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Performance evaluation of China's agricultural water rights markets (2002–2020)

Xiaoping Dai[a,*], Dustin Garrick[b], Jesper Svensson[c], Jingang Li[a] and Qiong Yue[a]
[a] College of Agricultural Science and Engineering, Hohai University, 8 Focheng West Road, Nanjing 211100, China
[b] School of Environment, Resources, and Sustainability, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada
[c] Department of Political Science, Lund University, Allhelgona kyrkogata 14, Lund 22100, Sweden
*Corresponding author. E-mail: xiaop-dai@163.com

XD, 0000-0002-7300-7540

ABSTRACT

The water rights market has been promoted in China since 2000. The lack of data and suitable evaluation methods impeded efforts to evaluate the market performance systematically. This research examines the characteristics, performance, and variation of China's agricultural water rights market (AWRM) on the basis of data from the field investigation, China Water Exchange, academic literature, and policy documents. We construct a comprehensive evaluation index system from the aspects of efficiency, fairness, and sustainability and quantitatively evaluate the performance of seven typical agricultural water markets in China. From 2002 to 2020, there were 1,752 cases of agricultural water transactions in China, with a total trading volume of 10.09 million m^3. The market scale is increasing and the development of AWRM can be divided into three stages. Most agricultural water rights transactions happened in the west and the north. The average performance of typical AWRMs was poor. Typical water markets had the highest score for fairness and the lowest score for sustainability. Water markets in the humid areas performed the best, whereas the markets in the higher transaction level performed better. Water markets in areas with higher economic development had better performance.

Key words: Characteristics, Efficiency, Fairness, Sustainability, Variation

HIGHLIGHTS

- The performance of China's agricultural water rights market (AWRM) was quantitatively examined.
- A comprehensive performance evaluation index system was constructed.
- The performance of China's typical AWRMs was poor.
- Typical AWRM performed the best in fairness and the worst in sustainability.
- Typical AWRM performed better in wetter and more developed regions.

1. INTRODUCTION

Urbanization, economic development, and agriculture production are intensifying competition for water. Agriculture is the primary water use industry in China. Agricultural water use accounted for 63% of the total water use of China in 2022 (Ministry of Water Resources of the People's Republic of China 2022). However, China's irrigation water use efficiency is only 0.572 in 2022 (Ministry of Water Resources of the People's Republic of China 2022). The contradiction between the increased water demand of non-agricultural industries and the eco-environment and limited water supply warranted agricultural water-saving. Water markets might improve water use efficiency (Dinar *et al.*, 1997; Fang & Wu, 2020; Zhang *et al.*, 2021), economic development (Wang & Tian, 2010; Guo *et al.*, 2018), and environmental outcomes (Grafton & Horne, 2014). Therefore, water rights and water markets are used to stimulate agricultural water-saving, increase water production, and solve water eco-environment problems in China around 2000.

Water rights were allocated to villages or farmers with the comprehensive reform of agricultural water prices in 2015 in China. The water rights allocation system of surface water and groundwater was different because of the difference between the management of the two water sources in China. For surface water irrigation, an irrigation system is mainly controlled by the irrigation district management agency (Moore, 2015). The agency usually supplies water through a canal system according to a fixed schedule. The schedule can hardly be changed by individual farmers or small farmer groups. Moreover, surface water is mainly used collectively. Farmers in a village use surface water to irrigate together. Singer farmers or small farmer groups cannot get water from the irrigation district management agency by themselves. For villages, the irrigation water fee of surface water is usually charged by water volume according to a progressive pricing system. In this system, irrigation water within the irrigation quota is charged with a lower initial water price, but the water exceeding the irrigation quota will be charged with a water price several times higher than the initial water price. For individual farmers, the irrigation water fee is usually charged by the irrigated area. Farmers shared the increase in the total water fee of the village according to their irrigated area. Surface water rights are usually allocated to villages or farmers in China. The water rights of a village are usually monitored but not the water rights of individual farmers. Farmers usually use water freely under the total water cap of a village.

For groundwater irrigation, the irrigation system is managed by the villages, farmer groups, or individual farmers. An individual farmer can use the well to irrigate by himself. He can irrigate at any time if nobody is using the well. There are two types of groundwater management system. First, irrigation water use of farmer households is monitored and charged. In this system, irrigation water fees can be charged by electricity, time, or water volume according to a progressive pricing system. Water rights are allocated to farmer households. The water rights of every household are monitored and controlled. Second, the irrigation water use of farmer groups is monitored and charged by electricity, time, or water volume according to a progressive pricing system. The water use of individual farmers was charged by the irrigated area. The water rights of individual farmer households are not monitored and controlled.

Thousands of agricultural water rights transactions (AWRTs) happened in China, and several agricultural water rights markets (AWRMs) have formed since 2000. However, the performance of China's agricultural water markets is unclear. The performance variation of AWRMs under different water management systems was not studied. A systematic evaluation of China's agricultural water market is important for adjusting the water rights policy in China and can provide other countries reference for water market development.

Water market performance is often evaluated from an economic efficiency perspective. The potential maximal water market income is usually estimated by optimizing the benefit of participants (Easter *et al.*, 1998; Qureshi *et al.*, 2009; Bekchanov *et al.*, 2015; Wang *et al.*, 2020; Iftekhar & Fogarty, 2022). The water market efficiency can also be estimated using the experimental economic method (Pan *et al.*, 2019). Crop production in the water market can be evaluated by an agent-based model (Du *et al.*, 2021). The differences-in-differences (DID) method was a more accurate method to evaluate the change of income after water rights transactions (Debaere & Li, 2020), but it has strict requirements for samples.

Although the water market may be beneficial, the benefit should be compared with the transaction costs. Zhang *et al.* (2009) found that transaction costs are a significant barrier to the proper functioning of the water user rights system in Zhangye City, China. The transaction costs of agricultural water trading accounted for 1–93% of the transaction price in the Heihe River Basin of China (Deng *et al.*, 2017). In the same region, the ratios of transaction costs to transaction prices ranged from 4.11 to 244.44% in the transactions between agriculture and industry (Deng *et al.*, 2018). Besides the case study of transaction costs, Garrick *et al.* (2013) established a transaction cost analysis framework to examine the evolution and performance of water markets. They found that transaction costs may rise or decline with fluctuation depending on the institutional arrangement.

The third-party impacts of water markets are not negligible. Water reallocation from agriculture to cities may decrease irrigation times (Zhao & Hu, 2007; Chen, 2008) and irrigation water reliability (Dai *et al.*, 2015) in some water reallocation cases. Water reallocation led farmers to seek alternative water sources and led to crop revenue decreasing (Dai *et al.*, 2016). The impact of water transactions on the local economy and ecological environment also raises concerns (Gould, 1988; Etchells *et al.*, 2006; Grafton *et al.*, 2012; Wheeler *et al.*, 2014; Grafton & Wheeler, 2018; Garrick *et al.*, 2020).

The effect of the water market on water use efficiency is controversial. Sun *et al.* (2016) found that water rights did not reduce farmers' irrigation application in the later phase of reform in Zhangye City, China. Tian *et al.* (2020) found that water rights trading had a positive role in promoting water use efficiency in China. Fang & Wu (2020) found that water rights trading can significantly promote water conservation in the pilot regions by 3.1% than in the non-pilot regions in China. Safari *et al.* (2023) found that water markets can recover 80% of groundwater loss in Iran using remotely sensed data.

The above methods can evaluate the partial performance of a single water market but cannot compare the performance of different water markets from a comprehensive perspective. Several studies used simple indicators to compare different water markets, and many of them use the scale of water transactions (Moore, 2014; Xu *et al.*, 2016; Svensson *et al.*, 2021). Xue (2017) used the criteria of 'win–win', 'win–lose', and 'lose–lose'; Liu *et al.* (2018) used the indicator of resilience. Grafton *et al.* (2011) first established an integrated framework to assess water markets in Australia, the United States, Chile, South Africa, and China. The framework includes 19 criteria in three categories: institutional foundations, economic efficiency, and environmental sustainability. However, it is only a qualitative evaluation framework. Wheeler *et al.* (2017) developed a water market readiness assessment framework to identify the stage of water markets and the necessary arrangements. This framework considers the variation of water market performance, but it is still a qualitative evaluation system.

This study is the first systematic and quantitative evaluation of the performance of China's AWRM, providing a comprehensive quantitative method to evaluate the performance of AWRM from the perspectives of fairness, efficiency, and sustainability. First, we explore the scale, structure, and transaction price of China's AWRM. Second, we evaluate the fairness, efficiency, and sustainability of the performance of China's typical AWRM. Third, we identify the temporal and spatial evolution characteristics of the performance of China's AWRM.

AWRMs in this research only include the markets between farming, forestry, and breeding industries and not the markets between agriculture and non-agricultural sectors. This is because planting is the primary agricultural water user in China, and most water rights transactions in China take place in the planting sector. Surface water and groundwater agricultural water rights are traded in China, and both of them are studied. Formal water markets only exist in areas where the Chinese government has implemented water rights reform, whereas informal water markets exist in other areas. This study only examines formal water markets.

2. MATERIAL AND METHODS

2.1. Data

The data include AWRT data and water rights market performance evaluation data. The AWRT data come from China Water Exchange (CWE), reports, and academic literature. China had no official water rights transaction collection and publication agency before the establishment of the CWE in 2016. The CWE participated in most AWRTs in China and posted these transactions on its website. The transaction data from CWE include the names of traders, transaction volume, transaction time, and transaction price since 2016. The AWRT that CWE did not publish is collected from academic papers and reports on the Internet. We try different keywords about agricultural water rights and water markets in various databases and search engines to collect transaction cases. Transactions that are neither listed by CWE nor researched or reported are excluded from this research. Water rights market performance evaluation data include water rights allocated, water price, and water consumption. The data were collected from published research, yearbooks of counties or cities where water markets are located, summary reports of agricultural water price and water rights reform of these counties or cities, and water rights allocation and water price reform plans for these areas.

Several agricultural water markets are investigated to improve our understanding of the markets and obtain transaction data. The investigated water markets are selected by their difference in water source, location, and running mechanism. We investigated water markets in Xiying and Qingyuan irrigation districts in Gansu Province, Qingxu County in Shanxi Province, and Chengan County in Hebei Province in 2019. Ninety-four households in Xiying and Qingyuan irrigation districts were surveyed to collect data on crop output, agricultural product price, and irrigation water use.

For every transaction, at least two relevant literatures were examined to guarantee the data accuracy. Some transaction data are further verified by the staff of irrigation district management agencies or local water bureaus.

2.2. Evaluation indicators

Based on the evaluation indicators in the literature and the agricultural water rights transaction situation in China, we design eight evaluation indicators from the aspects of efficiency, fairness, and sustainability (Table 1). Efficiency includes four indicators, and fairness and sustainability include two indicators each.

The economic efficiency of AWRM was evaluated by its ability to increase the social gross income of water rights transactions, reduce transaction costs, determine the transaction water price based on the value of water resources, and expand the transaction scale. The social gross income of transactions is often used to evaluate the efficiency of water transactions. It is usually calculated by the sum of benefits that stakeholders get from the transactions (Hearne & Easter, 1997; Qureshi *et al*., 2009). However, the social gross income of transactions is affected by time, water scarcity, and local economic development. As such, it cannot be used to compare the transactions in different times and areas. Therefore, the indicator of relative water rights transaction income is used. This indicator is estimated by the extent of the social gross income of transactions reflecting the value of water resources. The value of water resources is accessed by the water price of local urban domestic water supply. This is because the domestic water price is much higher than the irrigation price and lower than the industry water supply price. Moreover, the data on domestic water prices are the most common.

Instead of calculating water rights transaction costs, we use the water rights transaction subject index to reflect it. Water rights transactions between farmers' organizations require lower water rights allocation and supervision costs, whereas water rights transactions among farmers require higher transaction costs. The larger the farmer organization in the transaction, the lower the transaction cost was. Therefore, the village transaction subject is assigned the highest value, whereas the farmer transaction subject is assigned the lowest value in the transaction evaluation.

The efficiency of the water market can be evaluated by its ability to reflect the value of water (Moore, 2014). A water market with sufficient competition can form a transaction price that is closer to the water resources' value. Thus, the indicator of relative water rights transaction price is used to estimate the extent of transaction price reflects the value of water resources. The value of water resources is also assessed by the water price of local urban domestic water supply.

Table 1 | Evaluation indicators of the agricultural water rights market.

Indicators	Definition (higher value means better performance)	Calculation method
Efficiency		
Relative water rights transaction income	The average extent of the social gross income of transactions reflects the value of water resources.	Transaction revenue per unit of water ÷ water price of local urban domestic water supply
Relative water rights transaction price	Average extents of transaction price reflect the value of water resources.	Transaction price ÷ water price of local urban domestic water supply
Relative water rights transaction volume	The proportion of the amount of water rights traded among the allocated water rights.	Average annual trading water volume ÷ allocated water rights volume in a water market
Water rights transaction subjects	The degree of the organization of farmers in water rights transactions.	Farmers, 0; Farmer groups, 0.33; Villages, 0.67[a]
Fairness		
Source of water rights transaction water	The method by which the water seller produces surplus water.	Water-saving, 0.67; returning farmland to forest, 0.33; idle, 0
Distribution and use of water rights transaction income	Ways to manage the proceeds of water rights trading.	Assigned to farmers, 0.67; collectively managed and used for irrigation facility maintenance, 0.33; collectively managed but unreasonably used, 0
Sustainability		
Growth rate of water rights transaction volume	Geometric mean of the growth rate of the water rights transaction volume in different years.	If the growth rate is less than 0, the value is 0
Growth rate of water rights transaction cases	Geometric mean of the growth rate of the number of water rights transactions.	If the growth rate is less than 0, the value is 0

[a]The value of the classification indicators was determined according to tertiles between 0 and 1. This method was also used by Svensson *et al*. (2021).

The performance of water markets is often evaluated by its scale (Grafton *et al.*, 2011; Palomo-Hierro *et al.*, 2015). An efficient water market can stimulate more water transactions and trade more water. Therefore, the indicator of relative water rights transaction volume is used to evaluate the efficiency of water markets to expand the transaction scale. This indicator is assessed by the amount of water rights traded compared with the allocated water rights.

We evaluate the fairness of AWRM by examining whether the transaction water came from water-saving. If the transaction water came from water-saving, water sellers had inputted effort to get benefit from water rights transaction. This result can stimulate farmers to save water. If the allocated water rights volume is more than needed, or if water rights are not withdrawn even if farmland is occupied, then the surplus water rights are defined as idle water rights. In this case, water sellers do nothing to get water rights transaction benefits. This was unfair to other water users. If water rights volume is more than needed because farmers returned farmland to the forest, then farmers bear some loss from this transaction. This is more reasonable than the case of idle water rights. Therefore, the fairness of the water market is the highest if the transaction water comes from water-saving.

Another indicator of water market fairness is the distribution and use of water rights transaction income. If the transaction income is assigned to farmers, then only farmers save water and selling the water can benefit from the transaction. This condition can stimulate farmers to save water. If the transaction income is collectively managed and used for irrigation facility maintenance, whether farmers save water or not, they can benefit from the transaction. This is not fair for farmers who save water. If the transaction income is collectively managed but unreasonably used, then it is unfair to all the farmers. Therefore, the fairness of the water market is the highest if the transaction income is distributed to the farmers, and it is the lowest when the trading income is collectively managed but not used properly.

The sustainability of the AWRM was often referred to as environmental sustainability and is evaluated by environmental flows and water quality (Grafton *et al.*, 2011). However, agricultural water rights trading generally occurs within the scope of the basin; thus, it does not cause environmental flow changes in the basin. There are no water quality problems in water rights transactions between agricultural water users. Therefore, the environmental sustainability problem of AWRM is negligible. Besides environmental sustainability, the resilience of the water market is important in sustainability evaluation. Liu *et al.* (2018) emphasized the ongoing transactions in water markets as representative of their resilience. Therefore, we evaluate the sustainability of AWRM through the growth rate of water rights transaction volume and cases in different years. The greater the growth rates of transaction volume or transaction cases, the greater the sustainability of the market.

2.3. Calculation method of water rights transaction income

Water rights transaction income refers to the social gross income generated by water rights trading relative to the situation without water rights transaction. We divide agricultural water rights transactions into three types according to different transaction motives, namely, compulsory type, water price difference type, and buyback type.

Compulsory type water rights transaction refers to water rights transaction that happened because the government stipulates that irrigation water that exceeds water rights must be traded. Water users who lack water rights have to buy it from the users who have surplus water rights. This water rights transaction occurs between farmers, farmer groups, and villages.

Water price difference type water rights transaction refers to water rights transaction used to reduce irrigation water fee. The water buyer can reduce irrigation fees through water transactions because irrigation water is charged at different prices according to irrigation water use or types of arable land. In China, irrigation water within the irrigation quota is often charged with a lower price, whereas water exceeding the quota is charged with a price that is several times the initial price. Therefore, instead of paying for higher water prices, farmers buy water that exceeds the irrigation quota with lower prices and decreased irrigation fees. In some districts of China, only part of the arable land is allocated water rights. This arable land is called a water rights area. Irrigation water use in the water rights area is charged at a lower price, whereas water use on other arable lands was charged at a much higher price. Farmers can save irrigation fees if they buy water rights from other farmers to irrigate their arable lands without water rights.

Buyback type water rights transaction refers to water rights transaction in which the government acts as the buyer to improve agricultural water efficiency when there are no other buyers. The buyer is absent because there is no heterogeneity between agricultural water users. In this situation, water users usually plant similar crops and use similar irrigation water amounts. All the arable lands of farmers are allocated with water rights equally. Moreover, non-agricultural water users did not lack water rights because they were allocated more water than they currently needed. Therefore, all the water users have no stimulation to buy water rights. The government can sell the water rights they bought to other potential water users although it is difficult to find buyers.

Transaction income of water rights transactions is calculated by summing the net benefit of participants and subtracting the transaction cost. Transaction income of the three types of water rights transactions is calculated separately. The social gross income of compulsory type water rights transactions can be calculated as follows:

$$B_c = \frac{rf(w)}{w} - \frac{rf'(w)}{w} - S(w) - C_t \tag{1}$$

where B_c is the social gross income of compulsory type water rights transaction, CNY·m^{-3}; $f(w)$ is the water buyer' s net planting income using water w; w is the transaction water volume, m^3; r is the irrigation contribution coefficient, which indicates the contribution of irrigation to agricultural output; $f'(w)$ is the water seller's net planting income using water w, CNY·m^{-3}; $S(w)$ is the other cost of saving water w, CNY·m^{-3}; and C_t is the transaction cost, CNY·m^{-3}.

According to our survey, farmers do not sell water by reducing agricultural irrigation. Farmers generally input more labor into field water management to save water, which is ignored in this research. The direct water rights transaction cost is quite small in our investigation and is ignored. This is because information and negotiation costs in the transaction are low. First, the irrigation district management agency provides water rights supply and demand information to all villages for free. Second, only village leaders or farmer group leaders negotiate with one another to trade water. Therefore, formula (1) can be simplified as formula (2).

$$B_c = \frac{rf(w)}{w} \tag{2}$$

The social gross income of water price difference type water rights transaction is calculated by subtracting water-saving costs and transaction costs from the saved irrigation fee. The formula is as follows:

$$B_p = P_s - S(w) - C_t \tag{3}$$

where B_p is the social gross income of water price difference type water rights transaction, CNY·m^{-3}, and P_s is the saved irrigation water fees, CNY·m^{-3}. The social gross income is less than zero if considering the irrigation water fee loss of the irrigation water supplier. Thus, the loss of irrigation district is not included in formula (3). This may overestimate the social gross income of water price difference type water rights transactions. We also ignore the water-saving cost and the direct water rights transaction cost because they are small. Hence, formula (3) can be simplified as formula (4).

$$B_p = P_s \tag{4}$$

In the buyback type water rights transaction, if the government sells the repurchased water rights to other water users, they can get water rights transaction income. However, if the repurchased water rights cannot be sold, the government has no direct transaction income. The social gross income of water rights transaction when the government resells repurchased water rights can be calculated as follows:

$$B_r = r' \frac{I(w)}{w} - r \frac{f(w)}{w} - S(w) - C_t \tag{5}$$

where B_p is the social gross income of buyback type water rights transaction when the government resells repurchased water rights, CNY·m^{-3}; $I(w)$ is the net production income of water user who buys repurchased water rights from the government, CNY·m^{-3}; and r' is the water contribution coefficient, which indicates the contribution of water to the output of the water rights buyer.

In the typical buyback type water rights transaction in Changsha County, farmers neither reduce agricultural output nor invest in agricultural water-saving. The government plans to sell the repurchased water to a water company. The value of repurchased water is calculated by the raw water fee P_r, so formula (5) is simplified as formula (6).

$$B_r = P_r \tag{6}$$

The social gross income of water rights transactions when the government does not sell repurchased water rights can be calculated as follows:

$$B_r' = E(w) - r\frac{f(w)}{w} - S(w) - C_t \tag{7}$$

where B_r' is the social gross income of buyback type water rights transaction when the government does not sell repurchased water rights, CNY·m^{-3}, and $E(w)$ is the social-ecological value of water w, CNY·m^{-3}.

In the typical buyback type water rights market in Chengan County, repurchased water rights is used to replenish groundwater. The value of repurchased water is calculated by the replacement cost of groundwater protection C_g. The water seller has no agricultural production loss or agricultural water-saving input in the market, so formula (6) can be simplified as formula (7).

$$B_r' = C_g \tag{8}$$

2.4. Weights of evaluation indicators

The relative importance of efficiency, fairness, and sustainability is difficult to distinguish, so we assign the same weight to the first- and second-layer indicators. The value of upper-level indexes is calculated by the arithmetic mean of the lower-level indicators. The evaluation score of typical agricultural water rights market is the average score of indexes' efficiency, fairness, and sustainability.

3. RESULTS AND DISCUSSION

3.1. The characteristics of China's AWRM

3.1.1. Scale

China's AWRM scale is small. From 2002 to 2020, there were 1,752 cases of AWRTs in China, and the volume of AWRT was 10,092,700 m^3. China had an average of 103.06 cases of AWRTs per year, and the average annual volume of AWRT was 5,889,800 m^3. China's agricultural water consumption was 368.23 billion m^3 in 2019 (Ministry of Water Resources of the People's Republic of China 2020). The average annual volume of AWRT was only 0.000016 of China's agricultural water consumption. All AWRTs were short-term transactions within 1 year.

China's AWRM has characteristics of phased changes. According to the time variation of the number of transaction cases, the development of China's AWRM can be divided into three stages (Figure 1). The first stage is from 2000 to 2007, and the number of water rights transactions in this stage is in single digits. The second stage is from 2008 to 2014, and the number of water rights transactions is in the tens of digits. The third stage is from 2015 to 2020, and the number of water rights transactions is in the hundreds digit. According to the time variation of

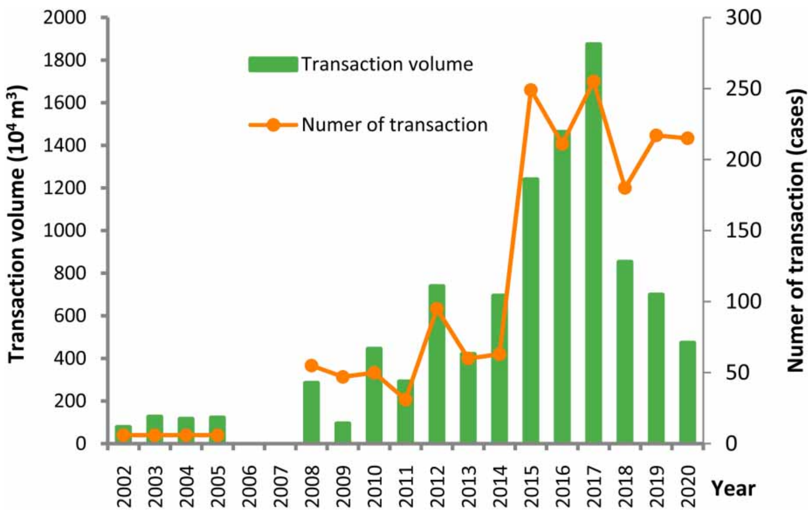

Fig. 1 | Time variation of China's agricultural water rights market between 2002 and 2020 (*Sources*: CWE, academic literature, and reports on Internet).

water rights transaction volume, China's AWRM showed a single-peak cycle of change, with an increasing phase from 2002 to 2017 and a decreasing phase from 2018 to 2020. From 2002 to 2020, the multi-year average growth rate of the volume of China's AWRT was 11.99%, and the multi-year average growth rate of the number of AWRT was 25.07%.

The distribution of AWRT in different provinces is uneven (Figure 2). Approximately 88.24% of China's AWRT occurred in Gansu Province, which contributed to 76.84% of the total water rights volume. Only Xinjiang Uygur

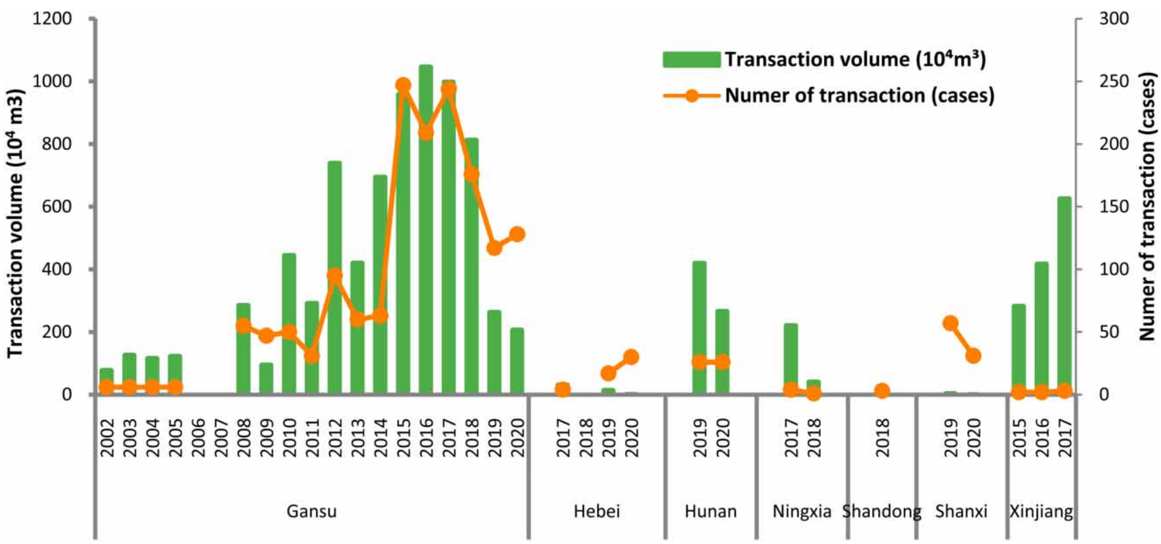

Fig. 2 | Time variation of agricultural water rights market scale in different provinces between 2002 and 2020 (*Sources*: CWE, academic literature, and reports on Internet).

Autonomous Region and Gansu Province had positive growth in water rights transaction volume. Water rights transaction volume in the Xinjiang Uygur Autonomous Region grew the most with a multi-year average growth rate of 48.91%. Only the Xinjiang Uygur Autonomous Region and Gansu and Hebei Provinces showed positive growth in the number of water rights transactions. The number of water rights transactions in Hebei Province grew the most with a multi-year average growth rate of 173.86%. Gansu Province, Xinjiang Uygur Autonomous Region, and Hebei Province were the hot spots in China's agricultural water market.

The scale of AWRM shows regional variation patterns. Water rights transactions were mainly distributed in arid and semi-arid regions (Figure 3(a)). The drier the climates, the more water rights transaction occurred. AWRM spread from arid areas to humid areas. AWRT mainly occurred in the west of China (Figure 3(b)). The number of AWRTs increased from eastern China to western China.

3.1.2. Structure

Surface water is more traded than groundwater in China's AWRM. There were 849 cases of surface water rights transactions, which traded 90.6 million m^3 of water. However, 903 cases of groundwater water rights transactions only traded 9.5 million m^3 of water. According to our investigation, the volume of surface water rights transactions per case was 106,700 m^3, which was 10.16 times that of groundwater. Therefore, groundwater water rights transactions traded less water although they had more transactions.

Most AWRTs happened between planting industries. AWRT involved transactions between planting, forestry, and aquaculture. In addition, the government repurchased water rights from the planting industry. Among them, the water rights transaction volume in the planting industry was 91.40 million m^3, accounting for 91.32% of the total water rights transaction volume. The number of water rights transactions in the planting industry was 1,679 cases, accounting for 95.83% of the total water rights transaction cases.

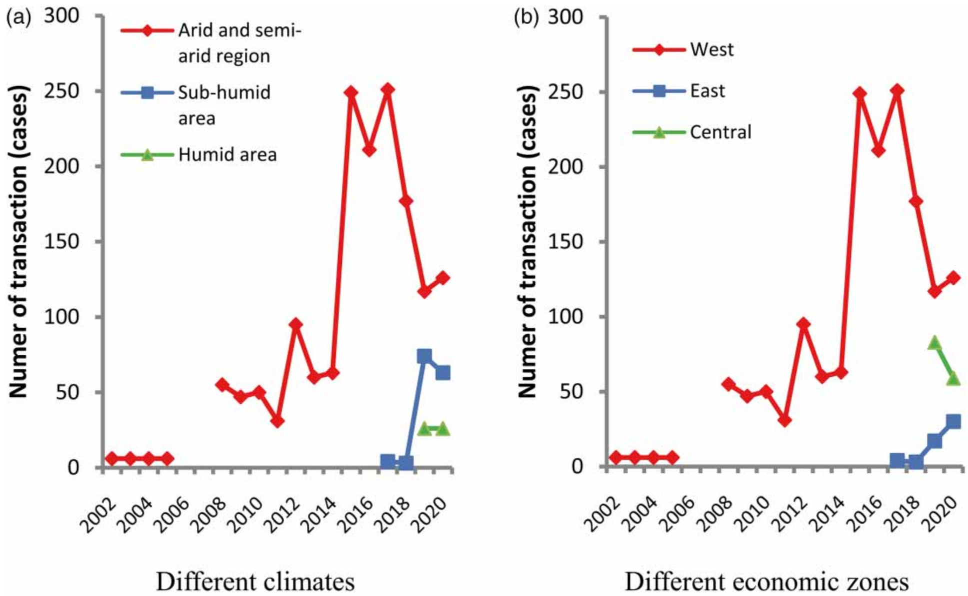

Fig. 3 | Agricultural water rights market scale in different regions between 2002 and 2020 (*Sources*: CWE, academic literature, and reports on Internet). (a) Different climates and (b) different economic zones.

AWRTs mainly occurred at the village and farmer group level. Water rights traders in the highest level was the irrigation district management agency, and that in the lowest level was farmers. The number of water rights transactions between farmers accounted for 89.78% of the total transactions.

Most AWRTs belonged to the compulsory type. The water rights transaction volume of the compulsory type AWRM was 79.51 million m^3, accounting for 79.44% of the total water rights transaction volume. The number of water rights transactions in the compulsory type AWRM was 1,549, accounting for 88.41% of the total water rights transaction cases.

3.2. Performance of China's typical AWRM

3.2.1. The characteristics of typical AWRM

There are 14 AWRMs located in 12 counties in China according to our investigation. Seven typical AWRMs are selected according to the transaction motives, the source of water trade, and the climate of the region where the water rights market is located. We chose three compulsory type AWRMs, two water price difference type AWRMs and two buyback type AWRMs (Table 2).

The number of AWRTs of typical AWRMs accounts for 82.48% of total AWRMs, and the water rights transaction volume of typical AWRMs accounts for 92.84% of total AWRMs (Table 2).

3.2.2. Performance evaluation results of typical AWRMs

The performance of typical AWRMs is low according to the evaluation results. The total performance evaluation score of typical AWRMs is between 0.115 and 0.386, with an average score of 0.245 (Table 3). Among them, the AWRM in Hutubi County has the highest performance evaluation, while the AWRM in Qingxu County has the worst. Typical AWRMs have the highest average score for fairness and the lowest average score for sustainability.

Can the evaluation results of typical AWRMs reflect the performance of the total market? We compare the values of different indexes between the typical AWRMs and the total market to analyze the representativeness and error of typical markets (Table 4). The typical AWRM show strong representative of China's total AWRM for efficiency evaluation and weak representative for sustainability evaluation. The representative of typical AWRM for fairness evaluation is unknown owing to a lack of data. The typical AWRM may overestimate the efficiency of the total AWRM in 'water rights transaction price' index, and it might underestimate the efficiency of the total AWRM in 'water rights transaction volume' index. The typical AWRM may underestimate the sustainability of the total AWRM in 'growth rate of water rights transaction volume and cases' evaluation indexes. Consequently, the evaluation results of the typical AWRM underestimated the performance of the total AWRM.

3.3. Variation of the performance of China's typical AWRM

3.3.1. Time variation

The total performance of typical AWRMs increases with time. The performance of typical AWRMs is the best in the third stage and worst in the second stage (Figure 4). However, the efficiency of typical AWRMs is decreasing. The fairness of typical AWRMs is the highest in the third stage and the lowest in the second stage. The typical AWRMs have the highest sustainability in the second stage and the lowest sustainability in the first stage.

3.3.2. Spatial variation

The performance of typical AWRMs in various provinces is not balanced (Figure 5). The performance of typical AWRMs in the Xinjiang Uygur Autonomous Region is the best, and that in Shanxi Province is the worst. Typical AWRMs in the Xinjiang Uygur Autonomous Region and Hebei Province have the best efficiency. Typical AWRMs in Hunan and Hebei Province had the highest fairness. The sustainability of typical AWRMs in the Xinjiang Uygur Autonomous Region is the strongest.

Table 2 | Basic characteristics of typical agricultural water rights markets.

Markets	Located province	Transaction volume (10^4 m^3)	Transaction price (CNY·m^{-3})	Transaction cases	Transaction motives	Climate	Region	Water Source	Stage
Maying River Irrigation District	Gansu	440.93	0.071	24	Compulsory	Arid and semi-arid	West	Surface water	First
Xiying Irrigation District	Gansu	6,041.56	0.135	646	Compulsory	Arid and semi-arid	West	Surface water	Second
Qingyuan Irrigation District	Gansu	739.91	0.069	625	Compulsory	Arid and semi-arid	West	Groundwater	Second
Hutubi County	Xinjiang	1,324.31	0.209	7	Water price difference	Arid and semi-arid	West	Surface water	Third
Qingxu County	Gansu	3.53	0.406	80	Water price difference	Semi-humid	Central	Groundwater	Third
Chengan County	Hebei	44.21	0.200	8	Buyback	Semi-humid	East	Groundwater	Third
Tongrenqiao Irrigation District	Hunan	698.58	0.008	55	Buyback	Humid	Central	Surface water	Third
Total	\	9,293.03	0.16	1,445	\	\	\	\	\

Sources: CWE, academic literature, reports on Internet, and field survey.

Table 3 | Performance evaluation score of typical agricultural water rights markets.

Markets	Time range	Efficiency score	Fairness score	Sustainability score	Total score
Xiying Irrigation District	2008–2018	0.24	0	0.20	0.146
Qingyuan Irrigation District	2012–2020	0.24	0	0.24	0.161
Chengan County	2017–2019	0.30	0.67	0.00	0.325
Maying River Irrigation District	2002–2005	0.33	0.335	0.08	0.250
Qingxu County	2019–2020	0.01	0.335	0.00	0.115
Hutubi County	2015–2017	0.30	0.5	0.36	0.386
Tongrenqiao Irrigation District	2019–2020	0.27	0.67	0.06	0.331
Mean		0.24	0.36	0.13	0.245
Standard deviation		0.11	0.28	0.14	0.11

Source: calculated by the authors.

Table 4 | Representativeness and error of typical agricultural water rights markets.

Indicators			Total	Typical	Representativeness	Error[a]
Efficiency	Water rights transaction income (CNY·m^{-3})		\	0.45	\	\
	Relative water rights transaction income		\	0.29	\	\
	Water rights transaction price (CNY·m^{-3})		0.13	0.16	Strong	+
	Relative water rights transaction price		\	0.07	\	\
	Water rights transaction volume (10^4 m^3 per year)		588.78	257.99	Strong	−
	Relative water rights transaction volume		\	0.06	\	\
	Water rights transaction subject (the number of water rights transaction)	Irrigation District Management Agency	2	\	Strong	0
		Villages	761	758		
		Agriculture and Forestry Farms	4	\		
		Farmer groups	812	734		
		Small farmer groups	24	\		
		Farmers	149	80		
Fairness	Source of water rights transaction (the number of typical AWRMs)	Idle	\	4	\	\
		Water-saving	\	2		
		Water-saving and returning farmland to forest	\	1		
	Distribution and use of water rights transaction income (the number of typical AWRMs)	Assigned to farmers	\	4	\	\
		Collectively managed	\	2		
		Partly Assigned to farmers and partly collectively managed	\	1		
Sustainability	Growth rate of water rights transaction volume (%)		11.99	−1.82	Weak	−
	Growth rate of water rights transaction cases (%)		25.07	0.21	Weak	−

[a]'+' represents overestimated, '−' represents underestimated, '0' represents close, and '\'represents lack data.
Source: calculated by the authors.

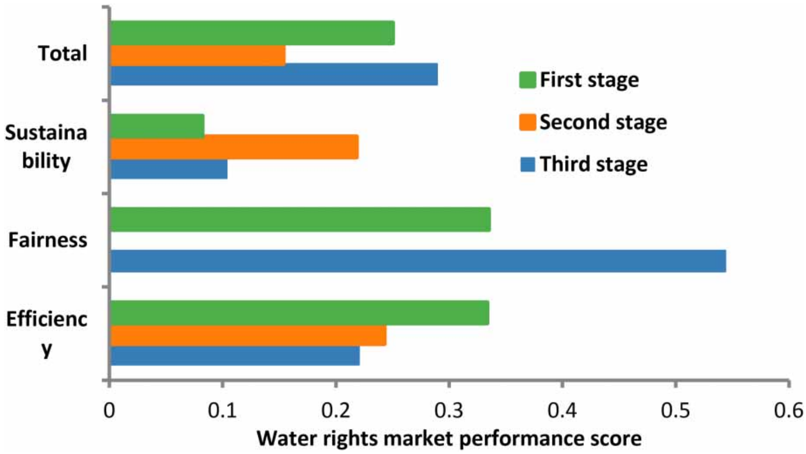

Fig. 4 | Variation of typical AWRMs performance in different stages (*Source*: calculated by the authors).

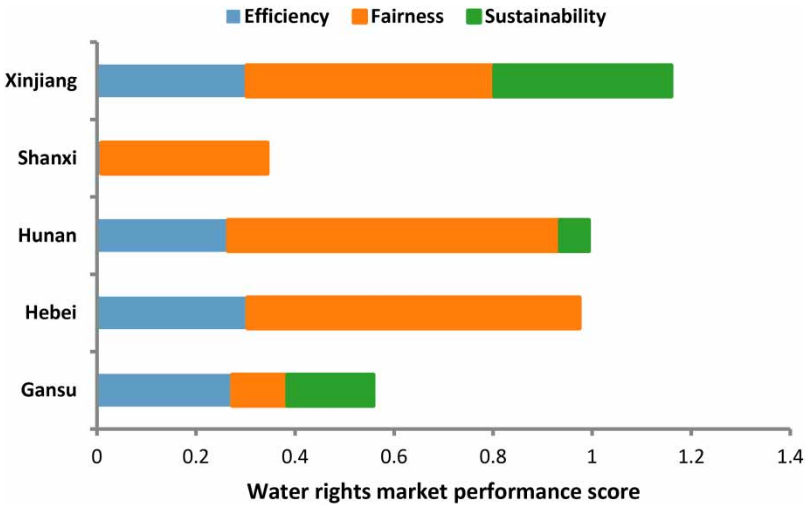

Fig. 5 | Performance of typical AWRMs in different provinces (*Source*: calculated by the authors).

The performance variance of typical AWRMs is not completely consistent with climate variance (Figure 6). The performance of typical AWRMs in humid areas is the highest, and that in semi-humid areas is the lowest. The efficiency of typical AWRMs is the highest in arid and semi-arid regions and the lowest in semi-humid regions. The fairness of typical AWRMs was lower when the climate was drier. The sustainability of typical AWRMs is the highest in arid and semi-arid regions and the lowest in semi-humid regions.

The performance of the typical AWRMs increases with the economic development. Typical AWRMs in the east have the highest average performance, and those in the central have the lowest performance. In the same area, the higher the extent of economic development, the better the performance of the typical AWRMs (Figure 7).

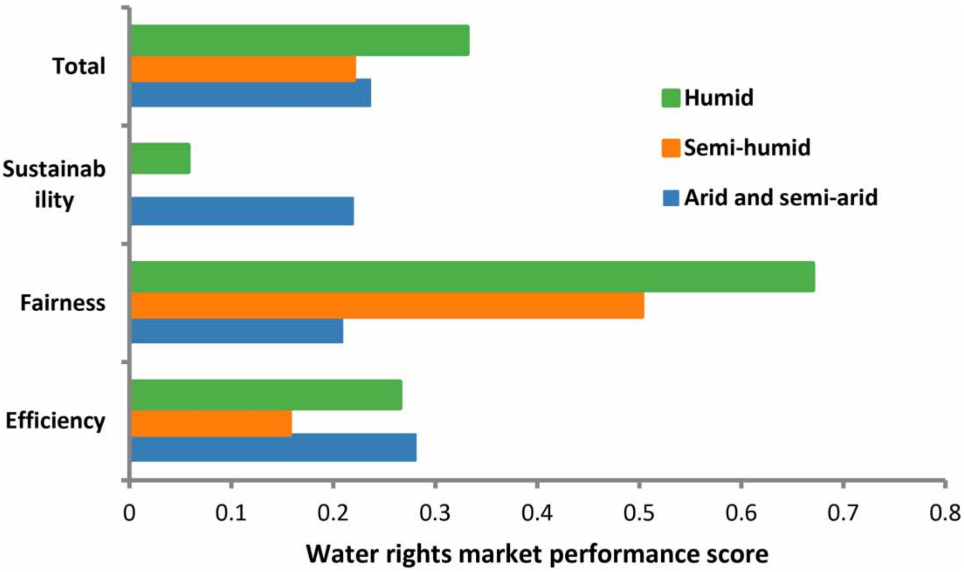

Fig. 6 | Performance of typical AWRMs in areas with different climates (*Source*: calculated by the authors).

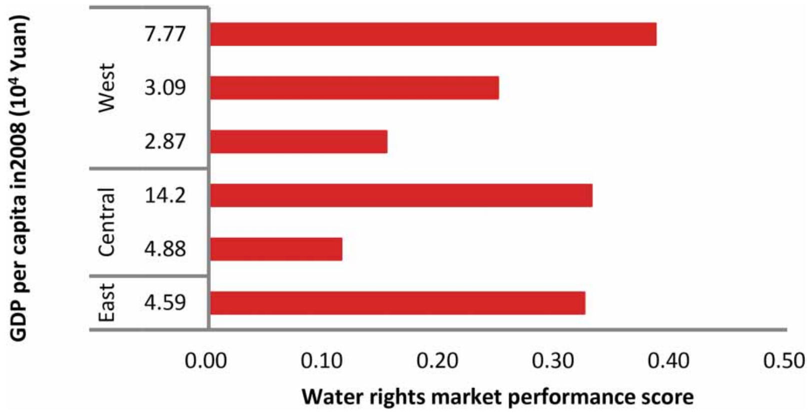

Fig. 7 | Variation of typical AWRMs performance in different economic development areas (*Source*: calculated by the authors).

3.3.3. Category variation

The buyback type AWRMs performed the best and the mandatory type performed the worst (Figure 8). The buyback type AWRMs have the highest efficiency; while the water price difference type has the lowest. The buyback type typical AWRMs have the highest fairness, while the mandatory type has the lowest. The water price difference type typical AWRMs are the most sustainable, while the buyback type is the least.

The total performance evaluation of the surface water rights market is higher than groundwater rights market. Moreover, the efficiency, fairness, and sustainability of the surface water rights market are all higher than groundwater rights market.

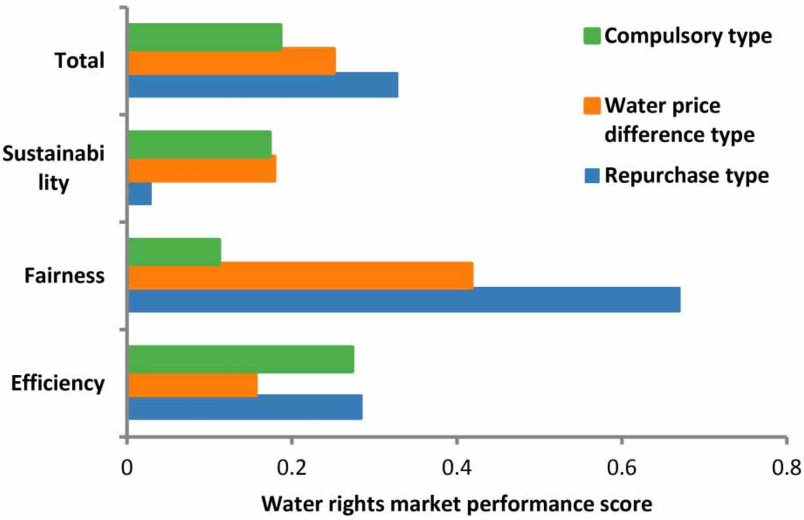

Fig. 8 | Performance of typical AWRMs with different transaction motives (*Source*: calculated by the authors).

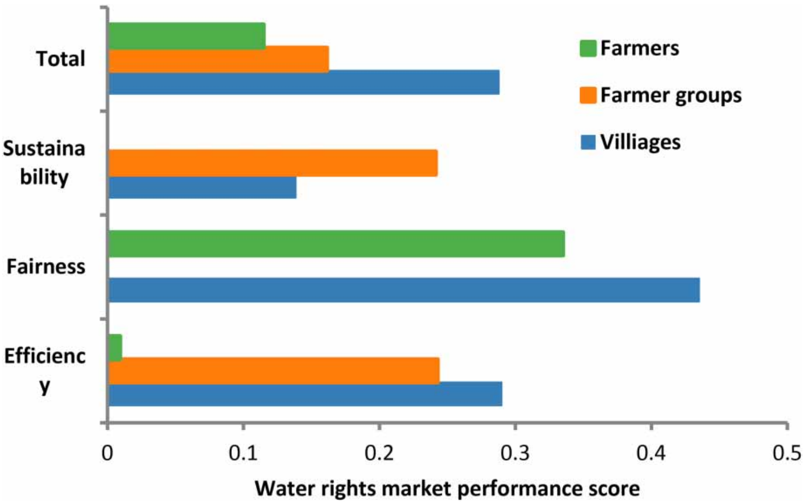

Fig. 9 | Performance of typical AWRMs in different transaction levels (*Source*: calculated by the authors).

The higher the transaction level, the better the performance of the typical AWRMs (Figure 9). The efficiency of typical water rights transactions at the village level was the highest, and that at the farmer level was the lowest. Village-level water rights transactions have the highest fairness, and group-level water rights transactions have the lowest. Group-level water rights transactions have the highest sustainability, and farmer-level water rights transactions have the lowest.

4. CONCLUSIONS

The scale of China's AWRM remains small after 20 years of development. Transactions are mainly concentrated in the west and the north of China. AWRTs primarily occur at the village and farmer group levels.

China's AWRM can be classified into three types according to the transaction motives: compulsory type, water price difference type, and buyback type. The compulsory type of water rights market had the largest transaction scale, and the buyback type water rights market had the smallest.

The total performance of typical AWRMs is low according to the evaluation. Typical AWRMs have the highest score for fairness and the lowest score for sustainability. In the same region, typical water markets in areas with higher economic development performed better. The buyback type typical AWRMs performed the best, and the mandatory type performed the worst. The higher the transaction level, the better the performance of the typical AWRMs.

The agricultural water market will remain a critical policy to solve the water conflict between agriculture, non-agriculture industries, and environment under climate change. We provide a comprehensive quantitative method to evaluate agricultural water rights market performance, which is more accurate than the single index and qualitative evaluation. The evaluation method can be used to assess the performance of agricultural water markets in other countries. The performance evaluation results can provide a reference for policymakers in China and other countries. It can also be used to analyze the cause of variance in water market performance.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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