Analysis of trades water rights allocation at Si’an reservoir in Changxing County

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Abstract. Water rights allocation is the key to water resource registration and fundamental for realizing the market-based allocation of water resources. Based on the concept of trades water rights and the scientific definition for calculating quantity of trades water use rights, this study analyzed the principles of trades water rights allocation and the subject of water rights in different industries. Furthermore, a hierarchical structural model of trades water rights allocation at the Si’an reservoir in Changxing County was established using the hierarchical analysis method and used for investigating the trades water rights allocation there. Results show that defining quantity of trades water use rights based on “guaranteed percentage” and “quantity” can effectively resolve the inconvenience issue in water resource management caused by the uncertainty of quantity of water use rights in different years. Furthermore, allocating quantity of reservoir water use rights to individual subjects of water rights in different industries can facilitate the development of a water property rights system with well-defined rights and responsibilities. Meanwhile, such a practice can provide data for the water administration authorities when performing approval examinations for water use permits for different entities in different industries.

1. Introduction
Promoting the development of a water rights system is an important measure to improve the property rights system of natural resource assets and to realize the reformation of an ecological civilization system. In particular, the allocation of water rights is the core component in the construction of a water rights system and the basis for water rights trading. Currently, the allocation of water rights has been explored by numerous studies which brought significant results. In 1995, Walmsley JJ [1] proposed two water rights allocation mechanisms built upon the centralized mechanism and the market-based mechanism. In 2002, Jerson Kelman [2] proposed an allocation model based on the opportunity cost of water for different users. Such models gave rise to a preliminary water rights allocation method based on a set of standards. Wang Li Zhong [3] proposed a comprehensive water rights allocation method in 2003 which considered equity, efficiency, and sustainability. In 2007, Wang [4] proposed three allocation models including a priority-based method, a modified riparian water rights allocation method, and a public water rights-based method. Yanhan Bao et al. [5] developed a water quantity allocation model using the hierarchical analysis method in 2009. They further applied this to analyze the allocation of water quantity in Huai River’s main stream. In 2011, Yanping Chen [6] constructed a multi-round dynamic gaming model to allocate the initial water rights in a watershed based on a
harmonic diagnosis method. Dan Wu et al. [7] explored the gaming mechanism for negotiating initial water rights allocation that was compatible with the watershed in 2012 under the branch structure. In 2015, Qicai Duan et al. [8] established a water allocation model for Yuanmou County based on the hierarchical analysis method.

The current research mainly focuses on the allocation of water rights among different regions along the watershed or different water users in one region. Few studies have explored the allocation of regional water rights among different industries. This study investigates the allocation of quantity of water use rights from a reservoir among different industries. Based on the concept of trades water rights and the scientific definition for calculating quantity of trades water use rights, the water rights allocation plan for the Si’an reservoir at Changxing County was examined using the hierarchical analysis method.

2. Overview of the research location
Changxing County is located in the northernmost part of Zhejiang Province. It is also located on the upper part of the Taihu Lake Basin and sits at the junction of three provinces including Jiangsu, Zhejiang, and Anhui. Si’an Reservoir is located in the upper reaches of Si’antang in Changxing County. The dam site is located in the town of Si’an. Si’an Reservoir is a medium-sized reservoir built mainly for flood control although it also serves other purposes including irrigation and power generation. The control area of the drainage basin above the dam site is 108 km². The river’s main stream length is 19.50 km, and the total storage capacity of the reservoir is 50 million m³.

The water from the Si’an reservoir was supplied to the Si’an and Lincheng towns in Changxing County through the Si’an water plant. The total population covered by the water supply is approximately 113,000. The residential water consumption and the industrial water consumption within the covering area of water supply are 9,400 m³/d and 12,900 m³/d, respectively. The Si’an water plant in Changxing County is owned by Changxing Si’an Xianshan Lake Water Co., Ltd. The water intake dispatch operation in the water plant is managed by the Si’an reservoir management office in Changxing County. The Si’an reservoir was designed to provide irrigation covering the whole Si’an irrigation region. The total irrigation area is 20,000 mu. With a water intake frequency of 25%, 50%, 75%, and 90%, the corresponding amount of water required to cover the reservoir irrigation region is 10.55 million m³, 11.54 million m³, 12.42 million m³, and 13.52 million m³, respectively. The regulation of Si’an reservoir for beneficial use is controlled by the Si’an reservoir management office in Changxing County. Regulation of the Si’an reservoir for beneficial use is designed on the following principle. First, the actual dispatch operation of the reservoir must ensure that the ecological environment’s water demand in the downstream river is satisfied. On such a basis, the priority of water dispatch is given to ensure urban water supply. Next, the water supply is regulated to satisfy the demand in irrigation regions.

3. Analysis of trades water rights
3.1. The concept of trades water rights
Very few studies have explored trades water rights. Jingfen Xie et al. [9] considered trades water rights to be the right to use water resources in different trades. Such a concept comprises all categories of water use right in different industries including residential, industrial, and agricultural water rights. Ming Ge et al. [10] believed trades water rights represent the allocation results of regional water use rights among the environment, resident, agriculture, industry, and tertiary industries. Ming Xu [11] believed that industrial water rights are the right to use industrial water resources. Summarizing these research results on trades water rights combined with the general national requirements on developing a water rights system, we propose that trades water rights are the collection of water use rights owned by water users in different industries. It is also right for industries to legally use all state-owned water resources and profit from them. In summary, trades water rights refer to the right to use water resources in a trade.
3.2. Characteristics of trades water rights

Based on the combination of the concept of trades water rights and water use in industries, the following characteristics in trades water rights have been identified in this paper:

1) The terminology “trades” does not involve an independent and concrete entity. However, based on the foundation of constructing a water rights system, trades water rights should involve an independent and clear subject of rights. From the perspective of water users, the subject of trades water rights includes both socio-economic organizations and individuals, as well as natural ecosystems along the rivers.

2) Trades water rights must be obtained legally. In China there are three ways to obtain water rights: First, the government allocates water resources with rational and reasonable planning so that the administrative districts at all levels can obtain regional water rights. Second, departments and individuals that have direct access to water resources from rivers, lakes, or groundwater can obtain water use rights through the water permit system. Third, rural collective economic organizations automatically have water use rights for their ponds or maintained/managed reservoirs.

3) Trades water rights are related to, though different from, regional water rights and user water rights. In specific contexts, the collection of user water rights becomes the trades water rights and the collection of trades water rights is the regional water rights.

4. Quantity of trades water use rights

4.1. Quantity of reservoir water use rights

Quantity of water use rights is the water supply capacity from specific water sources to users. Such supply capacity depends on many factors including the hydro-meteorological conditions, engineering conditions, and water requirements of the user. For a specific water source, the engineering condition is fixed. However, the hydro-meteorological conditions and user requirements can be random and indefinite where the actual value varies over different hydrological years and different horizontal years. Therefore, the value of quantity of water use rights in a specific water source engineering project is different over different hydrological years.

Quantity of reservoir water use rights equals the amount of water in the reservoir minus the amount of water that is not allowed to be used, and the amount of water that cannot be used. Among these, the amount of water that is not allowed to be used refers to the amount of water prohibited from being used. The goal is to avoid severe consequences in deterioration and destruction of the ecological environment. In other words, a certain amount of water must be preserved to satisfy the ecological environment’s water use in rivers. The amount of water that cannot be used refers to the water use limited by various external factors and conditions. The amount of water that cannot be used primarily includes the amount of flood water that exceeds the maximum capacity of the engineering project and water supply capacity. The calculation of quantity of reservoir water use rights is given by the following formula:

$$W_{rr} = W_{ra} - W_{ec} - W_{ab}$$  \hspace{1cm} (1)

where, $W_{rr}$ is the quantity of reservoir water use rights, $W_{ra}$ is the amount of reservoir water, $W_{ec}$ is the water required for the ecological environment in a river, and $W_{ab}$ is the amount of abandoned flood water that exceeds the maximum capacity of the engineering project and water supply capacity.

4.2. Quantity of trades water use rights

In the actual management of water resources, using different levels of quantity of water use rights in different hydrological years can bring many inconveniences and is cumbersome in practical operation. The allocation of water resources to different industries by the state is controlled to ensure that the water supply in a specific trade satisfies the designed percentage value. In other words, only the
minimal amount of water supply which meets the guaranteed supply percentage will be provided to the trade within the year. Therefore, the guaranteed water supply percentage is used as a basic parameter for determining quantity of trades water use rights in this study. Based on this, quantity of trades water use rights is defined as: during the year where the trade is guaranteed a certain water supply, the reservoir will allocate specific quantity of water use rights to the trade based on a set of standards and methods through legal procedures. It can be seen from this definition that quantity of trades water use rights contains two dimensions. The first dimension is the guaranteed percentage, and the other dimension is the quantity of water use rights.

4.3. Quantity of water use rights at the Si’an reservoir

The objective of analyzing quantity of reservoir water use rights is to lay the foundation for the allocation of trades water use rights. The guaranteed water supply percentage for resident and agriculture from Si’an reservoir are designed to be 95% and 90%, respectively. Additionally, the quantity of water use rights from Si’an reservoir was investigated using a water use frequency of 95% and 90%.

According to the annual flow rate measured for Si’an reservoir from 1958 to 2016, using a guaranteed percentage of 90% and a month-minimum daily-average method, the ecological environment water requirement in the downstream river was calculated to be 0.15 m$^3$/s and the annual ecological environment water demands was found to be 4.75 million m$^3$. Based on the annual flow rate measured for the Si’an reservoir from 1958 to 2016, the current water demand data collected from water users, and the characteristic parameters of the reservoir, the quantity of reservoir water use rights under a water supply frequency of 95% and 90% were calculated to be 25.13 million and 28.93 million m$^3$, respectively from the equation (1).

5. Allocation of trades water use rights based on a hierarchical analysis method

5.1. Allocation principle

According to the relevant national law and regulation as well as regulations and requirements enforced by policy-guiding documents such as the “Water Law” and “Water Use Permit and Water Resources Fee Collection Management Regulations,” the allocation of trades water use rights should stick to the following principles:

(1) The ecological water protection principle. To achieve sustainable development and use of water, maintain the stability of the ecological system in the river, and ensure equity within and between generations, priority must be given to ensure water use associated with the ecological environment in the river.

(2) The residential water priority principle. Water is the source of life. To protect the basic surviving and developing rights of residents, the allocation of industrial water use rights must give priority to satisfying the demand for residential water and ensuring the basic residential water use rights.

(3) Respecting history and the current status principle. Current water users have generally accepted the pattern of water use rights allocation formed during historical development. Therefore, the allocation of trades water use rights should maintain the stability associated with the original allocation pattern. With development over time, the water condition demanded by water users will also change accordingly. Thus, the allocation of trades water use rights should always be based on the current status of water use in different industries to ensure rational use of water.

(4) The equity principle. Water is an essential natural resource and a strategic economic resource. Therefore, water use rights represent the right for development. The allocation of trades water use rights following a principle of equity is of vital importance to the development of different regions and different water users.
5. The high-efficiency principle. The high-efficiency principle is the ultimate goal for allocation of trades water use rights. The allocation of industrial water use rights should essentially facilitate a high efficiency in water use.

6. The democratic negotiation principle. The allocation of trades water use rights is closely related to the vital interests of related industries and users. Therefore, the allocation of water use rights must involve participation from all interested parties and abide by the principle of democratic negotiation.

5.2. The subject of trades water use rights
The purpose of trades water use rights allocation is to obtain exclusive rights to water resource use through legal procedures. Therefore, there should be an independent and clear subject of water use rights. According to the concept and characteristics of trades water use rights, the subject of trades water use rights should be the actual water users in the trades. However, considering that the large quantity and high dispersion of water users make it challenging for centralized management, a representative of water users who have received authorization from the users can act as the subject of trades water use rights. For example, the water management and water supply companies in charge of the operation and management of urban water supply business can be selected as the subject of residential and industrial water use rights. For the subject of water use rights for agriculture, one may choose between the irrigation region management unit, the collective representative of farmers, and the agricultural water use association as the rights representative. For the subject of water use rights for the ecological environment, authorized departments in the government should generally be chosen as representatives.

For the Si’an reservoir, Changxing Si’an Xianshan Lake Water Co. was selected as the rights representative for residential and industrial water use rights, the Changxing Si’an reservoir management office was selected as the rights representative for agricultural water use rights, and the Changxing Water Conservation Bureau was selected as the rights representative for ecological environmental water use rights.

5.3. Allocation process
The allocation of trades water use rights is a complex problem involving numerous factors. Among different strategizing and analyzing methods, the hierarchical analysis method has been used by many researchers for allocating the initial water use rights due to its hierarchy and simplicity [12]. Therefore, the hierarchical analysis method was adopted here for allocating trades water use rights.

5.3.1. Hierarchical structure model construction. When constructing the hierarchical structure model, it is essential to consider the water use characteristics of each trade and the function feature of each trade in the development of national economies. Such considerations should be used in conjunction with the initial allocation principle of trades water use rights for selecting a proper set of standards and evaluation indicators.

1) Target layer
The target layer represents the target for the hierarchical analysis method. In this study, the target layer is the allocation of trades water use rights.

2) Establishing criteria layer
The criteria layer represents the principle for digesting the target problem in the hierarchical analysis method. Based on the trades water use rights allocation principle and following a hierarchical analysis theory, the criteria layer can be established by combining the principle of “guaranteed ecological water use and priority in resident water use” and the principle of “equity.” The criteria layer, based on the AHP model of trades water use rights allocation for the Si’an reservoir, was set as “respectful to history and current status, equity, [and] high efficiency.”

3) Establishing the indicator layer
The indicator layer is a quantified indicator of the criteria level. According to the endowment and requirements of the established criteria, the following quantified indicators were selected under each criterion:

①**Respectful to history and current status**: The principle of respecting history requires the water use rights allocation to respect the sequence of different industries in obtaining water use in this history. The principle of respecting the current status on the other hand requires being respectful to reasonable water use already formed in each trade. Therefore, the selected quantified indicator is “the sequence in obtaining the water use rights, the reasonable water usage in the current condition.”

②**Equity**: Multiple indicators can be chosen to reflect the principle of equity such as the indicator for promoting sustainable development of an economical society or the indicator for the impact of trades water use on the environment. To promote a sustainable development of an economical society, the allocation of trades water use rights is required to reflect the role and function of different industries in securing the development of an economical society. Therefore, the quantified indicator is the “priority in guaranteed water use.” To reflect the negative impact of water use from different industries on the ecological environment, another quantified indicator “sewage ratio for water withdrawing” is selected. A higher sewage ratio indicates a smaller amount of waste water disposal and therefore a smaller impact on the ecological environment with the same amount of water withdrawn.

③**Efficiency**: The efficiency indicator is the economic evaluation indicator associated with water use in different industries. The selection of efficiency indicator needs to consider not only the current economic scale in each trade but, also, the economic interest generated by water use in different industries. According to the analysis of water use economic indicators in various industries, the efficiency indicator used in the study is the “current GDP volume, and single side water GDP volume.”

(4) **Establishing the plan layer**

The plan layer is the result obtained from hierarchical analysis. Since the ecological environment water use has been pre-satisfied, the use rights of the remaining reservoir water is allocated in other industries including life, manufacture, and agriculture.

Based on the above analysis, the AHP structural model for allocation of trades water use rights is shown in Figure 1.
5.3.2. Construct judging matrix. The relative importance of each indicator element compared to the previous principle was evaluated by multiple methods including expert scoring and literature review. Afterward, the judging matrix A, B1, B2, and B3 at the criteria layer were constructed using a 1–9 scale rule method [13]. Table 1 shows the scaling rules using 1–9 scales and Table 2 shows the construction of the judging method.

| Table 1. The rules associated with scales 1–9. |
| Scale | Definition | Meaning |
|-------|------------|---------|
| 1     | Mutually important | Both elements or of the same importance to a specific property |
| 3     | Slightly more important | One element is slightly more important than the other one when comparing a specific property |
| 5     | Significantly more important | One element is significantly more important than the other one when comparing a specific property |
| 7     | Very important | One element is more important than the other one when comparing a specific property |
| 9     | Extremely important | One element is extremely more important than the other one when comparing a specific property |
| 2,4,6,8 | The mid-scale value between adjacent neighbor | Indicates the medium value between adjacent scales. |
| The reciprocal of the scales | Inverse proportional | The scale $a_{ij}$ represents the distance between element $i$ and element $j$, and the inverse charges $a_{ij}$ |

| Table 2. The judging matrix. |
|---|
| A | B1 | B2 | B3 |
|---|---|---|---|
| B1 | 1 | 3/1 | 6/1 |
| B2 | 1/3 | 1 | 2/1 |
| B3 | 1/6 | 1/2 | 1 |

(B1)

| B2 | C3 | C4 |
|---|---|---|
| C3 | 1 | 4/1 |
| C4 | 1/4 | 1 |

(B2)

| B3 | C5 | C6 |
|---|---|---|
| C5 | 1 | 1/3 |
| C6 | 3/1 | 1 |

(B3)

5.3.3. Calculating the weight of the allocation index. First, the maximum eigenvalue and the corresponding eigenvector of the established judging matrix was obtained. After normalization treatment, the single order weight vector was obtained. A consistency test was performed on the single order sequence of the layers. During the test, the indicator C.I. was first calculated by equation 2, then the value RI was determined from a numerical table of the random consistency indicator RI. Lastly, the consistency ratio, CR, was calculated using equation 3. The judging matrix was considered to pass the consistency test if CR < 0.1. Otherwise, the judging matrix was reconstructed until it passed the test.
\[
C.I. = \frac{\lambda_{\text{max}} - n}{n-1}
\]

(2)

\[
C.R. = \frac{C.I.}{R.I.}
\]

(3)

Table 3 shows the weight of each allocated indicator obtained through the above calculation process. 

**Table 3.** The weight of the allocated indicators.

| Layers | Layer A | Consistency test of the single order sequence | Weight of each indicator |
|--------|---------|-----------------------------------------------|-------------------------|
|        | B1      | B2    | B3    | \( \lambda_{\text{max}} = 1.2 \) | 0.34 |
|        |         |       |       | CR = 0                     | 0.34 |
|        | B1-C1   | 0.5   |       |                            | 0.34 |
|        | B1-C2   | 0.5   |       | \( \lambda_{\text{max}} = 2 \) | 0.18 |
|        | B2-C3   | 0.8   |       | CR = 0                     | 0.04 |
|        | B2-C4   | 0.2   |       |                            | 0.08 |
|        | B3-C5   | 0.75  |       | \( \lambda_{\text{max}} = 2 \) | 0.03 |
|        | B3-C6   | 0.25  |       | CR = 0                     | 0.03 |

5.3.4. Determining the value of the allocated indicator C1: The sequence of obtaining water use rights. Si’an reservoir obtained water use rights for agriculture, resident, and industry in 1959, 1995, and 2007, respectively. To more conveniently calculate the index membership degree, the sequence in obtaining water use rights for different industries was represented by the year gap from the time obtaining water use rights to the current year, namely 57, 21, and 9.

C2: Reasonable water use under current conditions. The reasonable annual water consumption for the Si’an Reservoir in residential and industrial use are 7.07 million m3 and 4.71 million m3, respectively. The water consumption in agricultural use is 13.52 million m3 under a designed guaranteed percentage.

C3: Priority in guaranteed water use. Based on the rule for trades water use rights allocation, the highest priority was given to resident water consumption. According to the principle of respecting history, the Si’an reservoir was historically used to secure agricultural water use. Therefore, the allocation of water use in agriculture is prioritized over that by industry. To more conveniently calculate the index membership degree, the sequence in water use priority for resident, agriculture, and industry were indicated using numerical values of 30, 15, and 1.

C4: Sewage ratio for water withdrawal. The water use consumption rate for resident, rice field irrigation, and general industry in Changxing County is 30%, 60%, and 34%, respectively. Thus, the sewage ratio for water withdrawal in resident, industry, and agriculture are 1.4, 1.5, and 2.5, respectively.

C5: Current GDP output. Within the range covered by water supply from the Si’an reservoir, the GDP output in 2016 from resident, industry, and agriculture are 2.65 billion, 1.79 billion, and 0.18 billion RMB, respectively.

C6: Unit water GDP output. Within the range covered by water supply from the Si’an reservoir, the unit water GDP output from resident, industry, and agriculture are 375 RMB/m3, 379 RMB/m3, 13 RMB/m3, respectively.

The indicator vector matrix in the hierarchical structure model of trades water use rights allocation in the Si’an reservoir can be obtained through the above analysis. Normalizing this matrix using the linear scaling transformation method [11] yields a linear ratio normalized matrix as shown in Table 4.

5.4. Allocation results
According to the analysis results of the weights of each allocated index and the value of the indicators, the degrees of membership of trades water use rights allocation index in the Si’an Reservoir are: \( K_{\text{resident}} = 0.61 \), \( K_{\text{industry}} = 0.61 \), and \( K_{\text{agriculture}} = 0.61 \). When analyzing the quantity of water
use rights of the Si’an reservoir, an initial quantity of water use rights of 4.75 million m³ was already pre-allocated to the ecological environment’s water use. The remaining quantity of water use rights from the Si’an reservoir was allocated to different trades including resident, industry, and agriculture. Based on this, the allocation results of trades water use rights in the Si’an reservoir with a water use frequency of 95% and 90% are shown in Table 5.

Table 4. The linear ratio normalized indicator vector matrix.

| Name of the indicator                                      | Resident | Industry | Agriculture |
|-----------------------------------------------------------|----------|----------|-------------|
| C1: The sequence of obtaining water use rights            | 0.37     | 0.16     | 1.00        |
| C2: Reasonable water use in current conditions (ten thousands/m³) | 0.52     | 0.35     | 1.00        |
| C3: Priority in guaranteed water use                      | 1.00     | 0.03     | 0.50        |
| C4: Sewage ratio for water withdrawal                     | 0.57     | 0.61     | 1.00        |
| C5: Current GDP output (0.1 billion RMB)                  | 1.00     | 0.67     | 0.07        |
| C6: Unit water GDP output (RMB/m³)                        | 0.99     | 1.00     | 0.03        |

Table 5. The allocation results of trades water use rights in Si’an reservoir.

| Year            | Quantity of trades water use rights(10,000 m³) |
|-----------------|-----------------------------------------------|
|                 | Ecological environment | Resident | Industry | Agriculture | Total |
| 95% frequency   | 475                          | 872      | 455      | 1186        | 2988  |
| 90% frequency   | 475                          | 1004     | 524      | 1365        | 3368  |

According to the results of Section 4.2, it was found that the quantity of water use rights of each trade in the Si’an reservoir should be selected according to the allocation result in the same year where the guaranteed percentage is enforced. Therefore, according to the allocation results shown in Table 5, the water use rights and guaranteed percentage for each trade in the Si’an reservoir can be obtained as shown in Table 6.

Table 6. The Quantity of trades water use rights and guaranteed percentage in Si’an reservoir.

| Name of trade | Quantity of trades water use rights(10,000 m³) | Ecological environment | Resident | Industry | Agriculture |
|---------------|-----------------------------------------------|------------------------|----------|----------|-------------|
| Guaranteed percentage | 100%                             | 95%                    | 90%      | 90%      |

6. Conclusions
The design of a water use rights system is a very complicated social practice problem which is not only restricted by the current water management system but also affected by the endowment of regional water resources. Water in southern China is abundant which makes it less practical to perform water use rights trading from system analysis. Meanwhile, water abundant regions in southern China have shown a significant shortage of high-quality water resources. Therefore, reform of the water use rights system should be oriented around the allocation of high-quality water resources. This study
finds that by constructing a scientific and reasonable allocation principle and allocation method, the use rights of reservoir water, the major source of high-quality water in the south region, can be diffused effectively among different industries. Therefore, there is a clear picture of the rights, responsibilities, and benefits during the development and use of high-quality water resources. The concept of water use rights also becomes clearer, more concrete, and legally based. The method proposed in this study will lay the foundation for water use rights trading or compensation work and also provide a basis for water administration authorities to check and approve water withdrawals for different industries. Meanwhile, the following topics are suggested to be explored in the future studies:

(1) Based on the trades water use rights allocation plan, the impact of current reservoir water dispatching operations on trades water use rights can be investigated by simulating the dispatching objective of the reservoir under the current dispatch operation rules.

(2) Based on the analysis of the impact of reservoir dispatch operation on trades water use rights, relevant compensation plans can be proposed according to the current laws and regulations in China.

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