Research on optimal allocation of water resources in the Western mining area of China based on WEAP

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Abstract
In order to solve the problem of water resources shortage in the Western mining area of China and make it reasonably and effectively allocated, the optimal allocation model of water resources was established based on Water Evaluation and Planning System in this paper. This model simulated the water resources changes of 8 scenarios from 2015 to 2035. These scenarios are consisted of different economic growth, population changes, water saving and greening intensity. The optimal development scenario applicable to the mining area and the water resources allocation results corresponding to the scenario were determined by calculating the comprehensive benefits of society, economy and ecology. The results show that the optimal development scenario for the mining area is high-speed economic growth, powerful water saving and moderate greening. Under this scenario, the total water demand of the mining area will reach 39.73 million cubic meters by 2035, the demand shortage will be 1.7 million cubic meters, and the water shortage rate will be 4.28%. The water resources allocation result corresponding to this scenario can be used as a reference for decision makers, which can provide a scientific basis for the rational use of water resources in the Western mining area.

Keywords Water resources allocation · WEAP · Western mining area · Optimal scenario

Introduction
Most of the water supply for production and living in the Western mining area of China is seasonal river, and the flow mainly comes from atmospheric precipitation. Therefore, there are frequent surges and falls (Gu 2012), which causes serious water shortage due to insufficient water supply or unreasonable distribution during certain periods of large water demand (Cao 2011). Moreover, the degree of imbalance between supply and demand in the water resources system has increased with the increase of mining intensity, population growth and other human activities. It will be of great significance to the sustainable development of the mining area (Liu et al. 2020; He 2003) if we can adopt a reasonable method to actively allocate water resources to maximize the comprehensive benefits of society, economy and ecology.

The mining area studied in this article is located in the North of Shennu County, Yulin City and the South of Ordos City, China. The mining area is about 40–90 km long from North to South, 35–55 km wide from East to West, and high in Northwest and low in Southeast. It is surrounded by Kubuqi Desert and Mu Us Desert; Its central part is a plain with undulating terrain and lakes in the lower part. In the mining area, there is a main river from Northwest to Southeast, with an average flow of 117 million cubic meters for many years. Various tributaries are distributed on both sides. Their flows are all affected by the season, so they are uneven with time. The water volume is mainly concentrated in March, July, August and September. March is the thawing period. July, August and September are the rainy season. The runoff in these three rainy months accounts for about 65% of the whole year (Dong 2011). Figure 1 shows the average rainfall in 2017 in the urban area where the studied mining area is located. In this studied area, the main sources of water supply include industrial reuse water, greening reuse water, water purification plants, reservoirs and so on. While the demand sites mainly include life, industry, production and ecological greening.
Water resources allocation (Wang and You 2008) needs to comprehensively consider economic, social, resource, ecological and other factors (Yang et al. 2013). There is an optimal allocation scheme which can be sought by weighing them. Some methods commonly used for simulating and predicting water resources include multi-objective programming (Chen et al. 2006; Haimes et al. 1972), linear programming (Ezenwaji et al. 2014; Buras 1972), chaos theory (Liu et al. 2011), artificial neural networks (Li et al. 2018; An 2018), etc. In order to more effectively integrate the local development planning and observe the water shortage status of each water demand site in real time, in this paper, WEAP is used to simulate the water resources of the study area from 2015 to 2035. Finally, by considering the comprehensive benefits of economy, society and ecology, the optimal development scenario is selected, and the corresponding water resource allocation suggestions are proposed, which will help achieve the sustainable development of water resources in the mining area.

Establishment of the water simulation model

Introduction of the WEAP

WEAP is a water resources assessment and planning system jointly developed by the Stockholm Environmental Research Institute and the Hydraulic Engineering Center of the US Army Corps of Engineers. It is a policy-oriented simulation method based on the principle of calculating water balance, as well as a database, forecasting tool and policy analysis tool (Yu 2014; Abdelkader et al. 2013). The biggest advantage of this system is that it comprehensively considers the supply-side and demand-side issues, and at the same time, it effectively assists rather than replaces experienced water resources planner with its powerful functions and ease of operation.

WEAP simulates water resources system by generalizing things related to water resources in reality into nodes. There are two types of nodes: supply and demand. The process of model operation (Chai 2017) includes five steps. First step: initially define the system, including setting the time range, time step, area boundary and generalizing the water resources system; Second step: set the current accounts of one year. The data for this year are the most accurate and complete. It is the basis for operation of the entire system; Third step: establish a reference scenario and develop one or more policy scenarios with alternative assumptions about future developments; Fourth step: set up key assumptions. It is convenient to uniformly adjust a certain parameter when modifying the scenario; Fifth step: choose the best scenario. By calculating the comprehensive benefit value of economy, society and ecology, the scenario with the largest comprehensive benefit value is selected as the final recommended development plan, and the water resources allocation results under the scenario are provided.

Generalized figure and calculation rules

Before the simulation, in order to facilitate the generalization of the water resources system of the entire mining area, the research area is divided into seven small zones according to the experience of the predecessors (Dong 2011) and actual mine condition, which is, respectively, named a-g mine. The data of 2015 are taken as the current accounts of the research. The time range is from January 2015 to December 2035, with month as the time step.

The final WEAP model of the mining area is generalized to 28 demand sites (Each of the 7 small zones has its own production, life, industry and greening demand sites, and the corresponding 7 industrial demand sites are also used as water supplies), 10 rivers (1 main stream and 9 tributaries), 8 other water sources (Including some mine water purification plants, seepage wells, oxidation ponds), 7 groundwater reservoirs (Li et al. 2013), 2 life wastewater treatment plants, 46 transmission links and 30 return flow links. The generalized figure (Fig. 2) is as follows:

Based on the generalized figure, WEAP model has its systematic calculation rules. By orderly calculating the water volume among the demand sites, supplies, transmission links and return flow links, the water distribution requirements can be satisfied in an optimal way. In the model, each node and link has a mass balance equation, \( \sum \text{Inflow} = \sum \text{Outflow} + \sum \text{Consumption} \), and some are constrained by other equations, such as maximum water intake, flow rate, water quality, etc. Some calculation rules are as follows:

1. A demand site’s (DS) demand for water is calculated as the sum of the demands for all the demand site’s bottom-level branches (Br). Taking a-mine production demand
As an example, the bottom-level branches include agriculture and other industries. The calculation formula is:

Annual Demand\(_{DS}\) = \(\sum (\text{Activity Level}_B \times \text{Water Use Rate}_B)\)

2. The demand for a month \((m)\) equals that month’s fraction of the annual demand. Taking agriculture demand site as an example, there is a significant difference in the proportion of water used in each month from January to December. According to the actual situation, the proportional value can be manually input. If there is no obvious difference in monthly use such as life demand site, the default form can be used. It will take the number of days per month / total days as a ratio.

Monthly Demand\(_{DS,m}\) = Monthly Variation Fraction\(_{DS,m}\) \(\times\) Annual Demand\(_{DS}\)

3. The supply requirement is the actual amount needed from the supply source.

Monthly Supply Requirement\(_{DS,m}\) = (Monthly Demand\(_{DS,m}\) \(\times\) \((1 - \text{Reuse Rate}_DS)\) \(\times\) \((1 - \text{DSM Saving}_DS))\)/\((1 - \text{Loss Rate}_DS)\)

4. The inflow to the demand site is connected to the outflow of the transmission link. In addition to the water consumed, the remainder flows to other demand sites for reuse, to the wastewater treatment plant for treatment, or to the groundwater.

\[
\text{Demand Site Inflow}_{DS} = \sum \text{Trans Link Outflow}_{Src,DS}
\]

\[
\text{Consumption}_{DS} = \text{Demand Site Inflow}_{DS} \times \text{Demand Site Consumption Rate}_{DS}
\]

\[
\text{Demand Site Return Flow}_{DS} = \text{Demand Site Inflow}_{DS} - \text{Consumption}_{DS}
\]

\[
\text{Demand Site Reuse Outflow}_{DS} = \text{Demand Site Return Flow}_{DS}
\]

5. The transmission link is from the supply source \((Src)\) to the demand site \((DS)\), and the return link is from the demand site \((DS)\) to the destination \((Dest)\).

\[
\text{Trans Link Outflow}_{Src,DS} = \text{Trans Link Inflow}_{Src,DS} - \text{Trans Link Loss}_{Src,DS}
\]

\[
\text{Trans Link Loss}_{Src,DS} = \text{Loss Rate}_{Src,DS} \times \text{Trans Link Inflow}_{Src,DS}
\]

\[
\text{Return Link Inflow}_{DS,Dest} = \text{Return Rate}_{Src,DS} \times \text{Demand Site Return Flow}_{Src,DS}
\]

If there is only one return link, the ratio is 100%, and if there are multiple links, the sum of the ratios is 100%.

The above are the basic rules for the operation of the WEAP model. In addition, there are infiltration, wastewater treatment plants, hydropower, and water quality. They can be learned and used in the “WEAP User Guide” according to the needs.

The calculation of demand sites and supply nodes needs to follow a certain order. Among the four demand sites set by the model in this paper, the water distribution priority must first meet the needs of life, followed by industry, production and finally greening. Since the water quality of each water supply is quite different, it is not allowed to supply water to the demand site at will. The order of water quality from good to bad is independent living water source and networked tap water, industrial reuse water and greening water. Domestic water has the highest requirements for water quality, so it can only be supplied by independent domestic water sources and networked tap water; The production site must be supplied by industrial...
reuse water first, and the insufficient part is supplied by networked tap water; The mining industry supplies part of the reused water for production, and the rest is used for greening as greening water; The greening demand is first supplied by industrial reuse water. If the industrial reuse water in the zone has no surplus after meeting the production, the networked tap water will be used. The principle of proximity is adopted between the water demand and supply of each zone.

**Establish scenarios**

Factors such as changes in the number of people based on population policies, different mining intensity, water saving intensity, greening degree and different economic development speed need to be considered when establishing the scenario (Wei and Jiang 2019). First according to the current development scale, the reference scenario is set. The population growth rate is still calculated based on the multi-year average population growth rate of 7.7 ‰. Per capita life water consumption is 450 cubic meters. With the development of the economy, the mining intensity will increase by 20% from 2015 to 2035. The change in the interval shows a linear growth. According to the trend of continuous construction of underground water reservoirs, the reuse rate of industrial water is set to increase by 15% compared with 2015, and the saving intensity of domestic water, production and greening water remains unchanged.

The 8 comprehensive scenarios are set as follows: Scenario 1: high-speed development, powerful water saving and strong greening; Scenario 2: high-speed development, powerful water saving and moderate greening; Scenario 3: high-speed development, moderate water saving and strong greening; Scenario 4: high-speed development, moderate water saving and moderate greening; Scenario 5: stable development, powerful water saving and strong greening; Scenario 6: stable development, powerful water saving and moderate greening; Scenario 7: stable development, moderate water saving and strong greening; Scenario 8: stable development, moderate water saving and moderate greening. The values behind the scenario are set as follows. Powerful water saving: by 2035, agricultural water consumption per hectare will be 60% of 2015, and the annual per capita life water consumption will reach 247.5 cubic meters; moderate water saving: agricultural water consumption will become 75% of 2015, with an annual per capita life water consumption of 315 cubic meters. Strong greening: the greening coverage rate of the study area is set to reach 34% by 2035; moderate greening: the greening coverage rate is set to reach 30% by 2035. High-speed development: since the economic growth of the mining area is mainly decided by mine development and other industries, by 2035, the mining intensity will increase by 35%, and the output value of other industries in production will double; stable development: the mining intensity will remain at 20%, and the output value of other industries will become 1.5 times by 2035. According to the opening of the second-child policy, the population will grow at a higher rate in the next period. Therefore, all scenarios use the average value of 11.25 ‰ of the higher population growth rate in the region for many years as the population parameter change. Then the corresponding parameters are changed according to the 8 scenarios to simulate the development or changes of water resources.

**Analysis of water resources simulation results**

After inputting the general information of the study area and setting the current accounts into the model, the parameters are modified to simulate the changes in water resources of different scenarios in 2015–2035. The figure below shows the average monthly change of water shortage at the demand sites of the mining area under the eight comprehensive scenarios in 2030.

![Fig. 3 The average monthly change in water shortage](image)

It can be seen from the figure (Fig. 3) that the trends of water shortage at the demand sites of the eight scenarios are consistent throughout the year. There is less water shortage in January and February. With the arrival of March, human activities, greening and agricultural water demand begin to increase, but since the thawing period in March provides sufficient water for each demand site, the water shortage only shows a small increase about 80,000 cubic meters. With the first concentrated increase in water demand for agriculture and greening after March, the water supply is insufficient to meet all water requirements, and the water shortage rises sharply to reach the first peak of the year, up to 640,000 cubic meters. After the first round of centralized irrigation and greening, the water consumption decreases, so the water shortage decreases slightly in May. By June, water consumption for
agriculture and greening increases again, and the shortage of demand appears the second peak in this year. Scenario 1 has the largest demand shortage, reaching 710 thousand cubic meters in June. With the arrival of the rainy season in July, August and September, the shortage of demand begins to decline rapidly, and basically stabilizes between 80,000 and 100,000 cubic meters in August and September. After entering the winter, with the decrease of water demand, the shortage begins to decline slowly. From the above analysis alone, it can be seen that Scenario 6 is an ideal development plan for the study area.

Figure 4 shows the changes in water demand of the 8 scenarios relative to the reference scenario. It can be seen from the figure that the water demand corresponding to scenario 3 and 4 increases year by year compared to the reference scenario, and by 2035, they will increase by 2.85 million cubic meters and 2.27 million cubic meters, respectively. Compared with the reference scenario, the water demand of scenario 1 and 2 first decrease slowly, gradually increase from 2024, and eventually will exceed the reference scenario by 2035. The main reason for this phenomenon is that the amount of water saved by the previous water saving measures is greater than the increased water demand due to economic development. Later, compared with the increase in mining intensity and the development of other industries, the proportion of water saving effect is getting smaller and smaller. From the perspective of water demand alone, if the research area adopts these two scenarios, it will be necessary to further increase water saving efforts in order to reduce the water demand. The water demand of the remaining four scenarios declines year by year compared to the reference scenario. Scenario 6 has the largest decline, with a decrease of 3.77 million cubic meters in 2035. Although the water demand of the eight scenarios differ from those of the reference scenario, the water demand of the reference scenario increases year by year, so the actual water demand of the eight scenarios also increase year by year.

Figure 5 shows the changes in water shortage at demand sites under scenario 2. The water shortage of Scenario 2 is large in the first three years, but after 2025, it gradually decreases. The main reason is that the industrial water demand of the mining area increases, and industrial reuse water is the main source of water for production and greening, which relieves the water shortage burden of them to a certain extent. The water shortages of Scenario 4 and Scenario 7, Scenario 2 and Scenario 5 are similar. Under the four powerful water saving scenarios, the rate of decline in the shortage slows down. The water shortages of Scenario 2, Scenario 5 and Scenario 6 finally stabilize at 1.7 million cubic meters, 1.7 million cubic meters and 1.45 million cubic meters, respectively. Even the water shortage of Scenario 1 shows an upward trend at the end. When adopting these scenarios, if only considering the demand shortage, it will be necessary to strengthen water conservation efforts or increase the amount of industrial reuse water in order to make the shortage continue to decline.
Figure 6 lists the changes in water shortage at each demand site under Scenario 2 over time. Through the figure, it can be seen that all demand sites with water shortage exist under this scenario, among which the water shortages of greening demand sites of c-mine c and e are relatively large, and basically show upward trend. The water shortages at the production demand sites of mine c, mine d, mine e and mine b, as well as the life demand site of mine e, decline year by year. It shows that this scenario has a greater impact on these demand sites. Among them, the water shortage of c-mine production demand site fall by up to 300 thousand cubic meters. By 2035, d-mine and b-mine production demand sites will no longer lack water. The special change is the greening demand site of mine d. The water shortage in 2015–2027 increases year by year. After 2027, the shortage begins to decline. The shortages of other demand sites with water shortage do not change much. By analyzing the changes in water shortage at the demand sites corresponding to each scenario, it can be seen that the degree of impact of different scenarios on different demand sites, so the corresponding scenario can be chosen according to the demand site which decision makers concern about.

The scenario usually established defaults to the same drought degree as the current account. In this paper, the hydrological year method is used to simulate different drought levels and study their impact on water resources, so that the corresponding emergency measures can be made when severe drought occurs. Fig. 7 is the changes in the water shortage of the eight scenarios under different drought levels, and Fig. 8 is the changes in the satisfaction degree of the greening demand site of mine f.

As can be seen from the comparison between Figs. 7 and 5, the relative size between the water shortage of each scenario after joining the drought level doesn’t change much, but only at the corresponding drought year 2019, 2023–2024, 2030–2032, the fluctuations occur. This part of the fluctuation can necessarily lead to changes in water shortage status at certain demand sites. As shown in Fig. 8, under scenario 2, the greening water demand of mine f is unsatisfied in the drought year, and the worst falls from 100 to 25%. Therefore, when taking the water resource allocation result corresponding to the optimal scenario as a reference, it is also necessary to pay attention to the change in the satisfaction degree of each demand site in this scenario when there is a drought, and formulate a corresponding protection plan for the demand site to reduce the pressure of water shortage.

From the above analysis, it can be seen that choosing a scenario from different perspectives can get different results. The development of a region requires comprehensive consideration of economy, society, ecology and other factors. Therefore, it is necessary to establish the multi-objective function to decide the optimal allocation scenario.

Optimal scenario and allocation result

In this paper, the calculation of comprehensive benefits takes into account social, economic and ecological factors, so it is a multi-objective optimization problem. Due to the dimensional differences among multi-objectives, the multi-objective function is converted into a single-objective function by the weighting method (Zhang et al. 2007). Using the Analytic Hierarchy Process (AHP) (Deng et al. 2012) to calculate the weight of social, economic and ecological benefits, the result is 0.1638, 0.5390 and 0.2973, respectively. Table 1 is

| Index   | Economic | Social | Ecological | Weight | Order |
|---------|----------|--------|------------|--------|-------|
| Economic| 1        | ½      | 2          | 0.2973 | 2     |
| Social  | 2        | 1      | 3          | 0.5390 | 1     |
| Ecological | 1/2   | 1/3    | 1          | 0.1638 | 3     |

![Fig. 7 Variation of water shortage in different scenarios of different drought levels](image)

![Fig. 8 Changes in satisfaction degree of greening demand site in f-mine](image)
The index judgment matrix established by the AHP method and the calculation result of the index weight.

The social benefit is expressed by the total water shortage of the mining area, and the economic benefit is expressed by the total water demand of the mining industry and other industries, the ecological benefit is expressed by the amount of water shortage in greening. The following tables (Tables 2, 3, 4) show the calculation results of social, economic, ecological and comprehensive benefits in 2035.

The comprehensive benefit value of the scenario from scenario 1 to scenario 8 is as follows: 0.2146, −0.3935, 0.7535, 0.1387, −0.0955, −0.8466, 0.5130, −0.2841. The scenario with the largest comprehensive benefit in 2035 is scenario 2, with a benefit value of 0.7985, the smallest is Scenario 7 with a benefit value of −0.8797. Therefore, in order to achieve the maximum benefit of the development of the mining area, it is recommended to adopt Scenario 2 (high-speed development, powerful water saving and moderate greening). By 2035, the total water demand will be 39.73 million cubic meters, the demand shortage will be 1.7 million cubic meters, and the water shortage rate can be 4.28%. The following tables (Tables 5, 6, 7, 8, 9, 10, 11) are the results of water resource allocation in 2025 and 2035 under this scenario:

The above table shows the distribution of water from their associated water sources to their respective industrial, greening, production and life demand sites. For mine a, if it is to achieve the highest benefit under the scenario, the greening demand site needs to be allocated 458,900 cubic meters by life wastewater treatment plant and 97,400 cubic meters water by industrial reuse water in 2025. In 2035, 421,900 cubic meters and 168,700 cubic meters of water are distributed by these two water sources. In 2025, the life demand site is distributed by a-mine water purification plant.

### Table 2 Social benefit value of each scenario in 2035

| Scenario | Social benefit | Z-score standardization | Weight | Social benefit |
|----------|----------------|-------------------------|--------|----------------|
| Scenario 1 | 199.798        | −0.03 078               | 0.1638 | −0.00 500      | Inverse indicator | 0.00 500 |
| Scenario 2 | 172.892        | −0.79 017               | −0.1295 | −0.2786       |                  | 0.2786   |
| Scenario 3 | 261.111        | 1.70 092                | 0.2786 | −0.2786       |                  | 0.2786   |
| Scenario 4 | 230.728        | 0.84 279                | 0.1380 | −0.1380       |                  | 0.1380   |
| Scenario 5 | 171.323        | −0.83 502               | −0.1368 | 0.1368        |                  | 0.1368   |
| Scenario 6 | 144.743        | −1.58 574               | −0.2597 | 0.2597        |                  | 0.2597   |
| Scenario 7 | 227.297        | 0.74 589                | 0.1222 | −0.1222       |                  | 0.1222   |
| Scenario 8 | 199.211        | −0.04 736               | −0.0078 | 0.0078        |                  | 0.0078   |

### Table 3 Economic benefit value of each scenario in 2035

| Scenario | Economic benefit | Z-score standardization | Weight | Economic benefit |
|----------|-----------------|-------------------------|--------|------------------|
| Scenario 1 | 3 048.345       | 0.74 790                | 0.539  | 0.4031           |
| Scenario 2 | 2 666.916       | −0.74 790               | 0.539  | 0.4031           |
| Scenario 3 | 3 136.912       | 1.20 027                | 0.6469 |                  |
| Scenario 4 | 3 136.912       | 1.20 027                | 0.6469 |                  |
| Scenario 5 | 144.743         | −0.74 790               | −0.4031|                  |
| Scenario 6 | 2 755.483       | 1.20 027                | −0.4031|                  |
| Scenario 7 | 166.774         | −1.20 027               | 0.5259 |                  |
| Scenario 8 | 146.988         | −1.20 027               | 0.5259 |                  |

### Table 4 Ecological benefit value of each scenario in 2035

| Scenario | Ecological benefit | Z-score standardization | Weight | Ecological benefit |
|----------|--------------------|--------------------------|--------|--------------------|
| Scenario 1 | 166.774           | 0.65 082                 | 0.2973 | 0.1935 Inverse indicator | −0.1935 |
| Scenario 2 | 139.868           | −0.74 282                |        | −0.2080           |
| Scenario 3 | 184.328           | −0.15 005                | 0.4638 | −0.4638           |
| Scenario 4 | 153.946           | −0.00 363                | 0.0041 | 0.0041            |
| Scenario 5 | 146.637           | −0.39 221                | 0.1166 | 0.1166            |
| Scenario 6 | 120.058           | −0.76 891                | 0.2597 | 0.2597            |
| Scenario 7 | 175.074           | 1.08 073                 | 0.3213 | −0.3213           |
| Scenario 8 | 146.988           | −0.37 403                | 0.1112 | 0.1112            |
with 110,600 cubic meters of water, tributary 6 with 639,800 cubic meters of water, and by 2035 with 50,300 cubic meters and 609,100 cubic meters of water, respectively. Similarly, the reference of corresponding water distribution to other zones can be provided to decision makers in the same way.

### Conclusion

In this paper, WEAP is used to establish a model for optimal allocation of water resources in mining areas, and the development and changes of water resources between 2015 and 2035 are analyzed by simulating 8 scenarios. Finally, the scenario 2 is selected as the optimal development plan from all 8 scenarios by using multi-objective
### Table 8  Results of water resources allocation in the d-mine area in 2025 and 2035

| Water source                        | Demand site |       |       |       |       |       |       |       |       |       |
|-------------------------------------|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                                     |             | 2025  |       |       | 2035  |       |       |       |       |       |
|                                     |             |       |       |       |       |       |       |       |       |       |
| Industry                           |             |       |       |       |       |       |       |       |       |       |
| D-mine industrial reuse water      | 0           | 4.8   | 1121.4| 0     | 0     | 93.3  | 1277.6| 0     |       |       |
| A-mine water purification plant    | 0           | 0     | 0     | 750.4 | 0     | 0     | 0     | 659.4 |       |       |
| Domestic wastewater treatment plant| 0           | 458.9 | 0     | 0     | 0     | 421.9 | 0     | 0     |       |       |
| Main river                         | 4741.2      | 0     | 0     | 0     | 5447.4| 0     | 0     | 0     |       |       |
| Sum                                | 4741.2      | 463.7 | 1121.4| 750.4 | 5447.4| 515.2 | 1277.6| 659.4 |       |       |

Unit: thousand CMS

### Table 9  Results of water resources allocation in the e-mine area in 2025 and 2035

| Water source                        | Demand site |       |       |       |       |       |       |       |       |       |
|-------------------------------------|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                                     |             | 2025  |       |       | 2035  |       |       |       |       |       |
|                                     |             |       |       |       |       |       |       |       |       |       |
| Industry                           |             |       |       |       |       |       |       |       |       |       |
| E-mine industrial reuse water      | 0           | 79.8  | 752.1 | 0     | 0     | 94.5  | 907.1 | 0     |       |       |
| Main river                         | 1451.7      | 0     | 0     | 0     | 0     | 1668.0| 0     | 0     | 609.0 |       |
| Tributary 6                        | 0           | 0     | 154.3 | 639.6 | 0     | 0     | 119.7 | 609.0 |       |       |
| Sum                                | 1451.7      | 79.8  | 906.4 | 639.6 | 1668.0| 94.5  | 1026.8| 609.0 |       |       |

Unit: thousand CMS

### Table 10  Results of water resources allocation in the f-mine area in 2025 and 2035

| Water source                        | Demand site |       |       |       |       |       |       |       |       |       |
|-------------------------------------|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                                     |             | 2025  |       |       | 2035  |       |       |       |       |       |
|                                     |             |       |       |       |       |       |       |       |       |       |
| Industry                           |             |       |       |       |       |       |       |       |       |       |
| F-mine industrial reuse water      | 0           | 22.8  | 424.2 | 0     | 0     | 32.0  | 520.9 | 0     |       |       |
| Shigetai water source              | 0           | 0     | 0     | 536.1 | 0     | 0     | 0     | 536.1 |       |       |
| Main river                         | 937.1       | 0     | 0     | 0     | 1076.7| 0     | 0     | 0     |       |       |
| Tributary 2                        | 0           | 533.5 | 745.0 | 214.3 | 0     | 558.7 | 756.8 | 123.3 |       |       |
| Sum                                | 937.1       | 556.3 | 1169.2| 750.4 | 1076.7| 590.7 | 1277.7| 659.4 |       |       |

Unit: thousand CMS

### Table 11  Results of water resources allocation in the g-mine area in 2025 and 2035

| Water source                        | Demand site |       |       |       |       |       |       |       |       |       |
|-------------------------------------|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                                     |             | 2025  |       |       | 2035  |       |       |       |       |       |
|                                     |             |       |       |       |       |       |       |       |       |       |
| Industry                           |             |       |       |       |       |       |       |       |       |       |
| G-mine industrial reuse water      | 0           | 44.5  | 428.4 | 0     | 0     | 53.0  | 510.9 | 0     |       |       |
| G-mine well clean water            | 0           | 0     | 0     | 375.2 | 0     | 0     | 0     | 329.7 |       |       |
| Main river                         | 811.4       | 0     | 0     | 0     | 932.3 | 0     | 0     | 0     |       |       |
| Reservoir                          | 0           | 0     | 156.0 | 0     | 932.3 | 0     | 0     | 127.9 |       |       |
| Sum                                | 811.4       | 44.5  | 584.5 | 375.2 | 932.3 | 53.0  | 638.7 | 329.7 |       |       |

Unit: thousand CMS
decision-making method to comprehensively consider the economic, social and ecological benefits of the mining area. Under this scenario, the total water demand will reach 39.73 million m$^3$ by 2035, the demand shortage will be 1.7 million m$^3$, and the water shortage rate will be 4.28%. Although the total water shortage rate is relatively small, the shortages of living and greening demand site in individual districts are still relatively large, which needs to be paid attention. The final water resource allocation results as reference for decision makers can help the mining area to achieve maximum benefits and maintain the sustainable development of water resources.

In the following research, by dividing the demand sites of each mining area in more detail, collecting and counting their detailed water supply and demand data, more accurate water resource allocation suggestions can be obtained under the simulation of WEAP model.

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**Declarations**

**Conflict of interest** There is not any conflict of interests in this work.

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