and good eco-environment.

The comprehensive evaluation is carried out in three different stages respectively before the construction, after the construction and after the expansion of the Project, and the improvement degree of the comprehensive benefits of the Project after the expansion compared with that in the previous two stages is emphatically analyzed, of which 2004 is the pre-construction level year and 2010 is the post-construction level year. See Tab. 2 for specific data, where the reference values are ideal, and the data in 2020 are obtained by calculation based on the evaluation of the economic and social development and the water resource exploitation and utilization trend of the area.

| Criteria Layer | Index Layer | In 2004 | In 2010 | In 2020 | Reference Value |
|----------------|-------------|---------|---------|---------|-----------------|
| Economic Influence Index | Proportion of value added of primary industry in project area to that in administrative area | 45 | 55 | 70 | 100 |
| | Proportion of value added of secondary industry in project area to that in administrative area | 50 | 65 | 80 | 100 |
| | Proportion of value added of tertiary industry in project area to that in administrative area | 40 | 50 | 60 | 100 |
| Social Influence Index | Urban and rural living water supply guarantee rate | 80 | 90 | 100 | 100 |
| | Industrial water supply guarantee rate | 20 | 40 | 90 | 100 |
| | Agricultural water supply guarantee rate | 70 | 75 | 80 | 100 |
| | Eco-environmental water supply guarantee rate | 50 | 60 | 70 | 100 |
| Environmental Influence Index | Water qualification rate in water function area | 45 | 50 | 79 | 100 |
| | Groundwater funnel water-level recovery rate | 30 | 50 | 70 | 100 |

Use Matlab to develop a calculation program which, after 17 iterations, enables the calculation accuracy to meet

$$\max |\omega^17_i - \omega^16_i| \leq 0.0001, \quad \max |\omega^17_{h,j} - \omega^16_{h,j}| \leq 0.0001, \text{ then the index weight vector}$$

$$\omega = (0.1908, 0.0854, 0.2471, 0.0169, 0.0440, 0.0298, 0.1653, 0.1230, 0.0976,)$$

It multiplies the weight of each evaluation index in the index layer by the relative membership degree of each index in the corresponding sample, and then adds them up to obtain the evaluation results of the criteria layer and the evaluation results of the target layer. See Tab. 3 to Tab. 5 for details.
It can be seen from Tab. 3 that the evaluation results of each index in the index layer increase with time, of which industrial water supply guarantee rate and groundwater funnel water-level recovery rate increase most significantly, respectively by 4.00 times and 2.33 times from 2004 to 2020, indicating the Project smoothly plays the water supply role, can provide water supply guarantee for the rapid and sustainable industrial development, and can significantly improve the groundwater over-exploitation in the project area. The results of the remaining seven indexes show that the increase multiples are between 1.24 to 1.76 from 2004 to 2020, indicating that the Project can effectively improve the economic, social and environmental benefits of the project area. The specific comparative analysis results show:

(1) In supporting the increase of the three industries: the index evaluation results show the increase multiples are basically same, indicating that the Project plays a relatively balanced role in supporting the three industries;

(2) In water supply guarantee rate increase multiple: industrial water supply guarantee rate > eco-environmental water supply guarantee rate > agricultural water supply guarantee rate, indicating that the Project’s smooth water supply has a significant effect on improving the industrial water supply guarantee rate and also effectively increases the eco-environmental water supply;

(3) In environmental influence: groundwater funnel water-level recovery rate > water qualification rate in water function area, indicating that, compared with improving the water quality in water function area in the project area, the Project plays a more obvious role in replacing groundwater and recovering groundwater level.

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It can be seen from Tab. 4 that, as time passes, the influence of the Project on the economy, society and environment gradually increases, with the greatest influence on economy, followed by that on society and finally eco-environment. It is clear from the comparison of the indexes in the criteria layer from 2004 to 2020 that the Project has the greatest change rate of the influence on the eco-environment of the project area: the influence degree in 2020 is 1.96 times that in 2004; followed by social influence change rate: the influence degree in 2020 is 1.55 times that in 2004; and finally economic influence change rate: the influence degree in 2020 is 1.54 times that in 2004. The above evaluation results fully show that the Project uses the Yellow River water to replace the groundwater in the project area, which can effectively improve the groundwater situation in the project area and has significant public welfare nature.

| Tab. 5 | Evaluation results of the target layer | Unit: % |
|--------|----------------------------------------|---------|
| Target Layer | Comprehensive Evaluation Index | In 2004 | In 2010 | In 2020 |
| T      | 43.79 | 55.02 | 71.03 |
| Multiple | 1.00 | 1.26 | 1.62 |

The Project was not put into service in 2004 and began to operate and came into play from 2010. From Tab. 5 it can be seen that, with 2004 as reference year, the comprehensive economic, social and environmental evaluation value in the project area in 2010 increases by 26% compared with 2004, and that in 2020 increases by 62% compared with 2004. Evidently, the normal operation of the Project will play a positive and significant role in promoting the economic, social and environmental improvement in the project area.

5. Conclusions
If the Project can fully play its water supply role as scheduled, it can not only provide a reliable water source for the industrial development of the project area and effectively promote the implementation and development of new industrial projects, so as to drive the social and economic development of the entire project area and even the administrative area, but also make full use of the Yellow River water right allocation indexes, effectively replace the groundwater exploitation amount and improve the deteriorating water eco-environment, bringing significant economic, social and eco-environmental benefits. It is suggested that the relevant governments at all levels of Ningxia strengthen cooperation, clarify labor division, actively promote the improvement of the Project and, in addition, innovate the construction and management systems of the Project and fully mobilize the enthusiasm of the enterprises to jointly maximize the benefits of the Project.

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