Two-way coordinated evaluation of mine water supply and demand in coal base—Empirical Research Based on TOPSIS Method

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Abstract. In order to understand the two-way coordination of mine water supply and demand in Ningdong coal base, the contradiction between water supply and demand in this area will be solved to some extent. Based on the theory of water resources balance analysis, this paper establishes a two-way coordinated evaluation index system for mine water supply and demand based on survey data. The analytic hierarchy process and entropy method are used to determine the weight of evaluation index. The TOPSIS method is used to evaluate Ningdong coal base Yinchuan, Shizuishan, Lingwu and Wuzhong. Regional mine water supply and demand two-way coordination. The results show that under the current mining mode, the two-way coordination of demand and supply of mine water in Yinchuan area of Ningdong coal base is the best, followed by Lingwu, Wuzhong is worse, and Shizuishan is the worst.

1. Introduction

China is a large mineral resource country and a major mining country. It has discovered 172 kinds of minerals and 162 proven resources. The National Development and Reform Commission and the State Department of Energy jointly issued the "Mineral Water Utilization Development Plan" clearly stated(National Development and Reform Commission, 2013). In 2015, the mine water discharge was about 7.1 billion m³, accounting for more than 80% of the total mine water discharge. The mine water discharge in the Yellow River Basin was about 5.6 billion m³, accounting for 79% of the national mine water discharge. More than 70% of the country's mines. Water comes from large coal bases in water-stressed areas and severely water-deficient areas.

This paper takes Ningdong coal base as the research object, and uses TOPSIS method to carry out two-way coordinated evaluation of mine water supply and demand in Ningdong coal base. Taking the two-way coordinated evaluation system of mine water supply and demand as the research object, constructing evaluation index system and using the range method to supply and demand. The data is processed, and the weights of the evaluation indicators are determined by the analytic hierarchy process and entropy method. The weighted normalized decision matrix is used to calculate the gray correlation degree of the evaluation indicators. According to the closeness of the scheme, the
comprehensive evaluation is made, and Yinchuan, Shizuishan, Lingwu and Wuzhong are obtained. Two-way coordination of supply and demand of mine water.

2. Study area
Ningdong Coal Base is located in the central and eastern part of Ningxia. It is one of the 14 large coal bases identified by the state and one of the 9 million kilowatt-scale large-scale coal-fired power bases under the “Energy Development Strategic Action Plan (2014-2020)”. The Ningdong coal base includes seven mining areas including Linwu, Wuhu, Hengcheng, Majiatan, Jijiajing, Tianshuihe and Weizhou, and an independent minefield in Shigou.

3. Analytical method
3.1 TOPSIS
The two-way coordination of supply and demand refers to the implementation of the promotion of mine water conservation and intensive policies and measures to promote the rational supply of mine water, the demand is appropriate, and strive to ensure the objective needs of economic and social development with minimum resource consumption. The calculation and analysis of water supply and demand balance refers to the process of calculating and analyzing the supply and demand of water resources and the relationship between them in a certain region(Yu WD et al,2003). Based on the regional status quo and the development trend of supply and demand water, it provides decision support for the rational development and utilization of regional water resources and the coordinated development of regional economy, society and ecology. Therefore, the two-way coordinated evaluation of mine water supply and demand refers to the measurement of mine water supply and demand status.

The full name of TOPSIS is "the sorting method that approximates the ideal value". It is an evaluation method when comparing multiple programs and multiple targets. It was first established in 1981 by CLHwang and K. Yoon(Wang Y et al,2011;Yang BC et al,2011;Chen W,et al,2011). In practical application, the analytic hierarchy process and entropy method are usually used to determine the index weight, and the gray correlation method is used to calculate the correlation degree. The basic steps are as follows:

Assume that the multi-attribute decision problem has an $A = \{A_1, A_2, \ldots, A_m\}$ evaluation scheme,Inclusive $F = \{F_1, F_2, \ldots, F_m\}$. Among them $M = \{1,2,\ldots,n\}$, $N = \{1,2,\ldots,n\}$. Set the decision matrix to $X = (x_{ij})_{m \times n}$, $x_{ij}$ is the attribute value of the $i$ scheme under the $j$ attribute $i \in M$, $j \in N$. Then the evaluation steps based on entropy weight-gray correlation-TOPSIS are as follows:

1) Data processing. The data processing method is consistent with the entropy weight method, and is processed by the range method. The processed matrix is $Y = (y_{ij})_{m \times n}$.

2) Determine the comprehensive weight of each attribute according to the results of analytic hierarchy process and entropy weight method $w = (w_1, w_2, \ldots, w_n)$. Generally choose 50% of each weight.

3) Calculating the weighted matrix $Z = (z_{ij})_{m \times n}$.

$$z_{ij} = w_j \cdot y_{ij} (i \in M, j \in N).$$

4) Determine the weighted normalization matrix $Z$ Positive and Negative ideal solution $Z^+, Z^-$. 

$$Z^+ = (z^+_1, z^+_2, \ldots, z^+_n) = w$$

$$Z^- = (z^-_1, z^-_2, \ldots, z^-_n) = 0$$

(1)
(5) Calculate Euclid distance of each plan to a Positive and Negative ideal solution \( Z^+ \), \( Z^- \):

\[
d_i^+ = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^+)^2}
\]

\[
d_i^- = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^-)^2} \quad (i \in M)
\]  

(6) Calculate the gray correlation coefficient matrices \( R^+ \) and \( R^- \) of each scheme with positive ideal solution \( Z^+ \) and negative ideal solution \( Z^- \). Among them:

\[
r_{ij}^+ = \frac{\min \min_{k \in I} [z_{ij} - z_{ik}] + \rho \max_{k \in U} \max_{i \in I} [z_{ij} - z_{ik}]}{z_{ij} - z_{ik} + \rho \max_{k \in U} \max_{i \in I} [z_{ij} - z_{ik}]} = \frac{\rho w_{ij}}{w_{ij} - z_{ij} + \rho w_{ij}} \quad (i \in M)
\]

\[
r_{ij}^- = \frac{\min \min_{k \in I} [z_{ij} - z_{ik}] + \rho \max_{k \in U} \max_{i \in I} [z_{ij} - z_{ik}]}{z_{ij} - z_{ik} + \rho \max_{k \in U} \max_{i \in I} [z_{ij} - z_{ik}]} = \frac{\rho w_{ij}}{z_{ij} + \rho w_{ij}} \quad (i \in M)
\]

\( \rho \in (0, \infty) \), Resolution coefficient. The smaller \( \rho \), the greater the resolution. Value range of \( \rho \) \((0,1)\). The specific value may be determined by the situation. When \( \rho \leq 0.5463 \), Best resolution, get \( \rho = 0.5 \).

(7) Calculate the gray correlation degree between each scheme and positive and negative ideal solution \( r_i^+ \), \( r_i^- \):

\[
r_i^+ = \frac{1}{n} \sum_{j=1}^{n} r_{ij}^+ \quad r_i^- = \frac{1}{n} \sum_{j=1}^{n} r_{ij}^- \quad (i \in M)
\]  

(8) The distance \( d_i^+ \), \( d_i^- \) and the degree of association \( r_i^+ \), \( r_i^- \) determined for the step (5) and the step (7), respectively. Then perform dimensionless processing to get \( D_i^+ \), \( D_i^- \), \( R_i^+ \), \( R_i^- \):

\[
D_i^+ = \frac{d_i^+}{\max d_i^+} \quad D_i^- = \frac{d_i^-}{\max d_i^-} \quad \text{max} = \max_{i \in M}
\]

\[
R_i^+ = \frac{r_i^+}{\max r_i^+} \quad R_i^- = \frac{r_i^-}{\max r_i^-} \quad (i \in M)
\]  

(9) Combine the dimensionless distance and the degree of association determined in the step (8). Since the values of \( D_i^+ \) and \( R_i^+ \) are larger, the scheme is closer to the positive ideal solution; and the larger the values of \( D_i^- \) and \( R_i^- \), the farther the scheme is from the positive ideal solution, so the combination formula can be determined as:

\[
S_i^+ = aD_i^- + \beta R_i^- \quad S_i^- = aD_i^+ + \beta R_i^+ \quad (i \in M)
\]
\[ \alpha + \beta = 1, \quad \alpha, \beta \in [0,1] \]

Decision makers can determine their values based on their own preferences. \( S^+ \) is the proximity of the scheme to the ideal scheme, and the larger the value, the better the scheme. \( S^- \) is the distance.

(10) Relative closeness of the construction scheme

\[
C_i^r = \frac{S^+_i}{S^+_i + S^-_i} \quad (i \in M)
\]

3.2 Establishment of evaluation index system

Through domestic research and data analysis, we have a certain understanding of the four aspects of mine water collection-treatment-reservation-utilization. Considering the potential of mine water development and utilization, the available quantities involve factors such as water quantity, water quality, treatment cost, and water supply households. The factors affecting the two-way coordination of supply and demand are summarized in Table 1.

### Table 1. Summary table of factors affecting mine water supply side

| Category          | Influencing factor                          | Impact factor | Explanation                                              |
|-------------------|---------------------------------------------|---------------|----------------------------------------------------------|
| Mine water inflow | Normal water inflow                         | Describe the amount of water inflow                   |
|                   | Maximum water inflow                        |               |                                                          |
|                   | Mining period                               | Influencing factors of water inflow stability       |
|                   | Mining planning                             |               |                                                          |
|                   | Development of water-conducting fracture    | Used to determine the magnitude and source of water inflow from mines |
| zone              |                                             |               |                                                          |
| Water consumption | Self-use of water                           | Used in the well for underground and underground water consumption |
|                   | Loss                                        | In-plant water loss                                  |
|                   | Developed utilization                       | Used for mine water, industrial, agricultural, ecological and other mines |
| Water quality     | Surface water                               | Used to distinguish mine water source                 |
|                   | Pore water                                  |                                                           |
|                   | Fissure water                               |                                                           |
|                   | Karst water                                 |                                                           |
|                   | Water quality category                      | Impact factors of water quality treatment           |
|                   | Treatment process                           |                                                           |
|                   | cost                                        |                                                           |
|                   | Processing equipment                        |                                                           |
|                   | working rate                                |                                                           |
|                   | Factory water quality                       | Describe the quality of mine water outside the factory |

### Table 2 Summary table of factors affecting mine water demand side

| Category                      | Influencing factor          | Impact factor | Explanation                              |
|-------------------------------|----------------------------|---------------|------------------------------------------|
| Demand                        | Enterprise                 | Supply water for enterprises |
|                               | Water user                 | Supply water for residents |
|                               | Agricultural irrigation    | For agricultural irrigation |
|                               | Breeding                   | For use in peripheral fish farming, etc |
|                               | Landscape water            | For landscape |
|                               | ecosystem                  | For ecological environment |
|                               | Guarantee rate             | Annual water supply guarantee rate requirement |
| Water quality                 | Processing cost            | Enterprise water needs to deepen the cost of water supply water treatment |
| Loss                          | Loss of transport route    | Loss of pipeline leakage, infiltration, etc |
| Economic Value                | output value               | Product benefits per ton of mine water |
| Demand policy                 | Policy planning, orientation, etc | Local future industrial planning, industrial layout, etc. |
Based on the existing research results, we believe that the two-way coordination factors of mine water supply and demand include: normal water inflow, maximum water inflow, mining impact coefficient, self-use of water, loss, developed and utilized, water source impact coefficient, water quality impact coefficient, pre-treatment cost, factory water quality, availability, potential, water demand of water users, post-processing costs, pipeline transportation rate, output value, mine water utilization rate.

4. Two-way coordinated evaluation of mine water supply and demand

4.1 Data Sources

The data sources are mainly the statistical bulletin of the national economic and social development of the study area, the statistical yearbook, the statistical yearbook of the coal industry and the relevant data of actual research. In order to balance the quantity distribution of the indicator factors of the criterion layer to facilitate the determination of the index weight and the quantitative evaluation, the preferred indicators can be appropriately classified. It can be classified from four aspects: resource factor, market factor, economic factor and social factor, so as to establish a two-way coordinated evaluation index system for mine water supply and demand, as a basis for calculation.

| Criteria layer | Indicator layer                                      | Index value       |
|----------------|-----------------------------------------------------|-------------------|
|                |                                                     | Yinchuan | Shizuishan | Lingwu | Wuzhou |
| Water factor   | Normal water inflow $S_1/m^3/s$                      | 1.12     | 0.25       | 0.21   | 0.21   |
|                | Maximum water inflow $S_2/m^3/s$                     | 1.44     | 0.32       | 0.28   | 0.28   |
|                | Mining influence coefficient $S_3$                   | 0.60     | 0.57       | 0.55   | 0.55   |
|                | Self-use of water $S_4/10^4 m^3$                     | 753.90   | 162.25     | 148.74 | 148.74 |
|                | Loss $S_5/10^4 m^3$                                  | 138.58   | 31.68      | 26.26  | 26.26  |
|                | Developed utilization $S_6/10^4 m^3$                 | 2999.84  | 626.86     | 556.62 | 556.62 |
|                | Water source influence coefficient $S_7$             | 1.00     | 1.00       | 1.00   | 1.00   |
|                | Water demand of water users $S_8/10^4 m^3$           | 7943.43  | 13863.35   | 26103.20 | 26103.20 |
|                | Pipeline rate $S_9/%$                                | 0.90     | 0.90       | 0.90   | 0.90   |
|                | Mine water utilization $S_{10}/%$                    | 0.85     | 0.79       | 0.83   | 0.83   |
|                | Available amounts $S_{11}/10^4 m^3$                  | 3386.85  | 764.15     | 647.71 | 647.71 |
|                | Potential amount $S_{12}/10^4 m^3$                   | 387.01   | 137.29     | 91.09  | 91.09  |
| Water quality factor(B2) | Water quality impact coefficient $S_{13}$           | 0.90     | 1.20       | 1.10   | 1.10   |
|                | Factory water quality $S_{14}$                       | 1.00     | 1.00       | 1.00   | 1.00   |
| Economic factors(B3) | Pre-processing cost $S_{15}/yuan/ton$               | 6.20     | 6.20       | 8.71   | 8.71   |
|                | Post-processing cost $S_{16}/yuan/ton$               | 2.00     | 2.00       | 2.00   | 2.00   |
|                | output value $S_{17}$/ yuan/ton                       | 428.31   | 94.82      | 80.38  | 80.38  |

4.2 Determining indicator weight

According to the data collected by the two-way coordinated evaluation index system of mine water supply and demand in Ningdong Coal Base, the TOPSIS measurement model was used to evaluate the two-way coordination of supply and demand of mine water in Yinchuan, Shizuishan, Lingwu and Wuzhong of the four cities involved in Ningdong Coal Base. First, the raw data is processed by the range method, and then the weights of the evaluation indicators are determined by the analytic hierarchy process and the entropy method, as shown in Table 4. It can be seen from the weight calculation and sorting that in the criterion level indicators, the water factor has the largest weight, the economic factor is the second, and finally the water quality factor. This is also in line with the fact that the mine water supply and demand is coordinated and evaluated. In the mine water supply and demand market, the water quantity factor is the most critical influencing factor, mainly affecting the mine water supply side; the economic factors mainly affect the mine water demand side; the water quality...
factor is the comprehensive impact. The factor is the influencing factor that must be considered in the multi-factor evaluation of the two-way coordination of mine water supply and demand.

The weights of the indicator layer are as follows: developed utilization, output value, self-use of water, normal water inflow, availability, loss, maximum water inflow, potential, water demand by water users, post-processing costs, pre-treatment costs, pipelines conveying rate, pipeline transportation rate, water source influence coefficient, mining influence coefficient, factory water quality, mine water utilization rate, water quality impact coefficient.

Table 4 Weights and ranking of evaluation indicators of each layer

| Criteria layer | Criterion layer weight | Indicator layer                   | Indicator layer weight | Index weighting |
|----------------|------------------------|----------------------------------|------------------------|-----------------|
| Water factor   | 0.7455                 | Normal water inflow S1            | 0.0776                 | 4               |
|                |                        | Maximum water inflow S2           | 0.0773                 | 7               |
|                |                        | Mining influence coefficient S3   | 0.0358                 | 14              |
|                |                        | Self-use of water S4              | 0.0781                 | 3               |
|                |                        | Loss S5                           | 0.0775                 | 6               |
|                |                        | Developed utilization S6          | 0.0799                 | 1               |
|                |                        | Water source influence coefficient S7 | 0.0375             | 13              |
|                |                        | Water demand of water users S8    | 0.0593                 | 9               |
|                |                        | Pipeline rate S9                  | 0.0470                 | 12              |
|                |                        | Mine water utilization S10         | 0.0341                 | 16              |
|                |                        | Available amount S11              | 0.0776                 | 5               |
|                |                        | Potential amount S12              | 0.0639                 | 8               |
|                | 0.0888                 | Water quality impact coefficient S13 | 0.0305             | 17              |
|                |                        | Factory water quality S14         | 0.0351                 | 15              |
|                |                        | Pre-processing costs S15          | 0.0537                 | 11              |
|                |                        | Post-processing costs S16         | 0.0569                 | 10              |
|                |                        | output value S17                  | 0.0783                 | 2               |
| Economic factors(B3) | 0.1889               |                                  |                        |                |

4.3 Weighted normalized decision matrix calculation

(1) From step (4), it can be determined that the positive ideal solution $Z^+$ and the negative ideal solution $Z^-$ of the weighted normalization matrix $Z$ are calculated as equation (2), and the results are shown in Table 5.

Table 5 Positive and negative ideal solutions after weighted normalization

| Index | S1  | S2  | S3  | S4  | S5  | S6  | S7  | S8  | S9  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $Z^+$ | 0.0776 | 0.0773 | 0.0358 | 0.0781 | 0.0775 | 0.0799 | 0.0375 | 0.0593 | 0.0470 |
| $Z^-$ | 4    | 7    | 14   | 3    | 6    | 1    | 13   | 9    | 12   |

(2) From step (5) (6) (7) (8), the dimensionless processing of $d^+$, $d^-$, $r^+$, $r^-$ are respectively obtained:

$D^+ = \{0.5036, 0.9562, 0.9142, 1.0000\}$
$D^- = \{1.0000, 0.2854, 0.4490, 0.4599\}$
$R^+ = \{1.0000, 0.5986, 0.6668, 0.7123\}$
$R^- = \{0.7665, 1.0000, 0.9116, 0.9619\}$

4.4 Comprehensive evaluation based on program closeness

Merging the dimensionless distance and the degree of association by step (9)(10), the relative closeness calculation formula of the construction scheme can be obtained:

$C^+ = \{0.6116, 0.3112, 0.3793, 0.3740\}$

According to the relative closeness, the two-way coordinated evaluation of mine water supply and demand in the four districts of Ningdong base is sorted, and you can get:
The above results show that the two-way coordination of water supply and demand in Yinchuan mine is the best, followed by Lingwu, Wuzhong is worse, and Shizuishan is the worst.

5. Conclusion

This paper mainly measures the two-way coordination degree of mine water supply and demand through quantitative analysis and evaluation. Firstly, a comprehensive evaluation model based on entropy weight-AHP-gray correlation-TOPSIS is established. Secondly, through analyzing and optimizing the influencing factors of mine water supply and demand two-way coordination, a two-way coordinated evaluation index system for mine water supply and demand is constructed. The two-way coordination of supply and demand of mine water in Yinchuan, Shizuishan, Lingwu and Wuzhong of the East Coal Base was comprehensively evaluated. The results show that the two-way coordination of water supply and demand in Yinchuan mine is the best, followed by Lingwu, Wuzhong is worse, and Shizuishan is the worst.

Mine water is a valuable resource. The coal mine water market development project advocated by the government and the state has a very positive role. It requires coal enterprises and local governments to actively think and plan, systematically analyze the mine water resources and introduce market mechanisms. Scientifically rational treatment and utilization of water resources in different mine areas to achieve rational allocation and sustainable use of mine water resources(Yuan H et al,2008).

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References

[1] National Development and Reform Commission .Mine water utilization development planning[S]. Development and reform[2013]118,2013.
[2] Yu WD,He QW,Zhang XJ. Forcast of water supply and water demand and It’s policy in Hejin city[J]. Journal of arid land resources and environment. 2003, 18(2):55-60. DOI:10.13448/j.cnki.jalre.2004.02.011.
[3] Wang Y,Zhang ZF,Lai ZZ. A multi-attribute assignment model for fourth party logistics based on TOPSIS method[J].Journal of systems and management. 2011,29(5):569-577.
[4] Yang BC,Chen Y. Grey relational decision-making model based on variable weight and TOPSIS method[J]. Systems engineering.2011,29(6):106-112.
[5] Chen W,Kang X,Feng ZJ. Research on the regional High-Tech industries operation efficiency of intellectual property based on the perspective of DEA-TOPSIS[J].Science of science and management of S. and T. 2011,32(11):125-130.
[6] Yuan Hang,Shi H.Research progress and prospect of coal mine water resource utilization[J].Journal of water resources and water engineering. 2008(5):50-57.