Coordinated development of agricultural water resources and the socio-economy in Shanxi province considering uncertainty

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Abstract
The conflict between agricultural water resources and socio-economic development is a global problem. Accurate evaluation of coordinated development of agricultural water resources and socio-economic factors and risk mitigation is necessary for sustainable development under uncertainty. In order to accurately evaluate the coordination between agricultural water resources and socio-economic development under uncertainty, an evaluation method was applied in this study by coupling an analytic hierarchy process method with an uncertainty analysis method. The evaluation method, including selection of criteria, data collection, determination of indicator weights, evaluation of coordinated development, prediction of parameters, and judgment of coordinated development state, has been proposed to study the degree of coordinated development. To deal with uncertainties, the Monte Carlo method and the fuzzy set method were used. The overall method was demonstrated to solve a real-world evaluation problem in Shanxi province, China. Results showed that degrees of coordinated development were (0.7, 0.8) for most of the cities in Shanxi in 2015, indicating that the state of coordinated development was intermediate. In 2020, the degree of coordinated development was expected to markedly decrease, the state of coordinated development to be minimal, and agricultural water resources utilization to lag behind socio-economic development.

KEYWORDS
agricultural water resources, coordinated development, Shanxi province, socio-economic development

Résumé
Le conflit entre les ressources en eau agricoles et le développement socio-économique est un problème mondial. Une évaluation précise du développement coordonné des ressources en eau agricoles et des facteurs socio-économiques et l’atténuation des risques sont nécessaires pour un développement durable dans l’incertitude. Afin d’évaluer avec précision la coord-
dination entre les ressources en eau agricoles et le développement socio-économique en situation d’incertitude, une méthode d’évaluation a été appliquée dans cette étude en couplant une méthode de processus de hiérarchie analytique avec une méthode d’analyse d’incertitude. La méthode d’évaluation, y compris la sélection des critères, la collecte de données, la détermination des poids des indicateurs, l’évaluation du développement coordonné, la prédiction des paramètres et le jugement de l’état de développement coordonné, a été proposée pour étudier le degré de développement coordonné. Pour faire face aux incertitudes, la méthode de Monte Carlo et la méthode des ensembles flous ont été utilisées. Il a été démontré que la méthode globale résout un problème d’évaluation dans le monde réel dans la province du Shanxi, en Chine. Les résultats ont montré que les degrés de développement coordonné étaient (0,7, 0,8) pour la plupart des villes du Shanxi en 2015, indiquant que l’état de développement coordonné était intermédiaire. En 2020, le degré de développement coordonné devrait nettement diminuer, l’état de développement coordonné sera minime et l’utilisation des ressources en eau agricoles sera à la traîne du développement socio-économique.

**MOTS CLÉS**

développement coordonné, ressources en eau agricoles, développement socio-économique, province du Shanxi

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1 | INTRODUCTION

Social development poses huge challenges in improving the utilization ratio of water resources and promoting economic growth. It is challenging to effectively design coordinated systems of water resources utilization and economic development. Agriculture is the largest consumer of freshwater for producing food used to feed a large number of people in China (Li *et al.*, 2020a). Agricultural water is a critical influence on food production. More food production helps increase agricultural economic output (Gong *et al.*, 2020); on the other hand, more food production means more agricultural water consumption and less industrial water consumption, and also may lead to weaker industrial, domestic, and ecological activities (Li *et al.*, 2020b). Therefore, modifying the distribution of agricultural water to coordinate economic development is significant, especially for water-deficient regions.

In recent years, studies have primarily focussed on investigating the causal relationship (Bao & He, 2015), developing applicable indicator systems (Yang *et al.*, 2018), and establishing evaluation models (Song *et al.*, 2018) of economic development level and water use. Methods include system analysis theory (Xiong *et al.*, 2015), state-space method and component analysis (Tang *et al.*, 2016), reduction model (Gu, Zhang, & Pan, 2017), and unified co-evolutionary model (Yao *et al.*, 2018). However, coordinated development of agricultural water resources and the economy is difficult due to changes in annual available agricultural water volume, complexity of the water economy system, and unpredictability of economic conditions (Yang *et al.*, 2017), which lead to uncertainty. Many studies have dealt with uncertainty in evaluation. However, only a few studies focussed on coordinated development of agricultural water resources and socio-economic factors with uncertainty. There are many factors affecting coordinated development, which makes the evaluation process considerably complicated. The value of parameters in models cannot be accurately predicted, especially when evaluating future risk.

To address uncertainties in the coordinated development of agricultural water resources and social-economic factors, some uncertainty methods, including stochastic mathematical programming, fuzzy mathematical programming, and interval mathematical programming, can be adopted. They are able to handle probabilistic, fuzzy uncertainties or interval uncertainties accordingly (Yang, Li, & Huo, 2019). In this study, the Monte Carlo method has been chosen to solve the complex uncertain problem.

Sustainable agricultural development is conducive to sustainable development of the economy in Shanxi and an important way to achieve regional grain balance.
However, the factors restricting agricultural production are becoming more and more prominent with population growth and socio-economic development. One aspect is a serious shortage in water resources. The per capita water resources are only $247–342$ m$^3$/year, of which about half is used for agriculture. Another aspect is that the development and utilization of agricultural water resources in Shanxi is unbalanced and inefficient. The effective utilization rate of water in well irrigation areas is about 60%, but in canal irrigation areas it is only about 40%. Therefore, an efficient evaluation method is desired for evaluating coordinated development of agricultural water resources and the economy, as well as identifying possible risks caused by uncertainty and complexity.

The purpose of this study is to establish an evaluation method to analyse the probability of coordinated development of agricultural water resources and the economy. The evaluation method is applied to a real case study in Shanxi province, China, a major agricultural province, in order to achieve sustainable regional development. The advantages of the proposed evaluation method are as follows: (i) It takes coordinated development of agricultural water resources and socio-economy into account; (ii) it deals with uncertainty by applying the Monte Carlo method; and (iii) it obtains possible risks caused by uncertainty and complexity.

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2 | METHODOLOGY

The evaluation process for the coordinated development of agricultural water resources and the economy includes selection of criteria, data collection, determination of weights, evaluation of coordinated development, prediction of parameters, judgment of coordinated development state, and final evaluation.

2.1 | Selection of criteria

The criteria should be selected based on the pursuit of sustainability in utilization of agricultural water resources and in socio-economic development. According to the concept of regional coordinated development, the criteria of the agricultural water resources system should measure the degree of water abundance, water use efficiency, and agricultural response conditions, and the criteria of the socio-economic development system should measure the level of economic development, social development, and effect on the environment.

Because the urban water environment is profoundly and continuously influenced by water usage and effluent water pollution, the ratio of ecological water consumption, wastewater treatment rate, and proportion of afforestation area were selected as measurement indicators for urban ecological water supply, environmental pollution, and ecological water increase, respectively. This study selected the following indicators to constitute the evaluation criteria, of which, nine evaluation indicators are for agricultural water resources and nine for socio-economic development. Details are shown in Table 1. The reason for choosing these indicators is that the specific data are easy to obtain and are representative. Most of the data have obvious sources, which are authoritative data that can be obtained from relevant policies or yearbooks.

2.2 | Determination of weight

Many methods can be used to determine the weights of indicators, including subjective weighting methods and objective weighting methods (Sahoo et al., 2016). Subjective weighting methods are methods where the opinions of experts are used to compare the importance of each indicator according to their subjective judgment, experience, and hobbies, such as the analytic hierarchy process (AHP) (Ren, Li, & Zhang, 2019). Objective weighting methods are based on actual data and objective information reflected by each indicator, such as principal component analysis method or multi-object planning method. In this study, the combined utilization of subjective and objective weighting methods can overcome the shortcomings of a single weighting method to some degree and obtain more scientific and reasonable evaluation results.

- **Determination of subjective weight.** Subjective evaluation matrices $A$ were established separately for the agricultural water resources system and the socio-economic development system. The elements of the matrices are $a_{ij}$, which are mean values of scale and are determined by the degree of influence between indicator $C_i$ and $C_j$ which belong to an indicator system.

To test consistency, it is necessary to calculate an approximate value of the maximum eigenvalue $\lambda$ using Equation 1:

$$\lambda = \frac{1}{n} \sum_{i=1}^{n} \left((\mathbf{Aw})/w_i\right),$$

in which $\mathbf{w}' = (w'_1, w'_2, \cdots, w'_n)^T$ is the column vector representing subjective weight, $w'_i = \bar{w}_i / \sum_{i=1}^{n} \bar{w}_i$
and $\tilde{w}_i (\tilde{w}_i = \sum_{j=1}^{n} \left( a_{ij} / \sum_{i=1}^{n} a_{ij} \right))$ are temporary variables in the process of calculating $w$, and $n$ is the number of indicators.

In order to confirm the consistency of reciprocal matrix criteria, the AHP was applied to decompose the decision process in a hierarchy of criteria, subcriteria, attributes, and alternatives. The consistency index (CI) is calculated according to $CI = (\lambda - n)/(n - 1)$. The closer the CI is to 0, the better the consistency. The consistency ratio (CR) is an important parameter, which is a measure of consistency in a pairwise comparison matrix (Saaty, 1980). CR $< 0.10$ indicates that the new model has satisfactory consistency. The calculation formula is $CR = CI/RI$, in which RI is the random CI and determined by the order of the judgment matrix $n$ (Debnath, Majumder, & Pal, 2015).

- **Determination of objective weight.** Objective evaluation matrices $B$ were established separately for the agricultural water resources system and the socio-economic development system. The elements of the matrices are $b_{ij}$, which are the collected values of indicators, in which $i$ is index of indicators and $j$ is index of regions. It is difficult to analyse these indicators directly because of their inconsistent units. Hence, we used the standardized method for dimensionless data to make the indicators comparable. The transformation methods are described as follows:

$$b'_j = \begin{cases} (b_j - b_{\min_j}) / (b_{\max_j} - b_{\min_j}) & \text{for positive indicators} \\ (b_{\max_j} - b_j) / (b_{\max_j} - b_{\min_j}) & \text{for negative indicators} \end{cases}$$

in which $b_{\max_j}$ and $b_{\min_j}$ are maximum value and minimum value of indicator $j$, respectively, and $b'_j$ are elements of the generated dimensionless matrix.

The column vector represented objective weight is $w'$:

| Target | Standard | Indicators |
|--------|----------|------------|
| Level of agricultural water resources \ (Fa) | Abundance of agricultural water resources \ (Fa_1) | Proportion of agricultural water consumption \ (Fa_{11}) \ (%) |
| | | Annual precipitation \ (Fa_{12}) \ (mm) |
| | | Well irrigation amount per area \ (Fa_{13}) \ (x10^6 \ ton) |
| Utilization state of agricultural water resources \ (Fa_2) | Agricultural water consumption per ten thousand RMB output \ (Fa_{21}) \ (m^3/RMB) |
| | | Agricultural intermediate consumption per area \ (Fa_{22}) \ (RMB/ha) |
| | | Efficient utilization coefficient \ (Fa_{23}) |
| Agricultural response condition \ (Fa_3) | Applied quantity of chemical fertilizer per area \ (Fa_{31}) \ (ton/ha) |
| | | Total power of agricultural machinery per area \ (Fa_{32}) \ (kw/ha) |
| | | Rural electricity consumption per capita \ (Fa_{33}) \ (x10^4 kWh/person) |
| Level of socio-economic development \ (Fe) | Level of economic development \ (Fe_1) | Ratio of primary industry to GDP \ (Fe_{11}) \ (%) |
| | | GDP per capita \ (Fe_{12}) \ (x10^3 RMB/person) |
| | | Ratio of total retail sales to GDP \ (Fe_{13}) \ (%) |
| Level of social development \ (Fe_2) | Natural population growth rate \ (Fe_{21}) |
| | | Engel’s coefficient \ (Fe_{22}) \ (%) |
| | | Urbanization rate \ (Fe_{23}) |
| Level of ecological development \ (Fe_3) | Proportion of ecological water use \ (Fe_{31}) |
| | | Rate of sewage treating \ (Fe_{32}) \ (%) |
| | | Annual afforestation area ratio \ (Fe_{33}) |

Abbreviations: GDP, gross domestic product; RMB, renminbi.
\[ w'' = (w''_1, w''_2, \cdots, w''_n)^T, \] (3)

in which \( w''_i (w''_i = \sigma_i / \sum_{i=1}^{n} \sigma_i ) \) is the objective weight coefficient and \( \sigma_i = \left( \frac{1}{n} \sum_{j=1}^{n} \left( b' - y \left( \frac{\sum_{j=1}^{n} y b'_{ij}}{n} \right) \right)^2 \right) \) is the mean square error of \( b'_{ij} \).

- **Determination of combination weight.** Combination weight is calculated as follows:

\[ w = aw' + bw'', \] (4)

in which \( w = (w_1, w_2, \cdots, w_n)^T \) is the column vector representing combination weight, \( a \) and \( b \) are weights of \( w' \) and \( w'' \), and \( a + b = 1 \).

### 2.3 Evaluation of coordinated development

According to Equation 2, objective evaluation matrices of agricultural water resources \( B_a \) and objective evaluation matrices of socio-economic development \( B_e \) are established. And the combination weight of agricultural water resources \( w_a \) and the combination weight of socio-economic development \( w_e \) are calculated by Equation 4. Then the comprehensive level of agricultural water resources \( F_a (F_a = w_a^T B_a) \) and the comprehensive level of socio-economic development \( F_e (F_e = w_e^T B_e) \) are calculated.

- **Determination of comprehensive level \( T \).** The comprehensive level of agricultural water resources and socio-economic development \( T \) is calculated according to Equation 5:

\[ T = a F_a + \beta F_e, \] (5)

in which \( \alpha \) is the weight of agricultural water resources, and \( \beta \) is the weight of socio-economic development, with \( \alpha + \beta = 1 \).

- **Determination of coordination degree.** Vector \( C \) expresses the degree of coordination between sustainable utilization of agricultural water resources and socio-economic development. Coordination degree is calculated according to Equation 6:

\[ C_i = \left( \frac{F_{ai} \times F_{ei}}{T_i^2} \right)^k, \] (6)

in which \( C_i, F_{ai}, F_{ei} \), and \( T_i \) are the \( i^{th} \) elements in vector \( C, F_a, F_e, \) and \( T \), and \( k \) is the coordinate coefficient with a general value of \( 2 \leq k \leq 5 \).

- **Determination of the degree of coordinated development.** The degree of coordinated development \( D \) is an improvement of coordination degree \( C \). It reflects the sustainability of agricultural water utilization and socio-economic development models indirectly (Liu, Zhang, & Zhang, 2009). The calculating formula is \( D_i = \sqrt{C_i / T_i} \), in which \( D_i \) is the \( i^{th} \) element in vector \( D \).

### 2.4 Judgement of coordinated development state

To effectively illustrate the evolution of coordinated development of agricultural water and socio-economic systems, a fuzzy set method was introduced to establish evaluation criteria for coordinated development (Yuan et al., 2014). The method has been widely applied in the evaluation process as the degree of fuzzy membership.

Otherwise, whether agricultural water resources or socio-economic development will be lagging behind in development depends on the value of \( F_{ai} - F_{ei} \). When \( F_{ai} \) is closer to \( F_{ei} \), and the distance between them is less than a small value, they can be approximately considered equal. Let the small value be \( \Delta_i = 0.1 |F_{ai} - F_{ei}| \).

### 2.5 Forecast and uncertainty analysis

The purpose of this study is to evaluate coordinated development. However, because most parameters are uncertain, it is difficult to obtain an accurate forecast and analysis of future coordinated development between agricultural water resources and socio-economic development. To get a more reliable analysis, the Monte Carlo method has been adopted to handle parametrical uncertainty analysis. Using this method, some groups of discrete data are generated randomly. Then, through the above methodology, the degree of coordinated development in a particular year in the future can be obtained.
3 | APPLICATION

3.1 | Study area

The methods were applied to a real case study in Shanxi province. Shanxi, a province in central China, covers 11 county-level cities and 85 counties as of 2017. The distribution of cities and precipitation is shown in Figure 1. The province is currently experiencing economic reform and agricultural development. It has been a key problem to research coordinated development of agricultural water resources and the economy.

In this study, subjective weight and objective weight have been considered to have the same importance, so $a = b = 0.5$ in Equation 11. Since rural socio-economic development level and resources-environment level are equally important in rural development, let $\alpha = \beta = 0.5$ in Equation 14, and $k = 2$ in Equation 15 (Liu, Zhang, & Zhang, 2009).

3.2 | Data collection

Data were collected from local statistical information published by the government, such as statistical yearbooks, water resource bulletins, and statistics bulletins of national economy and social development of Shanxi province from 2005 to 2015.

4 | ANALYSIS AND RESULTS

4.1 | Analysis of coordinated development among cities

Based on the methodology, coordinated development results among cities were obtained. Some key results are shown in Table 2. The comprehensive levels of agricultural water resources and socio-economic development are compared. The comprehensive level of agricultural water resources is higher than the comprehensive level of socio-economic development in Taiyuan, Datong, Yangquan, Changzhi, Shuozhou, and Lvliang. Big gaps existed in Yangquan ($F_a - F_e = 0.674 - 0.523$) and Yuncheng ($F_a - F_e = 0.337 - 0.573$).

The efficient utilization coefficients for Taiyuan, Shuozhou, Datong, and Lvliang were high, and precipitation in Yangquan was abundant. Therefore, it was easier to satisfy the demand of agricultural water, resulting in $F_a > F_e$. Moreover, the ratio of primary industry to gross domestic product was high in Jinzhong and Yuncheng, and accordingly their economic development is better than utilization of agricultural water.

Degrees of coordinated development were (0.7, 0.8) for most of the cities. Jincheng had the highest degree of coordinated development (0.837) and Yuncheng had the lowest (0.640). Coordinated development of agricultural water resources and the economy in Jincheng was best among cities because its comprehensive level was also the highest of all cities ($F_a = 0.688$, $F_e = 0.713$). The situation of agricultural water resources in Yuncheng was tougher owing to its large gaps in comprehensive levels ($F_a - F_e = -0.236$).

In view of the overall situation, the state of coordinated development in Shanxi was intermediate in 2015. The state of coordinated development of Taiyuan and Yuncheng was primary, and the state of coordinated development of Jincheng and Linfen was well coordinated. Taiyuan and Yangquan had slow socio-economic development. Jinzhong, Yuncheng, and Xinzhou had low utilization of agricultural water resources.

To achieve balanced development, it is critical to focus on socio-economic development of Taiyuan and Yangquan. In addition, improving agricultural water resources utilization of Jinzhong, Yuncheng, and Xinzhou is also important to maintain the momentum of sustained development, especially in Yuncheng.
Analysis of coordinated development from 2005 to 2015

Evaluation results of Shanxi from 2005 to 2015 are shown in Table 3. The comprehensive levels of agricultural water resources and socio-economic development were compared from 2005 to 2015. The comprehensive levels of agricultural water resources were lower than the comprehensive levels of socio-economic development, except in 2008; a big gap existed in 2007 ($F_a - F_e = -0.150$).

The average degree of coordinated development was 0.758. The average degree slowly decreased from 2005 to 2015. The state of coordinated development in 2005 was well coordinated, while states of coordinated development in other years were intermediate. According to the present trend, imbalance might happen.

4.3 Analysis of future coordinated development

In order to evaluate possible risks in the future, this study analysed various data uncertainties of the evaluation system. Interval ranges of indicators are listed in Table 4.

### Table 3 Evaluation results of Shanxi from 2005 to 2015

| Year | $F_a$ | $F_e$ | $T$  | $C$  | $D$  | Coordinate development state | Object of maladjustment |
|------|------|------|------|------|------|------------------------------|--------------------------|
| 2005 | 0.64 | 0.681| 0.661| 0.998| 0.812| W                           | B                        |
| 2006 | 0.617| 0.682| 0.649| 0.995| 0.804| W                           | A                        |
| 2007 | 0.551| 0.685| 0.618| 0.976| 0.777| I                           | A                        |
| 2008 | 0.61 | 0.564| 0.587| 0.997| 0.765| I                           | B                        |
| 2009 | 0.606| 0.596| 0.601| 1    | 0.775| I                           | B                        |
| 2010 | 0.589| 0.596| 0.592| 1    | 0.77 | I                           | B                        |
| 2011 | 0.511| 0.586| 0.549| 0.991| 0.737| I                           | A                        |
| 2012 | 0.55 | 0.605| 0.577| 0.995| 0.758| I                           | B                        |
| 2013 | 0.468| 0.591| 0.529| 0.974| 0.718| I                           | A                        |
| 2014 | 0.511| 0.582| 0.546| 0.991| 0.736| I                           | A                        |
| 2015 | 0.526| 0.617| 0.572| 0.988| 0.751| I                           | A                        |

**Abbreviations:** A, agricultural water resources; B, both agricultural water resources and socio-economic development; C, degree of coordination; D, degree of coordinated development; $F_a$, level of agricultural water resources; $F_e$, level of socio-economic development; I, intermediate coordination; $T$, comprehensive level of agricultural water resources and socio-economic development; W, well coordination.
Analysis results of predictions for 2020 and 2025 were obtained using the Monte Carlo method, as shown in Table 5. \( D \) varied between 0.5 and 0.6, the state of coordinated development is very low, and agricultural water resources utilization lags behind socio-economic development. All results show that utilization of agricultural water resources cannot catch up with socio-economic development.

Figure 2 shows distribution statistics of the degree of coordinated development predicted for 2020 and 2025. In 2020, the interval of \( D \) is \([0.50, 0.66]\), and the average value is 0.588. In 2025, the interval of \( D \) is \([0.42, 0.60]\), and the average value is 0.524. The degree of coordinated development has a trend of decreasing markedly, which indicates that agricultural water resources and socio-economic development will be in transitional states. If no effective measures are applied to balance agricultural water resources and socio-economic development in Shanxi, they might be maladjusted in the foreseeable future. To solve this problem, developing available water resources, popularizing irrigation water saving facilities, and raising the cyclic utilization rate of water are potential effective countermeasures.

**Table 4** Prediction of interval numbers of agricultural water resources system and socio-economy development system in 2020 and 2025

| Indicators | 2020            | 2025            |
|------------|-----------------|-----------------|
| \( F_{a11} \) | \[0.513, 0.581\] | \[0.512, 0.581\] |
| \( F_{a12} \) | \[463, 602\]    | \[463, 602\]    |
| \( F_{a13} \) | \[0.025, 0.028\] | \[0.026, 0.029\] |
| \( F_{a21} \) | \[0.00, 0.00\]  | \[0.00, 0.00\]  |
| \( F_{a22} \) | \[1.59, 1.77\]  | \[2.05, 2.23\]  |
| \( F_{a23} \) | \[0.560, 0.560\]| \[0.590, 0.590\]|
| \( F_{a31} \) | \[0.373, 0.396\]| \[0.400, 0.423\]|
| \( F_{a32} \) | \[11.0, 11.6\]  | \[12.4, 13.0\]  |
| \( F_{a33} \) | \[0.069, 0.076\]| \[0.082, 0.089\]|
| \( F_{e11} \) | \[0.014, 0.167\]| \[0.012, 0.164\]|
| \( F_{e12} \) | \[47.3, 53.7\]  | \[59.9, 66.2\]  |
| \( F_{e13} \) | \[0.465, 0.548\]| \[0.537, 0.620\]|
| \( F_{e21} \) | \[3.67, 4.46\]  | \[3.11, 3.91\]  |
| \( F_{e22} \) | \[20.7, 26.3\]  | \[14.4, 19.9\]  |
| \( F_{e23} \) | \[0.382, 0.395\]| \[0.316, 0.329\]|
| \( F_{e31} \) | \[0.039, 0.043\]| \[0.046, 0.050\]|
| \( F_{e32} \) | \[107, 121\]    | \[125, 139\]    |
| \( F_{e33} \) | \[0.018, 0.022\]| \[0.018, 0.022\]|

Abbreviations: \( F_{a11} \), Proportion of agricultural water consumption; \( F_{a12} \), Annual precipitation; \( F_{a13} \), Well irrigation amount per area; \( F_{a21} \), Agricultural water consumption per ten thousand RMB output; \( F_{a22} \), Agricultural intermediate consumption per area; \( F_{a23} \), Efficient utilization coefficient; \( F_{a31} \), Applied quantity of chemical fertilizer per area; \( F_{a32} \), Total power of agricultural machinery per area; \( F_{a33} \), Applied quantity of fuel per area; \( F_{e11} \), Ratio of primary industry to GDP; \( F_{e12} \), GDP per capita; \( F_{e13} \), Ratio of total retail sales to GDP; \( F_{e21} \), Natural population growth rate; \( F_{e22} \), Engel’s coefficient; \( F_{e23} \), Urbanization rate; \( F_{e31} \), Proportion of ecological water use; \( F_{e32} \), Rate of sewage treating; \( F_{e33} \), Annual afforestation area ratio.

**Table 5** Average evaluation results of Shanxi in 2020 and 2025

| Indicators | 2020 | 2025 |
|------------|------|------|
| \( F_a \)  | 0.296| 0.235|
| \( F_c \)  | 0.522| 0.478|
| \( T \)    | 0.409| 0.357|
| \( C \)    | 0.847| 0.772|
| \( D \)    | 0.588| 0.524|

| Coordinate development state | R | R |
| Object of maladjustment      | A | A |

Abbreviations: \( A \), agricultural water resources; \( C \), degree of coordination; \( D \), degree of coordinated development; \( F_a \), level of agricultural water resources; \( F_c \), level of socio-economic development; \( R \), barely coordinated; \( T \), comprehensive level of agricultural water resources and socio-economic development.
5 | CONCLUSIONS

This study identified nine evaluation indicators of agricultural water resources and nine evaluation indicators of socio-economic development as criteria, according to the concept of coordinated regional development. Based on the combined objective and subjective weights, the comprehensive level, degree of coordination, and the state of coordinated development of agricultural water resources and socio-economic development were evaluated. Results showed that the degrees of coordinated development were (0.7, 0.8) for most of the cities of Shanxi in 2015. Jincheng had the highest degree of coordinated development (0.837) and Yuncheng had the lowest (0.640). To achieve balanced development, it is critical to focus on the socio-economic development of Taiyuan and Yangquan and on the utilization of agricultural water resources in Jinzhong, Yuncheng, and Xinzhou. The average degree of coordinated development was 0.758, and the state of coordinated development was intermediate from 2006 to 2015. According to predicted evaluation results for 2020 and 2025, the degrees of coordinated development varied between 0.5 and 0.6, the state of coordinated development was very low, and agricultural water resources utilization lagged behind socio-economic development. The degree of coordinated development decreased markedly, which indicates that agricultural water resources and socio-economic development will be in a transitional state. To avoid imbalanced development, some measures, such as developing available water resources, popularizing irrigation water saving facilities, and raising the cyclic utilization rate of water, should be implemented.

ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China (51709195, 41807130), the Science and Technology Research Fund of Shanxi Province (201901D111251), the Taiyuan University of Science and Technology Scientific Research Initial Funding (20172012, 20182040), and the Graduate Education Innovation Project of Shanxi Province (2020SY426).

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How to cite this article: Yang, G., Ding, L., Huo, L. & Hu, Y. (2021) Coordinated development of agricultural water resources and the socio-economy in Shanxi province considering uncertainty. *Irrigation and Drainage*, 70(4), 861–870. Available from: https://doi.org/10.1002/ird.2581