

Review of agricultural water-saving policies and measures in recent years – a case study of Jiangsu Province, China

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ABSTRACT

The scarcity of water resources has posed serious threats to the sustainable development of agriculture. China is a largely agricultural country with a large population, and agricultural water consumption accounts for more than 50% of the total water consumption. The application of water-saving irrigation is the main way to realize the sustainable development of water resources and economics. To comprehensively improve crop water-use efficiency and reduce agricultural water consumption, the Chinese central government have promulgated a series of agricultural water-saving policies since 2012, such as strengthening water management, increasing financial investment, and strengthening project construction and operation management and protection. Taking Jiangsu as an example, this paper reviews the main water-saving policies and measures of governments after 2012, as well as the conflicting interest between different water-saving participants. Results showed that, through water-saving policies and measures, its effective utilization coefficient of agricultural irrigation water (EUCAIW) has increased from 0.59 in 2014 to 0.614 in 2019. By 2019, the area of irrigated arable land controlled by water-saving technologies is 2.848 million hectares, accounting for 67.8% of the irrigated arable land area in Jiangsu. Jiangsu's water-saving policies have been implemented well, and it has guidance on water-saving reform work in other places.

Key words: agricultural water-saving, China, conflicting interest, Jiangsu Province, policies and measures

HIGHLIGHTS

- China's agricultural water-saving policies and measures in recent years are systematically introduced.
- Major agricultural water-saving measures in Jiangsu, especially unique water metering methods, are introduced.
- Conflicting interest between different participant games in agricultural water saving is analyzed.

INTRODUCTION

In September 2015, the United Nations (UN) published the 2030 Agenda for Sustainable Development (UN 2019) including 17 Sustainable Development Goals (SDGs) and 169 targets (Hellegers & Halsema 2021). It states that by 2030, through enhanced international cooperation, global governments will increase investment in rural infrastructure, agricultural research and extension services, and technology development to enhance agricultural productive capacity in developing countries (SDG 2) (Cláudia *et al.* 2021). SDG6 also addresses that by 2030, 'substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of fresh water to reduce the number of people suffering from water scarcity' (GEMI 2019). According to the Intergovernmental Panel on Climate Change (IPCC), maize, wheat, and other major crops have experienced significant yield reductions at the global level of 40 megatons per year between 1981 and 2002 due to a warmer climate (Liu *et al.* 2021a). SDG 11 indicates that by 2030, 'substantially decrease the direct economic losses relative to global gross domestic product caused by disasters' (Lee *et al.* 2021). From the viewpoint of sustainable development, a negative growth of agricultural water use is necessary for sustainable agricultural development. The key to extending this strategy is the development of water-saving in agriculture (Cheng *et al.* 2021). Better use of agricultural water-saving measures can help improve the livelihoods of farming communities and increase the resilience and sustainability of farming systems (Yao *et al.* 2021).

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Rapid urbanization is exerting pressure on fresh water supplies, sewage, and the living environment, and many parts of the world are experiencing serious freshwater shortages (Naiman & Turner 2000), such as China (Jiao 2010; Cheng *et al.* 2009), the United States (Eslick & Miller 2011; Worland *et al.* 2018), India (Faibish & Konishi 2003; Thakkar 2008) and so on. The main reason for water scarcity is the lack of freshwater resources on earth. Another reason is inefficient water management, and some are also caused by water pollution. Unfortunately, even in some places where rainfall is abundant, massive waste and disorderly use of water resources, caused by poor water management and people's indifference to water conservation, can result in water scarcity. In addition, climate and land-use change are also affecting water supplies (Han & Dong 2016). In response to the water crisis, governments around the world have been vigorously studying agricultural water-saving policies, measures and technologies in recent decades. Liu *et al.* (2021b) introduced the 'Water-Saving Management Contract' used in China, which was an innovative business model aimed at reducing water consumption and improving water use efficiency. Mourad *et al.* (2011) evaluated the potential for potable water saving by greywater reuse in Syria. Canedo-Arguelles *et al.* (2016) developed an innovative water resource management system by integrating freshwater, sea-water and reclaimed grey water into a sustainable, low-freshwater demand, low-energy consumption, and low-cost water supply system. The system has been demonstrated at the Hong Kong International Airport, reducing 52% of its freshwater demand.

Agriculture is the world's largest employment sector, providing livelihoods for 40% of the world's population. There are approximately 500 million small farms worldwide, most of which are still rain-fed (Zhong *et al.* 2020). Agriculture is the main water-consuming sector in the world. The irrigated agriculture consumes about 72% of available freshwater resources on a global scale (Jun *et al.* 2013; Davarpanah & Ahmadi 2021), 90% of which is used in developing countries (Misra 2013). For example, agriculture water consumption accounts for 95.24% of the total water demand in Pakistan (Lohano & Marri 2020). In India, agriculture accounts for most water use, as much as 85% of the total annual draft (Adhikari *et al.* 2013). This issue causes substantial conflicts in freshwater allocation between agriculture and other economic sectors (Chai *et al.* 2016), and water saving in agriculture is therefore key to alleviating this issue. China is an agricultural country, and agriculture is the major user of the available fresh water resources (Deng *et al.* 2018), more than 60% of which is used for irrigation water (Jiang *et al.* 2017). In some areas it even exceeded 90%. For example, irrigation water accounts for more than 95% of total water demand in an arid inland river basin in northwestern China (Guo *et al.* 2015). Agriculture in the Heilongjiang region of northern China is the largest water user in the area, requiring 84% of the total water supply (Jin *et al.* 1999).

China is actually very vulnerable in maintaining its food security (Du *et al.* 2014). The challenge for the Chinese government now is how to resolve the conflict between growing food demand and decreasing water supplies (Han & Zhao 2007). To ensure China's food security, China has extensively carried out agricultural water-saving research on agricultural management, biological and engineering measures (Blanke *et al.* 2007; Chai *et al.* 2014). Yao *et al.* (2017) analyzed the government regulation mechanism, government design-bid funding mechanism and user participation mechanism for water-saving irrigation in China. Yang *et al.* (2003) discussed the effectiveness of price-based water policies in solving the current shortage of agricultural irrigation water in China. Cao *et al.* (2020) used a data envelopment analysis (DEA) model to explore the efficiencies of water-saving initiatives in the agricultural sector in China. Wang *et al.* (2018) used a water-balance model to assess the effects of water-saving irrigation policies and provided options for implementing water-price reforms in Gaoyou, China. In Aksu River Basin of northwest China, the implementation of water-saving measures reduced the irrigation quota by up to 48% (Hu *et al.* 2019). Zhou *et al.* (2020a) proposed an integrated high-efficient irrigation strategy for water-saving and quality-improving of cash crops. Of course, no matter what water saving technology is used by farmers, including sprinkler irrigation, drip irrigation, and drought-tolerant crop cultivar (Du *et al.* 2021), government promotion is the key to influence the decisions of farmers (Dai *et al.* 2015).

Jiangsu, located in the Yangtze River Delta region, is one of the most developed provinces in China. Agricultural irrigation water accounts for 64.4% of the total water consumption in Jiangsu. Rice is the major user, taking up more than 70% of the agricultural irrigation water. Jiangsu has the problem of water shortage (Zhou *et al.* 2013), especially during drought years (e.g. 2004, 2006, 2009, 2019). In 2019, Jiangsu's per capita water resource was 287.45 m³, ranking among the bottom 10 in China. With the modernization process, agriculture faces a structural water shortage, and the contradiction of water use between sectors will be further sharpened. As 98% of the lakes were polluted to varying degrees, such as the eutrophication of Taihu Lake (Chen *et al.* 2018) and over-exploitation of groundwater in coastal areas (Wang *et al.* 2021b), it affects not only drinking water but also irrigation water. Meanwhile, due to the serious waste of agricultural water and poor irrigation management system, most of the irrigation districts have not achieved the design benefits (Zhou *et al.* 2020b), causing soil

stain and reduction of agricultural yield. In consideration of the above challenges to the sustainable agricultural development in Jiangsu Province, Zhou *et al.* (2013) suggested increasing water diversion from the Yangze River, collecting and storing rainfall, implementing water-saving technology, treating sewage, and improving policies and other measures to relieve the shortage of regional water resources. Cao *et al.* (2018) suggested using a water footprint to formulate water resources management policies in Jiangsu. Although Jiangsu is facing water stresses, total water use can meet the 2030 targets set by the Jiangsu provincial government with several integrated measures (Zhou *et al.* 2019). By 2025, Jiangsu Province will basically achieve agricultural modernization. Water-saving policies and measures are fundamental principles for sustainable agricultural development, which will meet the demand for grain from the increasing population and enhance the living standard and national economic development (Huang *et al.* 2017).

Taking Jiangsu as an example, this paper reviews the water-saving policies, measures and facilities of China, so as to provide references for the sustainable development of agriculture in other Chinese provinces or developing countries. Following the introduction, the remaining parts of this paper are organized as follows. First, we introduce the basic situation of agricultural water supply in Jiangsu. Second, we introduce major agricultural water-saving policies and plans in Jiangsu. Third, we introduce major agricultural water-saving measures in Jiangsu. Fourth, conflicting interest between different participant games in agricultural water saving is analyzed. Finally, the conclusions are summarized.

GEOGRAPHICAL LOCATION OF JIANGSU AND CURRENT SITUATION OF AGRICULTURAL WATER SUPPLY IN JIANGSU

Location and irrigation districts of Jiangsu

Jiangsu (Figure 1) lies between $116^{\circ}18' \sim 121^{\circ}57' \text{ E}$, $30^{\circ}45' \sim 35^{\circ}20' \text{ N}$ and covers an area of 107,200 km². There are 13 municipalities in Jiangsu, including Nanjing, Wuxi, Yancheng, *etc.* Jiangsu is a major producer of agricultural commodities, with a total cultivated area of approximately 4.539 million hectares. Jiangsu's existing irrigated arable land is about 4.188 million hectares, mainly distributed in irrigation districts which have independent irrigation systems and management agencies. Irrigation districts are divided into large-scale irrigation districts ($\geq 20,000$ hectares), medium-scale irrigation districts (66.667–20,000 hectares) and small-scale irrigation districts (≤ 66.667 hectares). There are 32 large-scale irrigation districts (Figure 1) in Jiangsu.

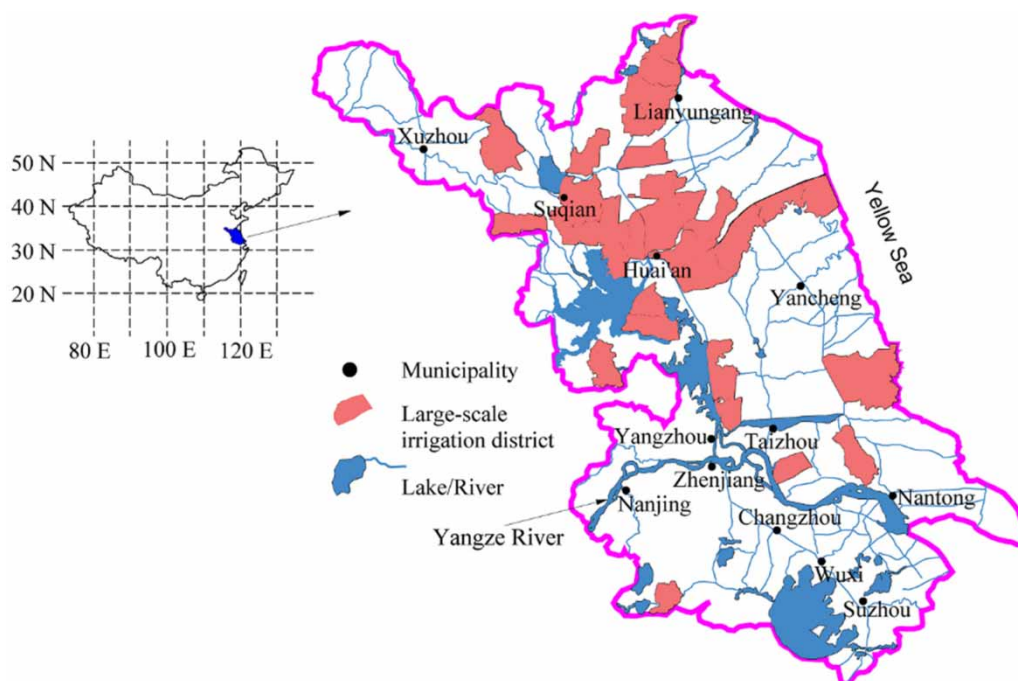


Figure 1 | Geographical location of Jiangsu and distribution of large-scale irrigation districts in Jiangsu.

Planting structure of main crops in Jiangsu

As shown in Figure 2, Jiangsu's main crops include grain crops (e.g. wheat, rice, corn, soybeans), cash crops (e.g. oilseeds, cotton, peanuts, medicinal herbs) and other crops (e.g. vegetables, fruits, green manure crop). In 2019, the cultivated area of grain crops was 5,381,480 hectares, accounting for 72.31% of the total cultivated area of crops. In Jiangsu, grain crops, especially rice, are the largest user of agricultural water (Zhang *et al.* 2020).

Current situation of agricultural water supply in Jiangsu

Jiangsu's water resources include local water resources and transit water resources. The annual average local water resources over the years are 32.695 billion m³. The average transit water volume in Jiangsu over the years is 1025.4 billion m³. The transit water from the Yangtze River accounts for about 95% of the total transit water volume. Table 1 shows the statistical results of annual water consumption in Jiangsu from 2014 to 2019. During the six years, (i) the annual total water consumption (ATWC) was 45.32–49.34 billion m³, and the average annual water consumption was 46.9 billion m³; (ii) the annual water consumption of the primary industry (e.g. agriculture, fishery, *etc*) was 27.01–30.31 billion m³, with an annual average of 28.4 billion m³, accounting for 60.6% of the ATWC; (iii) the annual average water consumption for agricultural irrigation was 24.81 billion m³, accounting for 52.9% of the ATWC; (iv) the average water consumption in the secondary and tertiary industries was 12.69 and 1.74 billion m³, accounting for 27.1 and 3.7% of the ATWC, respectively; (v) the annual average domestic water consumption and other water consumption were 3.81 and 250 million m³, respectively, accounting for 8.1 and 0.5% of the ATWC.

In Jiangsu, the water consumption of rice is generally 495–695 m³/mu, the water consumption of wheat, corn and cotton is generally 50–90 m³/mu, and that of cash crops and other crops is generally 30–165 m³/mu. According to the planting structure and areas shown in Figure 2, it is estimated that the annual irrigation water demand in Jiangsu is about

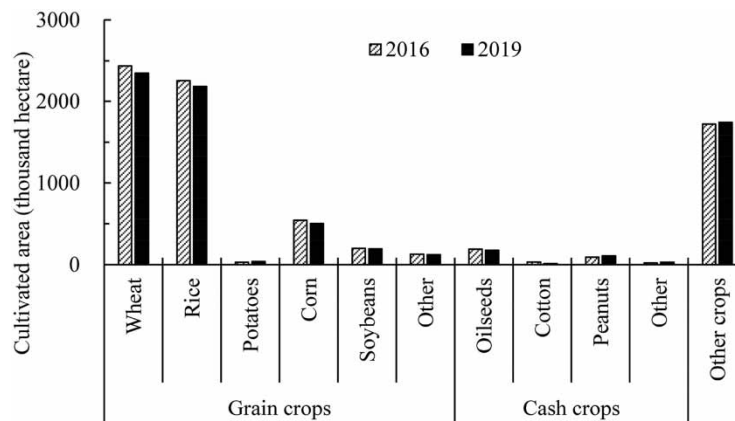


Figure 2 | Planting structure of main crops in Jiangsu.

Table 1 | Statistical results of annual water consumption (unit: 100 million m³) in Jiangsu from 2014 to 2019

Year	ATWC	Primary industry			Secondary industry	Tertiary industry	Domestic	Other
		Consumption	Agricultural Irrigation (AI)	Proportion of AI in ATWC (%)				
2014	480.7	297.8	259.5	54.0	129.5	14.9	35.8	2.7
2015	460.6	279.1	242.8	52.7	127.3	15.6	36.6	2
2016	453.2	270.1	237.2	52.3	126.6	16.3	37.5	2
2017	465.9	280.6	247.8	53.2	127	17.5	38.7	2.1
2018	460.2	273.4	233.2	50.7	125.8	19.3	39.2	2.5
2019	493.4	303.1	268.1	54.3	125.4	20.5	40.6	3.8
Average	469.0	284.0	248.1	52.9	126.9	17.4	38.1	2.5

20.78–28.87 billion m³, which is relatively consistent with the actual agricultural irrigation water consumption in Table 1. In general, there is a shortage of local water in Jiangsu, but because of the abundant transit water, the total water demand of Jiangsu can be ensured, including that for agriculture. However, droughts mainly occur in northern Jiangsu. The cost of transferring water from the Yangtze River to the north is high, which is 5–10 times the cost of local water resource utilization, increasing the financial burden of local governments. In 2019, there was a severe drought in northern Jiangsu and the water of the Yangtze River was used to exceed 10 billion m³. Therefore, water-saving has great economic significance to Jiangsu.

Analysis of agricultural water-saving potential in Jiangsu

The effective utilization coefficient of agricultural irrigation water (EUCAIW) is the most important water-saving indicator. It is used for evaluating the engineering condition and management standard of irrigation canal systems, which reflects both the leakage loss of channels and the water loss during the management process in the irrigation districts (Yang *et al.* 2021). The formula is shown as follows:

$$\eta = \frac{W_n}{W_g} \quad (1)$$

where η is EUCAIW, W_n is the irrigation water consumption in irrigation districts (m³), and W_g is the gross amount of irrigation water in irrigation districts (m³).

As shown in Figure 3(a), from 2011 to 2020, the EUCAIW in Jiangsu and China showed an increasing trend annually, among which the highest increase rate was 1.54 and 1.34% in 2014, respectively. By 2020, the EUCAIW in Jiangsu was 0.616, which was 8.64% higher than that of 2011. Figure 3(b) shows that in 2014, the EUCAIW in Jiangsu was only 0.539

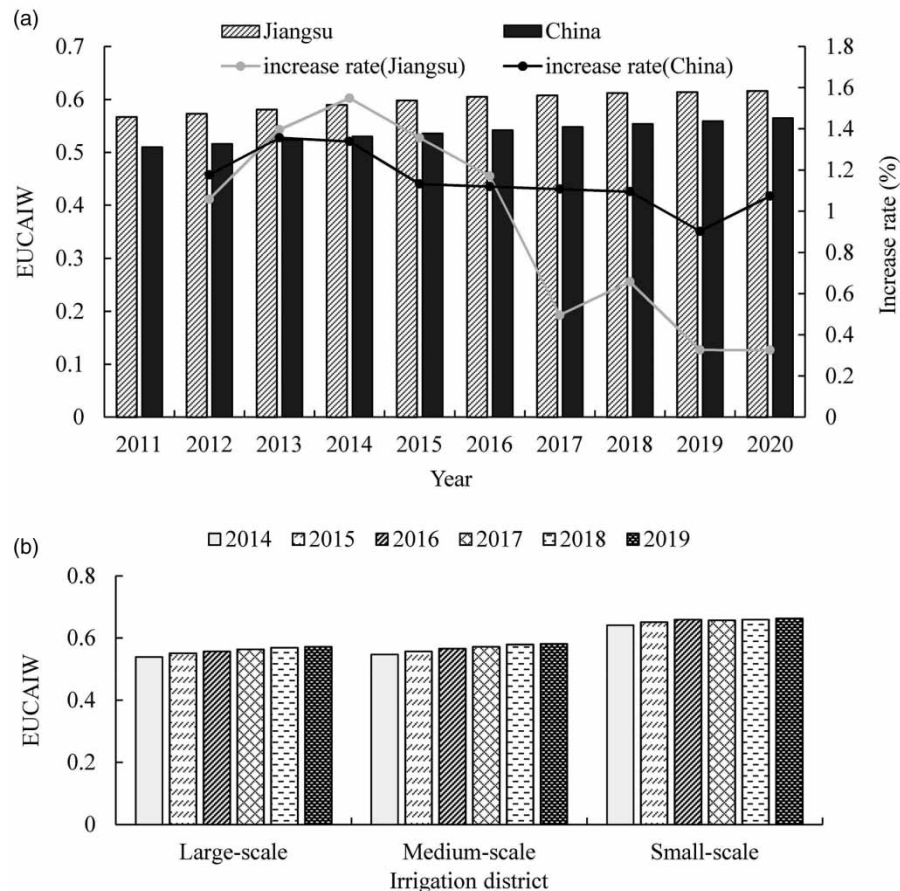


Figure 3 | (a) EUCAIW and its increase rate in Jiangsu and China from 2011 to 2020; (b) EUCAIW of irrigation districts in Jiangsu from 2014 to 2019.

in large-scale irrigation districts, 0.547 in medium-scale irrigation districts and 0.641 in small-scale irrigation districts, with an average of 0.590. In 2019, they were 0.572, 0.581 and 0.663, respectively, with an average of 0.614. With the continuous improvement of the EUCAIW in Jiangsu, in 2019, the water-saving amount reached 2.003 billion m³, accounting for 4.1% of the total social water consumption, and the water saved could meet the water demand of the tertiary industry. In addition, the EUCAIW in developed countries generally reached 0.7–0.8, or even up to 0.9. In comparison, the EUCAIW of Jiangsu is just more than half of developed countries (Zhang *et al.* 2019). The agricultural water-saving potential is great. If we adopt advanced irrigation technology, the EUCAIW will be improved by 10–20%, which is essential in alleviating the contradiction between water supply and demand.

MAJOR AGRICULTURAL WATER-SAVING POLICIES AND PLANS IN JIANGSU

Promoting the realization of national strategic goals through policies, plans and technical standards is a successful experience of China's national governance. Water-saving irrigation, promoted by Chinese government, is a major strategic task for the sustainable development of China's economy and society. Central government formulates agricultural water-saving policies, plans and technical standards, on the basis of which local governments issue detailed supporting policies and plans to carry out water-saving activities. This mode of cooperation between the central and local governments is conducive to promote China's agricultural water saving as a whole.

Close collaboration between government departments

As shown in Figure 4, Chinese government departments at all levels involved in agricultural water saving mainly include the development and reform sector (DARS), water resources sector (WRS), agriculture and rural sector (ADRS), and financial sector (FS). Among them, DARS's main role is to verify and approve projects and agricultural water pricing related to water saving, WRS's main role is to formulate irrigation quotas and allocate water resources, ADRS's main role is to promote agricultural water-saving technologies, and FS's main role is to implement agricultural water-saving subsidies and water-saving incentives. The management agencies, organizations or farmers of irrigation districts located in each county (or county-level city or district) implement specific water-saving measures under the guidance of county government.

The irrigation quota for a crop is the amount of water that the crop consumes during its growth period. The determination of irrigation quotas is affected by factors such as climate, soil, crop species, water sources, irrigation technology, etc. Irrigation quotas for different crops are generally determined through long-term, large-scale investigation, field tests and data analysis (Han *et al.* 2019). The irrigation quota is a quantity control on agricultural water use, without affecting crop production for the purpose of reducing agricultural water use (Shi *et al.* 2014). Wang *et al.* (2021a) showed that the recommended irrigation quota saved 11–60% irrigation water and improved water use efficiency by 11–65% without reducing maize yields in some climatic conditions. Zhao *et al.* (2021) used the irrigation quota and AquaCrop model to optimize the irrigation schedule of summer maize.

Formulating clear water-saving policies and plans

In 2012, Chinese central government issued the 'National Agricultural Water Saving Outline (2012–2020)', which was the first national outline for agricultural water saving. The outline defined the goals and tasks for China's agricultural water saving in the future. A few key tasks are briefly listed: (i) Formulating plans related to agricultural water saving; (ii) Improving agricultural water-saving policies and regulations; (iii) Strictly controlling the total amount of agricultural water use and irrigation quotas; (iv) Promoting agricultural water pricing reform so that water prices can be used to regulate water consumption; (v) Comprehensively promoting high-efficiency water-saving irrigation techniques on irrigated farmland, especially in large and medium-scale irrigation districts; (vi) Equipping agricultural water metering facilities; (vii) Increasing the water fee collection rate and improving the efficiency of expenditures of water fee; (viii) Promoting the establishment of farmer-based water cooperation organizations, which are used to assist government in the operation and maintenance (O&M) of irrigation systems; (ix) Promoting legislation on rural water conservancy.

Figure 5 shows the policies and plans formulated by the central government based on the above water-saving requirements, as well as the supporting water price reform policies and technical standards. The specific implementation of the water-saving policies is in local governments. Local governments at all levels should combine local conditions and the policies, plans, and standards of the central and higher-level governments to formulate their own water-saving measures, with the focus on highlighting policy coordination among the central, provincial, municipal, and county governments. Figure 6 shows the various

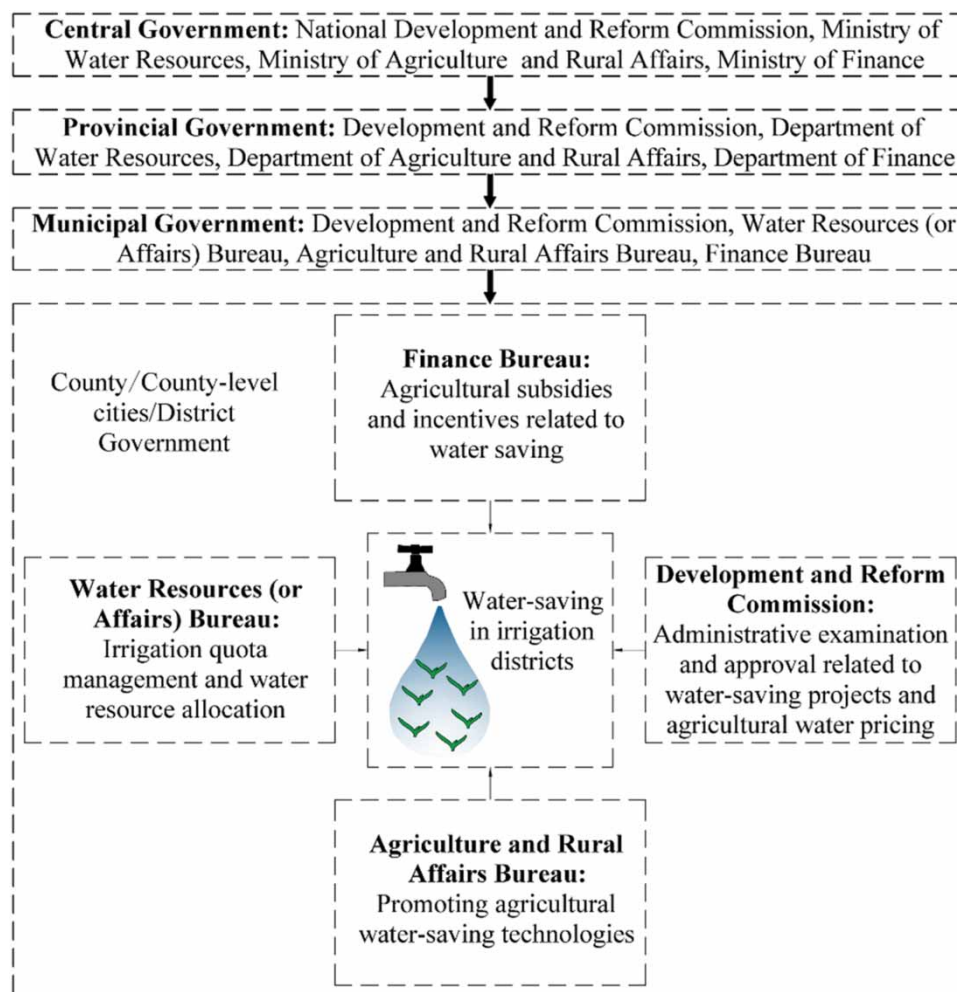


Figure 4 | Chinese government departments at all levels involved in agricultural water saving.

water-saving policies, plans, and standards formulated by Jiangsu government in the last 10 years to support the water-saving work of the central government. Through policy guidance, awards and subsidies, technical guidance, institutional constraints and information services, etc., farmers' enthusiasm for water saving has been aroused, and Jiangsu's agriculture is developing from a traditional model to a high-efficiency modern water-saving model.

Forming an effective water-saving assessment mechanism

The promotion of water-saving irrigation is led by Chinese governments at all levels, so it is necessary to evaluate the effectiveness of water-saving work by governments at all levels and their main leaders. In China, the effectiveness of water saving is usually assessed through the 'provincial governor responsibility system for grain security (PGRS-GS)' and the 'performance appraisal system for the strictest water resource management (PAS-SWRM)'. PGRS-GS evaluates grain supply-demand balance and the stability of grain prices in China. PAS-SWRM evaluates the sustainable development, utilization and conservation of China's water resources. The targets of the two assessments are provincial governments and their main leaders. Concerning these two systems, provincial-level governments adopt similar measures to assess their municipal governments and their chief officials, and municipal governments apply similar measures to their county-level governments.

The PGRS-GS and PAS-SWRM are assessed by the scoring method, and the full score is 100 points. The assessment results are divided into four grades: excellent, good, qualified, and unqualified. Those with scores above 90, 80–90, 60–80 and below 60 are considered excellent, good, qualified and unqualified, respectively. As shown in Figure 7, in PGRS-GS, the indicators directly related to water saving include 'Construction of well-facilitated farmland (4–5 points)', 'Construction of agricultural water conservancy facilities; Construction of major water-saving projects in agriculture (4–5 points)'. In PAS-SWRM, the

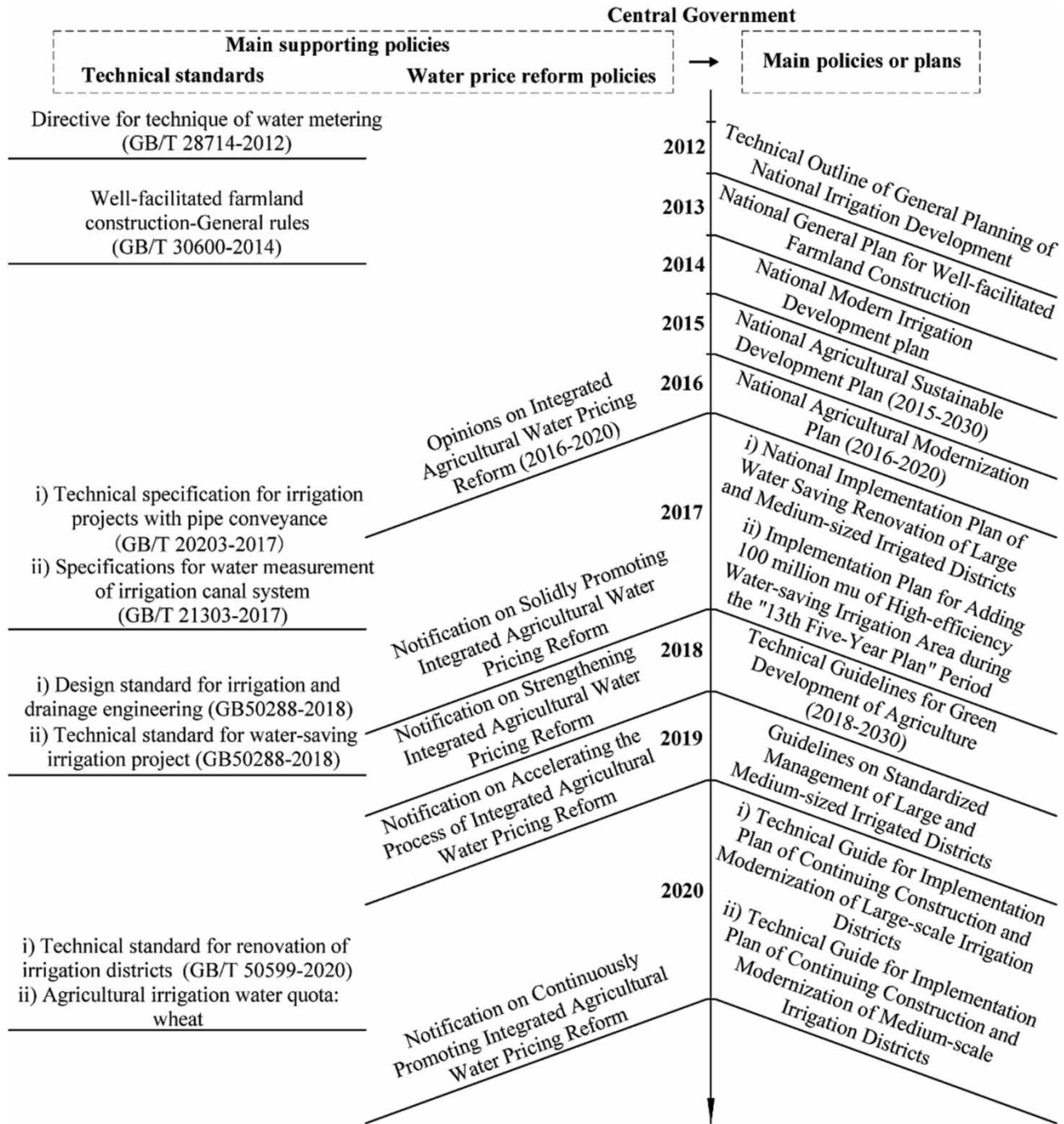


Figure 5 | Important policies related to agricultural water saving formulated by the central government.

indicators directly related to water saving include 'Total water consumption (ten points)', 'EUCAIW (3–4 points)', 'Water quota and planned water management (2 points)', 'Water pricing reform and water resource fee collection (2 points)', etc.

In order to meet the water-saving regulations in PGRS-GS and PAS-SWRM, the Jiangsu government was actively carrying out special assessment of the effectiveness of water-saving work in irrigation districts. The early assessment rules of water-saving irrigation in Jiangsu adopted the 'Jiangsu provincial evaluating standard for water-saving irrigation scheme (DB32/T 1368-2009)'. Central government promulgated the assessment standard for water-saving irrigation in 2021, based on which, the Jiangsu government was carrying out the formulation of a new 'Jiangsu assessment standard for the effectiveness of water-saving irrigation in irrigation districts' (Figure 8).

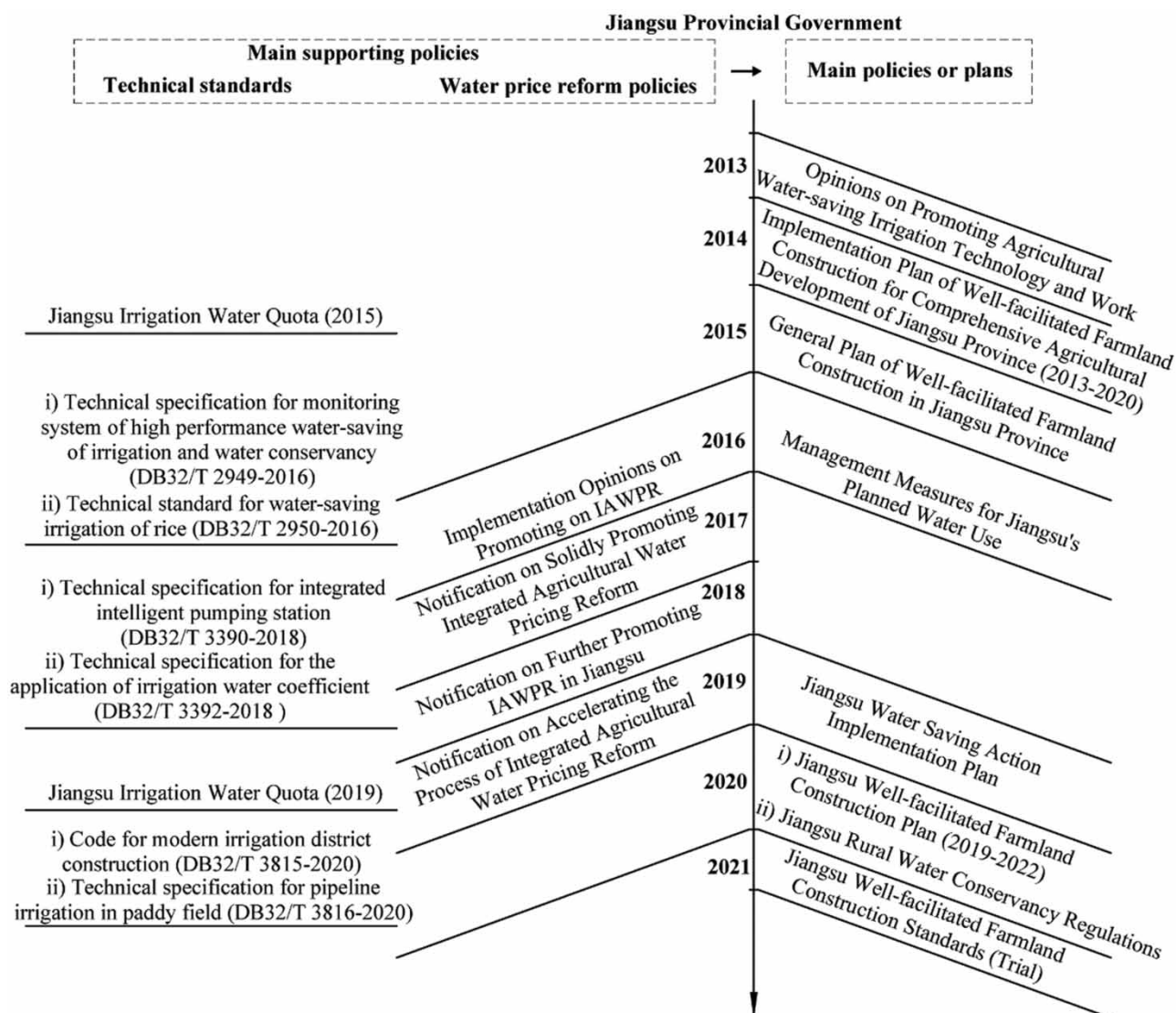


Figure 6 | Important policies related to agricultural water-saving formulated by Jiangsu government.

MAJOR AGRICULTURAL WATER-SAVING MEASURES IN JIANGSU

According to the aforementioned analysis, the low efficiency of irrigation water use is the main factor affecting water saving in Jiangsu. The adoption of water-saving irrigation measures (i.e. engineering, agronomic and management measures) in irrigated districts still needs further promotion to meet the requirements of national or local water saving policies and plans. Jiangsu has formulated a number of measures to promote agricultural water saving mainly by improving water use efficiency of irrigated crops and reducing the total amount of agricultural water use, and by improving the effectiveness of the irrigation system mainly by increasing O&M funds and O&M organizations, as shown in Table 2. The details of the main water-saving measures are described below.

Formulating irrigation quotas

Jiangsu government promulgated the 'Jiangsu Irrigation Water Quota (2015)' for the first time in 2015, which was used as the basis for irrigation water allocation in irrigation districts. In 2019, the irrigation quotas in Jiangsu were revised, and 'Jiangsu Irrigation Water Quota (2019)' was issued by the government. This revised version divides the whole area of Jiangsu into 15

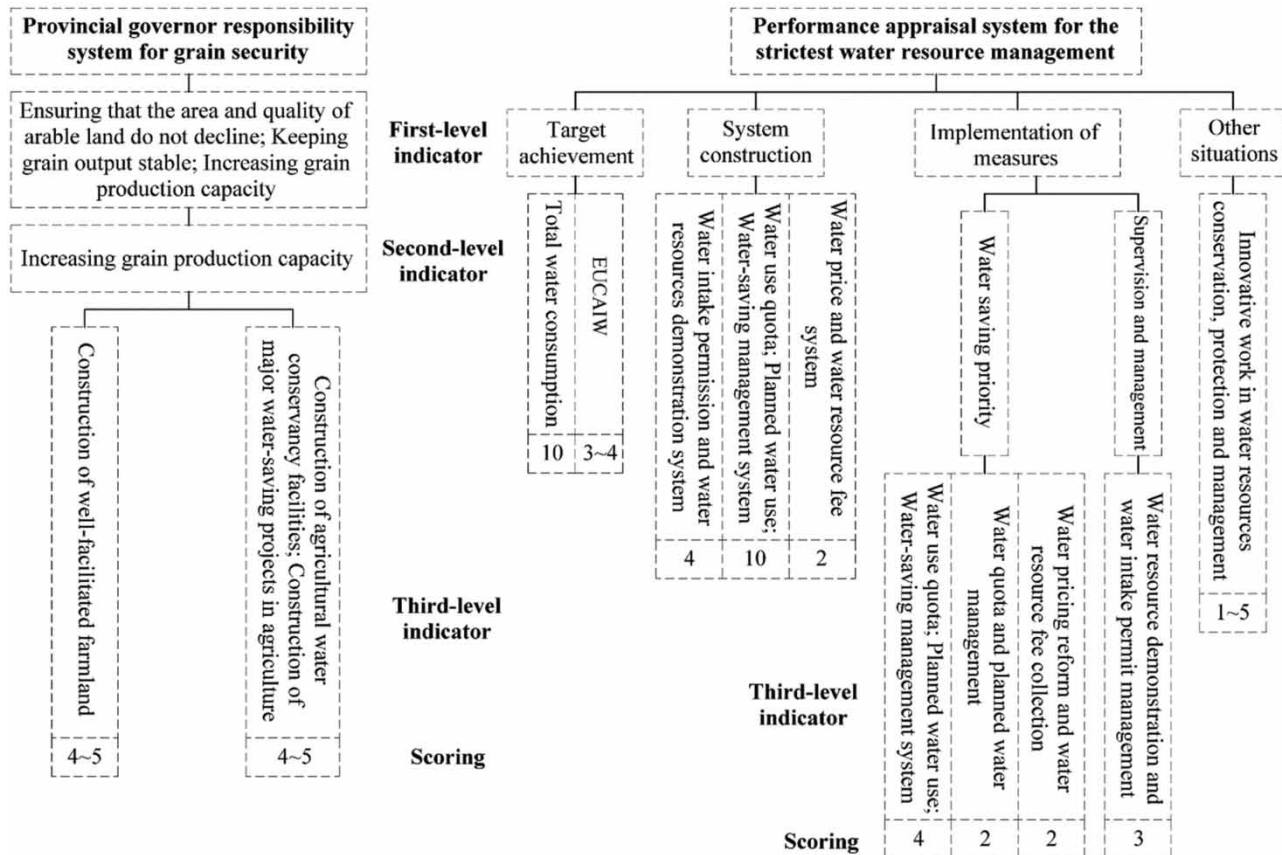


Figure 7 | Indicators most directly related to water-saving in PGRS-GS and PAS-SWRM.

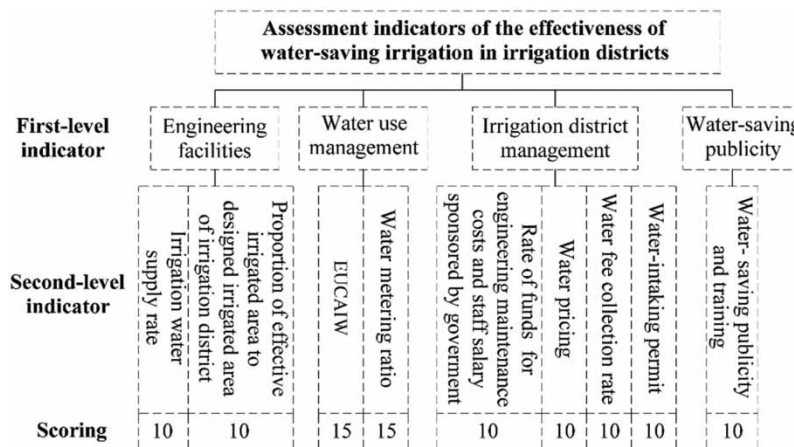
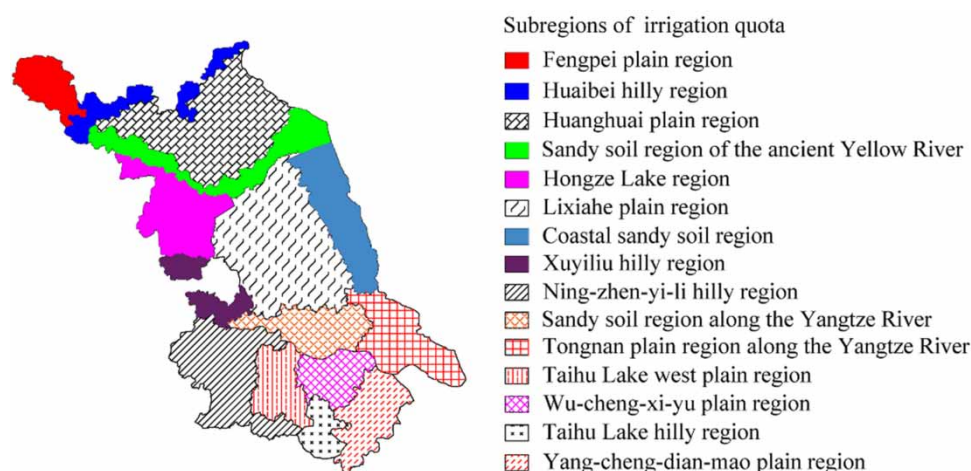


Figure 8 | Indicators of the effectiveness of water-saving irrigation in irrigation districts in Jiangsu.

subregions (i.e. Fengpei plain region, sandy soil region of the ancient Yellow River, coastal sandy soil region, Tongnan plain region along the Yangtze River, etc., shown in Figure 9) with detailed irrigation quotas for ten major crops (i.e. rice, corn, wheat, cotton, tomatoes, peppers, etc.). Figure 10 shows rice and maize quotas in some subdivisions.

Table 2 | Main water-saving measures formulated by Jiangsu government

Objectives	No.	Main supporting measures
Promoting agricultural water saving by improving water use efficiency of irrigated crops and reducing the total amount of agricultural water use	1	The 'Agricultural Irrigation Water Quota in Jiangsu in 2019' had been promulgated by Jiangsu government to guide water quota for irrigation districts based on crop types and geographic regions.
	2	Compare water consumption quota, reward for water saving, punishment for overuse.
	3	Jiangsu is exploring water trading rules with Suqian City as a pilot reform. In 2020, the Suqian government approved the 'Suqian City's Implementation Plan on Accelerating the Pilot Reform of Groundwater Rights Trading'.
	4	The Jiangsu government has used financial funds to carry out water-saving renovations in irrigation districts.
Promoting agricultural water saving by improving the effectiveness of the irrigation system mainly by increasing O&M funds and O&M organizations	1	Since 2016, according to different irrigated distinctes and crop types, agricultural water O&M cost accounting had been carried out in Jiangsu. The governments provide agricultural water at a cost between 0.080 and 0.171 yuan/m ³ in Jiangsu.
	2	At present, the irrigation districts of Jiangsu are equipped with a total of 137,235 sets of metrological facilities.
	3	The Jiangsu government has established 5675 non-governmental farmer-based organizations, and each organization has about 10–20 sub-organizations, which are mainly used for the O&M of the irrigation systems, the collection of water fees, etc.
	4	The Jiangsu government has established water fee collection rules that weigh the farmers' affordability and local financial resources, focusing on solving two problems, namely, the financing of agricultural water use subsidies and the financing of O&M of the irrigation systems.

**Figure 9** | Irrigation quota subregions in Jiangsu.

Water use supervision based on metering

Water metering is an important means to supervise the just allocation and use of irrigation water. Since 2014, Jiangsu had vigorously promoted the installation of metering facilities. By 2020, the province's irrigation districts were equipped with 137,235 metering facilities such as electromagnetic flowmeters, ultrasonic flowmeters, water-measuring structures (e.g. flumes, orifices, weirs), 'water volume – electricity consumption' conversion method (WECM) based on an electricity

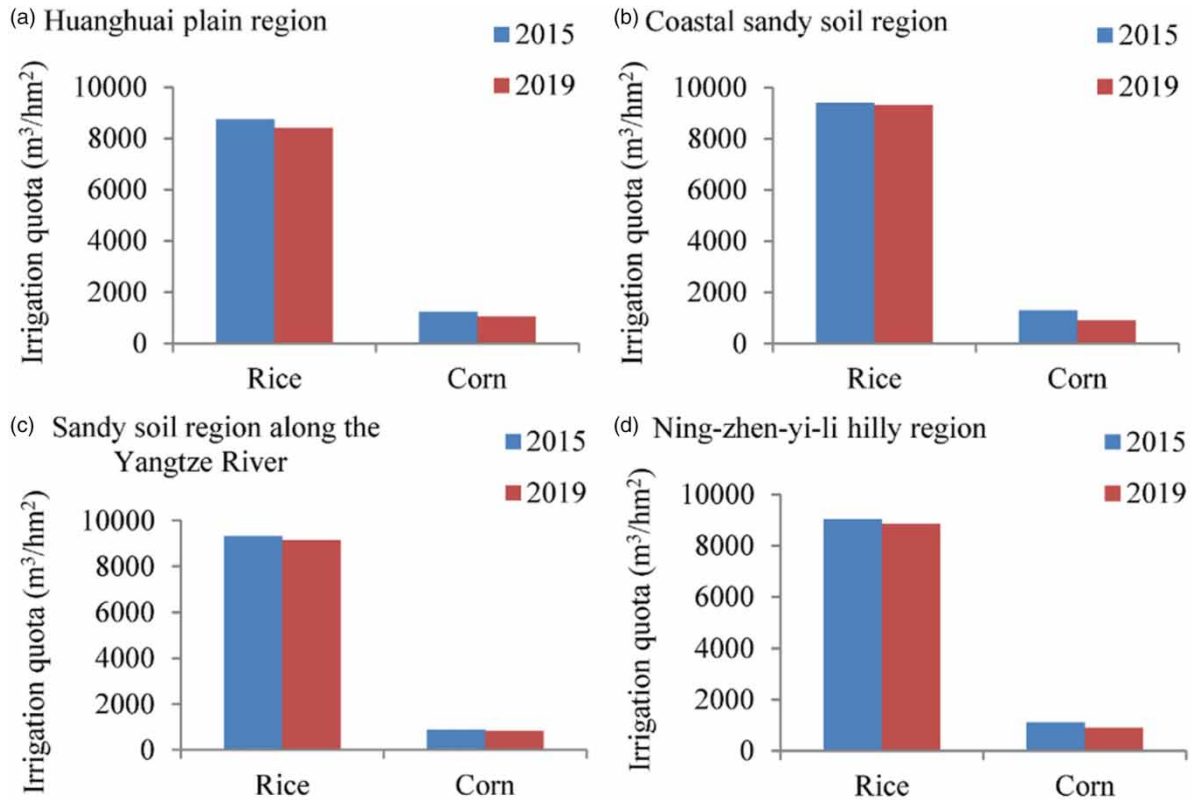


Figure 10 | Rice and maize quotas in some subdivisions.

meter, ‘water volume – time’ conversion method (WTCM) based on timers, etc. Among them, the WECM and WTCM are the most popular measurement methods for farmers because of their low costs, easy installation and use, accounting for 73% of the total, followed by electromagnetic and ultrasonic flowmeters, which account for 16%.

In the WECM, the water output of a pump can be deduced according to the ‘water volume – electricity consumption’ conversion coefficient (T_c) obtained by calibration. T_c is generally defined as the ratio of the total water output of a pump to the total electricity consumption in a period. The formula is as follows:

$$T_c = \frac{A_w}{A_E} \quad (2)$$

where A_w is the water output (m³); A_E is electricity consumption (kWh); T_c is the conversion coefficient (m³/kWh).

In the WTCM, the water output of a pump can be deduced according to the ‘water volume – time’ conversion coefficient (T_T) obtained by calibration. T_T is the ratio of the flow rate to time in a period. The formula is as follows:

$$T_T = \frac{A_w}{A_H \times Q_r} \quad (3)$$

where T_T is the conversion coefficient; A_H is time (h); Q_r is the rated flow rate of a water pump (m³/h).

The schematic diagram of WECM and WTCM is shown in Figure 11. A_w depends on the in-situ measurements (e.g. hydrological method, ultrasonic flowmeter, etc.). A_E is obtained through the electric meter and A_H through the timers in pump house. T_c and T_T are calculated by Equations (2) and (3), respectively. T_c and T_T were mainly affected by pump types (e.g. axial flow pumps, mixed flow pumps, and centrifugal pumps), installation parameters (e.g. discharge head, and motor power), service life, etc. (Liang & El-Kadri 2018).

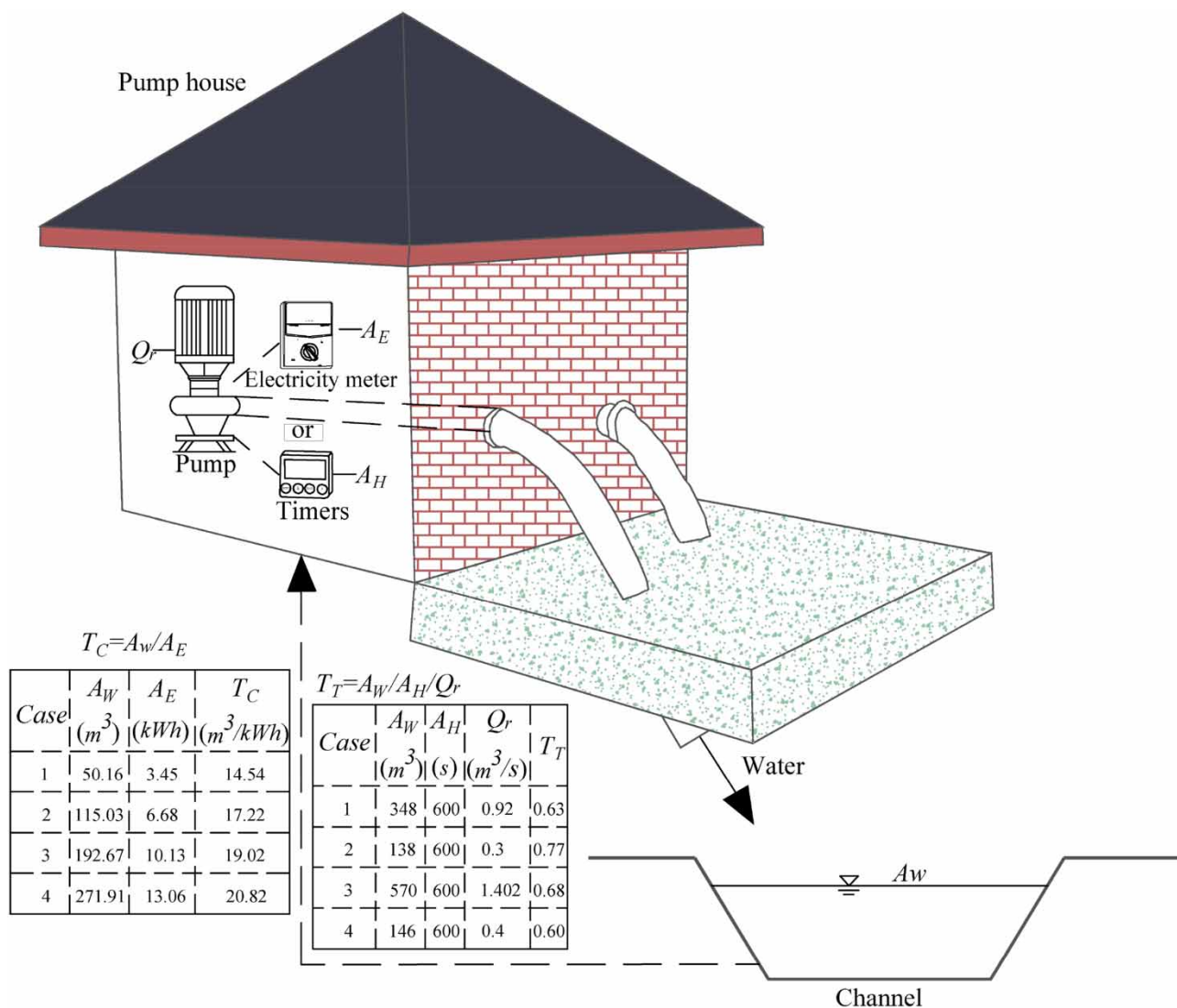


Figure 11 | Schematic diagram of WECM and WTCM.

Promoting water-saving irrigation

In the last five years, in order to guide the use of innovative water-saving technologies, Jiangsu government has issued ‘Technical specification for monitoring system of high performance water-saving of irrigation and water conservancy (DB32/T 2949-2016)’, ‘Technical specification for integrated intelligent pumping station (DB32/T 3390-2018)’, ‘Code for modern irrigation district construction (DB32/T 3815-2020)’, etc. At present, governments at all levels in Jiangsu are actively promoting a high-efficiency water-saving irrigation model, which is mainly based on pipe irrigation for grain crops, sprinkler irrigation for vegetables, and micro-irrigation for fruit trees and seedlings. By 2019, the area of irrigated arable land controlled by water-saving technologies is 2.848 million hectares, accounting for 67.8% of the irrigated arable land area in Jiangsu. It is expected to reach more than 95% by 2025.

Increasing agricultural water price

The water fee charged to farmers is low, only reaching about 30% of the operation and maintenance (O&M) costs (excluding depreciation) of irrigation systems. The idea that water is free or cheap is pervasive and deeply rooted within farmers. Therefore, farmers have no incentives to save water. In accordance with the unified deployment of Chinese central government, 22 provinces (including Jiangsu, Guangdong, Shandong, etc.), five autonomous regions (including Inner Mongolia, Xinjiang,

Tibet, etc.) and four municipalities directly under the central government (i.e. Beijing, Shanghai, Tianjin, Chongqing), began the agricultural water pricing reform within their respective jurisdictions in 2016. In December 2019, Jiangsu completed the basic tasks of the reform ahead of schedule. According to the O&M costs of irrigation systems in Jiangsu, the current agricultural water price in Jiangsu is 0.080–0.171 yuan/m³, of which over 35% is mainly borne by governments, so as not to increase the burden on farmers.

Establishing reward and penalty rules for agricultural water use

The 79 agriculture-related counties (districts or county-level cities) under the jurisdiction of Jiangsu provincial government have established water-saving incentive mechanisms and penalty mechanisms for excess water consumption exceeding the water quota. Taking the irrigation quota as the benchmark, the excess is punished and the saving is rewarded by local county government. This further improves farmers' awareness and enthusiasm of water saving. Taking Jiangning District of Nanjing City as an example, the water-saving rewards given by Jiangning government are divided into four levels. When the water-saving amount is less than 5, 5–10, 10–20, or more than 20% of the quota, the corresponding rewards will be the water-saving amount multiplied by 0.5, 1, 2, or 3 times normal water price (NWP), respectively. Conversely, penalties for excess water consumption are divided into three levels. When the excess water is less than 20, 20–30, or more than 30% of the quota, the excess water is charged at 1, 2, and 3 times NWP, respectively.

CONFLICTING INTEREST BETWEEN DIFFERENT PARTICIPANTS

As shown in Figure 12, agricultural water saving is a complex process, which needs to take into account the interests of all participants, and the effect of water saving is the result of multi-participant interest game. The following is a brief description of the conflicting interest between different participants.

- (i) Central government's funds (CGF) can effectively guide the agricultural water-saving work in various regions. At present, CGF are mainly allocated to major grain-producing, underdeveloped and poor regions. However, even for the developed regions, local government's burden caused by agricultural subsidies is heavy. Moreover, in China, the developed regions still have the responsibility of supporting the economic construction of the less developed regions. The mechanism of central government subsidies is worth further study.
- (ii) In 2019, the GDP of Jiangsu reached 9963.15 billion yuan, ranking second in the country, among which the GDP of the primary industry reached 429.63 billion yuan, only accounting for 4.31% of the total GDP. How to improve the enthusiasm of local governments in developed regions to promote agricultural production and agricultural water-saving work needs more clear reward and punishment measures from the central government.
- (iii) Farmers want lower water prices and better water services which mean more agricultural subsidies and more fiscal burdens for the governments. The governments should consult with water users, listen to their interests, reduce their resistance to the policies, and implement water relief to maintain social stability when the basic water demand of some water users cannot be met due to the impact of water-saving policies. This requires Chinese governments at all levels to actively carry out the analysis of the economic and social benefits of water-saving policies, and weigh the relationship between them.

CONCLUSIONS

Water is one of the most vital economic resources, and water scarcity will be an essential constraint to sustainable socio-economic development. By reviewing the agricultural water-saving policies and measures in recent years in China, especially in Jiangsu, we can draw the following conclusions:

1. China's central and local governments have worked closely together to promote China's agricultural water saving. The central government formulates key agricultural water-saving policies and measures, which are used to guide local governments to issue their detailed supporting policies and plans. Since the release of 'National Agricultural Water Saving Outline (2012–2020)' in 2012, China has vigorously promoted various water-saving work through updating water-saving mechanisms and policies. As a developed province, Jiangsu's annual agricultural irrigation water consumption accounts for more than 50% of its total water consumption. For this, Jiangsu has formulated various supporting water-saving policies and measures in agriculture in accordance with water-saving policies and measures of the central government.

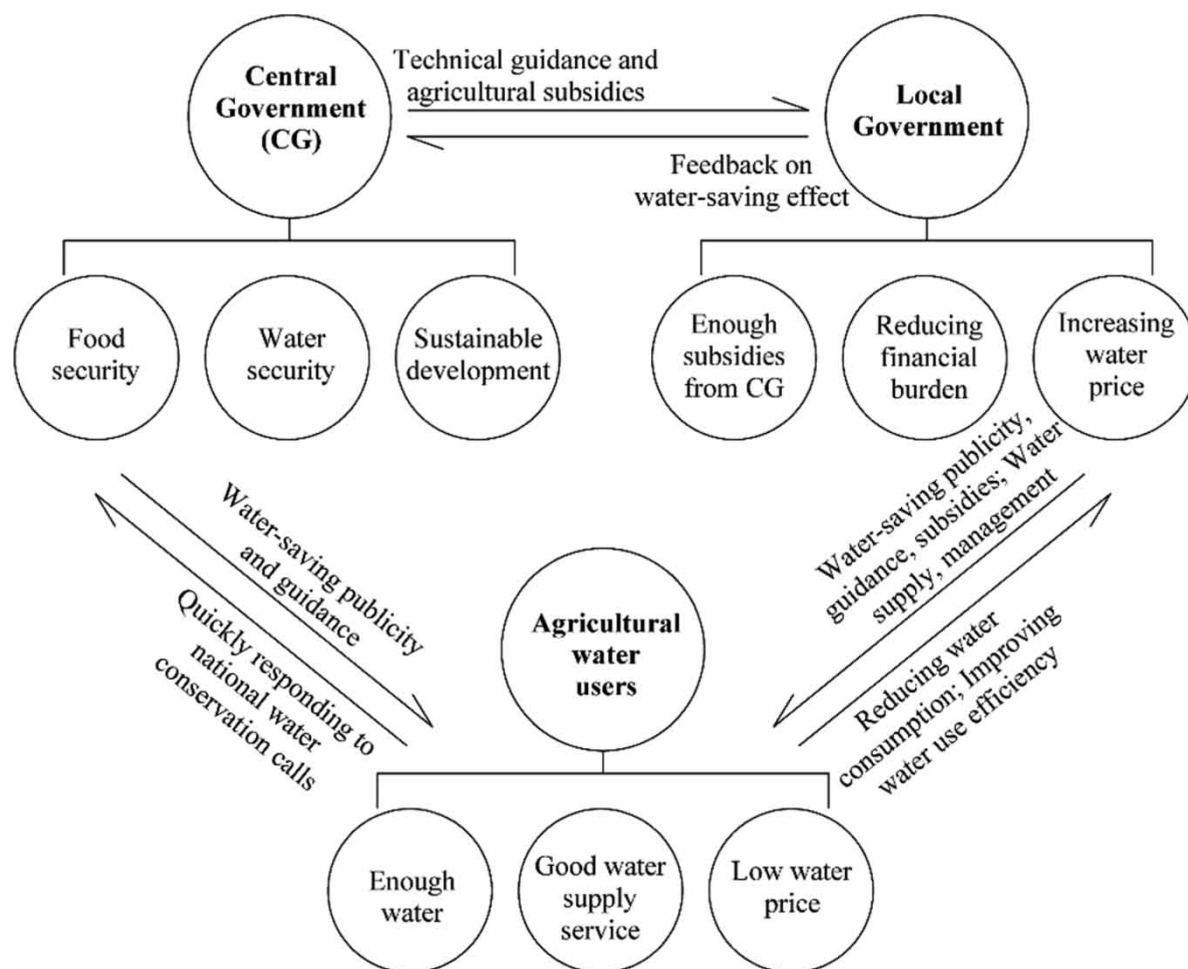


Figure 12 | Conflicting interest between different participants games in China.

2. The average EUCAIW in Jiangsu is 0.59 in irrigation districts (including large-, medium- and small-scale irrigation districts) in 2014, which is much lower than EUCAIW of 0.7–0.9 in developed countries. Jiangsu has great potential of water saving in agriculture. By carrying out water-saving work (i.e. formulating irrigation quotas, water use supervision based on metering, promoting water-saving irrigation, increasing agricultural water price, establishing reward and penalty rules for agricultural water use) in Jiangsu, its EUCAIW had increased to 0.614 and the agricultural water saved could meet the water demand of its tertiary industry in 2019. By 2025, the areas of irrigated arable land controlled by water-saving technologies are expected to reach more than 95% of the irrigated arable land area in Jiangsu.
3. There are still some conflicting interests between different participants in China's agricultural water-saving process. It is a complex process including the allocation of subsidies from the central government, the balance between farmers' interest demands and the heavy financial burden of local governments. All these problems need further in-depth study and discussion. It is also necessary to enhance public awareness of agricultural water saving, vigorously develop agricultural water-saving technologies, and formulate simple and easy water-saving policies to improve the implementation effect of policies. How to analyze the economic and social benefits of water-saving policies and reduce the contradiction of agricultural water use is worthy of further study.

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DATA AVAILABILITY STATEMENT

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

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