

## 'Overuse-charge' agricultural water price mechanism in groundwater overdraft areas

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### ABSTRACT

The irrigation water price is an indispensable element for the modernization of agriculture and the realization of rural revitalization. As a pilot initiative for agricultural water price reform, Hebei Province has explored various effective patterns. This study analyzed 714 first-hand data points obtained from agricultural irrigation areas in Hebei Province. The 'two lines and three grades' water price policy is difficult to implement in practice. The 'overuse-charge' includes two levels of water use standards, the water price and reward standards in each level are inconsistent, especially, actual irrigation water use is far more than Individual Allowable Water Volume (IAWV). Similarly, there is a negative relationship between irrigation water use and water fees at the critical point of IAWV, that is, the more water used, the less water fees are paid. The 'one line and two grades' water price policy is proposed. The water volume less than the irrigation quota should be purchased by the government or rewarded farmers; on the contrary, the water price should be increased. It is suggested to improve the installation of irrigation metering facilities, popularization of field water-saving technology and quota management in the groundwater water irrigation region.

**Key words:** China, Government's repurchase, Groundwater, Hebei Province, Individual Allowable Water Volume, Irrigation quota, Irrigation water price, 'Overuse-charge'

### HIGHLIGHTS

- The price of agricultural water is the primary means to coordinate ecological and economic use of water.
- Agricultural water price is an indispensable element for the modernization of agriculture.
- It is crucial for the government to repurchase the agricultural water which could recover groundwater level.
- Establishing an incentive mechanism can improve farmers' enthusiasm to transfer surplus water to the government.

### INTRODUCTION

Agriculture is the largest sector of water use. Reasonable price policies can reduce agricultural water use and transfer the water resources to non-agricultural. Agricultural water price reform is an important policy means to regulate irrigation water and agricultural production effectively. Water price reform has a significant positive impact on farmers' water-saving efforts, and increasing the price of water can reduce farmers' utilization of water resources (Jia & Kang, 2000; Schoengold & Sunding, 2006; Bar-Shira *et al.*, 2014; Vasileiou *et al.*, 2014). In 2004, China's agricultural tax relief, food subsidies, and agricultural water price adjustments faced great challenges (Wang *et al.*, 2016). Considerably low water prices make it difficult to improve the efficient use of irrigation water, and extremely high water prices exceed farmers' affordability (Dinar & Saleth, 2005). The water charge of most irrigation districts in northern China is 0.02–0.20 yuan per cubic meter. Although agricultural water

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prices have increased in varying degrees in recent years, the average current agricultural water price is less than 50% of the water supply cost (Li & Wang, 2016). This does not stimulate farmers to adopt water-saving technology and is not conducive to the effective development of water-saving agriculture. Raising agricultural water prices without affecting farmers' income is a common problem faced by many countries with low water prices (Hellegers & Perry, 2006). Increasing water prices may cause farmers to stop farming crops requiring high water use, which will lead to a change in planting structure and indirectly reduce the agricultural labor force. This will affect food security, social stability, and increase poverty rates (Aidam, 2015).

China's irrigation management system has been growing. Following attempts by the 'water users association' and the Individual Allowable Water Volume (IAWV) trading system, a comprehensive reform policy for agricultural water prices was conducted in 2014. This included improvements in water supply metering facilities, the establishment of an agricultural IAWV system, exploring and innovating terminal water management mode, establishing and improving an agricultural water price formation mechanism, and a water-saving incentive mechanism. The goal is to improve water use efficiency of farmers and reduce the total amount and intensity of agricultural water use (Liu *et al.*, 2018). Wang *et al.* (2007) studied the water price reform policy in the upper reaches of the Yellow River and found that the agricultural water price in the area has been increasing since the 1980s. However, it still does not play the role of price leverage, and the coexistence of water shortages and waste is widespread.

The process of the comprehensive reform of water prices is slow, particularly in groundwater irrigation areas. With global climate change, the groundwater crisis has been further exacerbated. For example, in southern Chile, parts of Brazil, central United States, the Mediterranean and China, the groundwater volume decreases annually (Reinecke *et al.* 2021). According to the latest data from the Sri Lanka Meteorological Bureau, the temperature rises by 0.2 °C every decade. The increase in continuous drought days and over-exploitation of groundwater leads to increasingly serious water resource shortages (Wickramasinghe *et al.*, 2021). India's groundwater over-exploitation is assumed to have contributed significantly to the recent sea level rise (Konikow, 2011). In the face of the increasingly serious groundwater crisis, the international community follows the 'Groundwater Policy Action Framework' formulating groundwater management policies. In order to stop the excessive exploitation of groundwater, Spain strictly implements the well exploitation registration system (Llamas & Martínez-Cortina 2009). The African region has developed a legal system for groundwater exploitation with environmental protection as the main principle (Knueppe & Pahl-Wostl, 2011). In England, the order of groundwater usage is drinking water, environmental water, and irrigation water (Mechlem, 2013). The main model of groundwater management policy in South Asia is self-governance (Van der & Lipponen, 2010). India collects rainwater during monsoons to supplement groundwater, alleviating groundwater over-exploitation and groundwater salinization (Shah, 2007). Groundwater over-exploitation in China is serious, mainly concentrated in North China, such as the North China Plain (Giordano & Villholth, 2007). Hebei province is located in the North China Plain, east of the Bohai Sea, and surrounds the inner ring of Beijing and Tianjin. It is critical to China's economic development from east to west and an important grain and cotton-producing area. Water resources in Hebei province are extremely scarce. The ratio of grain output to water resources is unbalanced. In 2019, the per capita water resources of Hebei province was 149.9 cubic meters – only 7.2% of national per capita water resources.

Hebei province has explored different ways to control groundwater overdraft for many years as a pilot project of comprehensive groundwater management in China (Lili *et al.*, 2020). The current model of 'overuse-charge' agricultural water price policy is represented in Cheng'an county, Handan city. This study analyzed first-hand 714 data points obtained from agricultural irrigation areas in Hebei province. The content includes implementation status, challenges, and improvement suggestions for the agricultural water price reform policy.

## THE CONNOTATION OF 'OVERUSE-CHARGE'

In recent years, China's groundwater resources have gradually decreased. From 2001 to 2016, the total amount of groundwater resources averaged 799.4 billion cubic meters, which may be reduced by 2% compared with the earlier period (Chen *et al.*, 2020). The situation in Hebei Province is particularly serious. It has become the largest groundwater funnel area in China, causing several geological and environmental disasters such as land subsidence and wetland shrinkage. Hebei Province is one of the provinces with critical groundwater overdraft. According to statistics, China's total water amount was 2,746.25 billion cubic meters in 2018, of which groundwater accounted for more than 30%. China's water use was 601.55 billion cubic meters in 2018, of which 61.4% was taken up by the agricultural sector. However, the irrigation water efficiency of Hebei province is low, and the irrigation water utilization coefficient is 0.5–0.7 (Wang & Sun, 2018). Therefore, comprehensive agricultural water saving and reduction of total water amount are important measures to curb groundwater over-exploitation.

The comprehensive reform of agricultural water prices is widely used to reduce the consequences of groundwater overdraft and reduce agricultural water use. The 'overuse-charge' is a significant component of comprehensive agricultural water price reform according to the differences in water resources endowment, irrigation conditions, economic development levels, planting, and breeding structures in different regions. The 'Individual Allowable Water Volume (IAWV)' and 'Agricultural Irrigation Water Quota (AIWQ)' are adopted as the division standard. The IAWV referred to in this paper is different from the right to use water expressed in water law. It refers to the distribution amount of water obtained by farmers. That is, the total agricultural water available in an area is divided by the total cultivated land area to obtain the distributable water per unit of cultivated land area. The product of the unit of cultivated land area and the total cultivated land area of the farmer is the farmer's water right. AIWQ refers to the irrigation water use per unit area of a crop approved for the specified area and specified hydrological year in a growth period (DB13T1161-2016).

The IAWV transaction form of the policy is mainly government repurchase, which is the transaction between farmers and the government. When the actual irrigation water volume of a farmer is lower than the IAWV, the surplus water use of the farmer is purchased by the government, and the purchased water volume is retained in the groundwater aquifer of the well irrigation area, which is equivalent to the water that has not been pumped out. The AIWU is the Actual Irrigation Water Use. It is obtained directly from metering facilities or indirectly according to the calculation method of 'water converted to electricity' (Wang & Sun, 2018). Most farmers pay water fees and replace water fees with electricity fees.

The policy implies that water within the limit of the IAWV is charged according to the current agricultural water prices. If the water usage is lower than the IAWV limit, the IAWV transaction is encouraged, and the transaction price is 0.2 yuan per cubic meters. The irrigation water use exceeding the water use quota is increased by more than 20% based on the current agricultural water price, and the average current water price is 0.5 yuan per cubic meters. It is approximately 0.6 yuan per cubic meters above the rated water price.

To encourage farmers to save water, we should turn water saving into farmers' income. The amount of IAWV confirmation in Hebei province is the amount of conventional water resources that can be used sustainably in the county – the distributable water amount. This includes the average annual exploitable quantity of shallow groundwater, the inflow from other regions, and the distribution of the Middle Route Project of the South to North Water Diversion. The distributable water volume in the county should not be higher than the 'three red lines' control index determined by the strictest water resources management system. The distributable water volume per unit of cultivated land is evenly distributed according to the agricultural distributable water volume in the county.

The formula is expressed as follows:

$$IAWV = (TAWV/TCLA) \times ICLA$$

where IAWV is the Individual Allowable Water Volume ( $m^3$ ); TAWV is the Total Allowable Water Volume ( $m^3$ ); TCLA is the Total Cultivated Land Area (ha); ICLA is the Individual Cultivated Land Area (ha). The ‘individual’ in this study refers to small peasant households under China’s national conditions.

The specific implementation of ‘overuse-charge’ agricultural water price policy is as follows. When the water use of farmers is within the IAWV, the water users can save the surplus water (the difference between the IAWV quota and water use) for the following year’s use or IAWV transaction, and no reward will be provided. If the water use is above the IAWV quota and within the irrigation quota, the surplus water (the difference between the irrigation quota and the AIWU) will be rewarded. For every cubic meter of water saved, grain water users get rewarded by twice the price increase. For each cubic meter of water saved, other water users are rewarded according to the amount of price increase. The reward standard for water saving by grain water users is generally higher than that for other water users. The above can be summarized as ‘two lines and three grades’ of the water charge collection mode. The core of ‘overuse-charge’ is that the IAWV can be traded without price increases, and the price increase exceeds the quota (Figure 1). The water use is divided into three grades; each grade adopts different water prices, and the water-saving reward within each quota is different. The division of policy content is extremely complex, which makes it difficult for farmers to understand.

The water users association, a cooperative organization of county, township, and village water users (water managers or contractors), is the main body that collects water fees in the ‘overuse-charge’ agricultural water price reform mode. Using unified bills, the premium section is handed to the county agricultural water cooperation organization and included in the water-saving reward and subsidy fund. There are two variations of water charge collection: one is the installation of intelligent metering and charging by card, and the other is to convert electricity into water, which is collected by farmers’ water use cooperative organizations, well managers, or electricians. Similarly, the distribution of bonuses and subsidy funds can be divided into two categories. One is for those who have installed intelligent metering facilities, and the bonus and subsidy funds are directly transferred from the bank into individual accounts. The other is for those who calculate the water use by converting electricity into water, and they are sent to the well management or the water user association and the water-saving households. The collection of

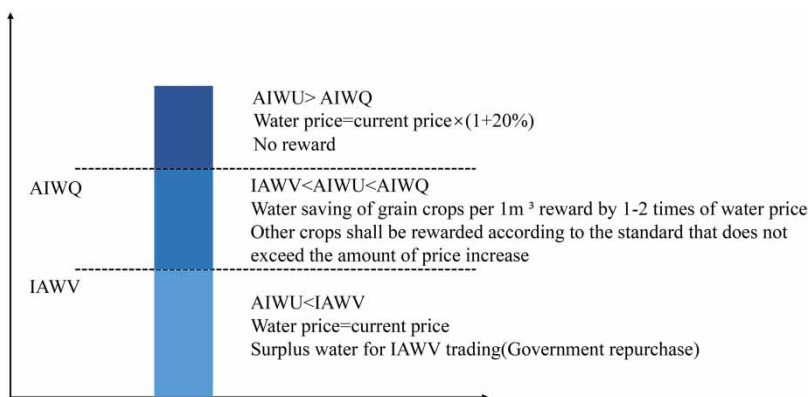


Fig. 1. | The accurate reward mode of ‘two lines and three grades’.

water charges and the distribution of bonuses and subsidy funds are supervised throughout the process, with public standards, signatures, and accounts (Figure 2).

## THE IMPLEMENTATION STATUS OF 'OVERUSE-CHARGE' POLICY

### The descriptive analysis of survey area

To evaluate the implementation of the 'overuse-charge' policy, the data were obtained through a questionnaire survey. The research areas included Cheng'an county of Handan city, Yuanshi county of Shijiazhuang city, Nanpi county, Xian county, and Haixing county of Cangzhou city. A total of 714 questionnaires were obtained using a random stratified sampling. The planting proportion of grain crops in the sample area was 0.907. The proportion of low water-use crops was low and mainly involved high water-use crops such as wheat and corn. The yield of wheat and corn accounts for more than 90% of the total yield of grain crops in Hebei province. Wheat is the most important overwintering crop in Hebei province. It is usually sown in autumn and harvested in June. Corn is the most important summer crop, mostly with wheat rotation, generally sown in June and harvested in October. A few farmers plant two seasons of corn, including spring corn and autumn corn. The research contents of this study include farmers' personal characteristics, family planting and management characteristics, water resources utilization, farmers' personal cognition, agricultural water price reform, social capital, and so on. According to the characteristics of the sample farmers (Table 1), the current farmers engaged in grain planting are generally older. The proportion of farmers under 35 years old was only 2.2%, while that of farmers over 66 years old was 30%. In addition, the education level of the sample farmers was generally low, and 74% of the farmers had an education level of junior middle school or below. In the survey area, small-scale planting was the main type. The proportion of farmers with a planting area less than 0.67 ha was 72.1%, while that of farmers with a planting area of more than 0.67 ha was only 27.9%. The proportion of land blocks less than 3 was 59.7%, 4–6 was 30.4%, and more than 6 was 9.9%. The aforementioned data reveal that the problem of land fragmentation is critical. From the perspective of planting structure, wheat and corn are the most important crops in the study area, with 94.6 and 98.2% of farmers, respectively. A certain number of farmers planted fruit trees, cotton, soybeans, capsicum, peanuts, and other economic crops. There were regional differences in all the aspects.

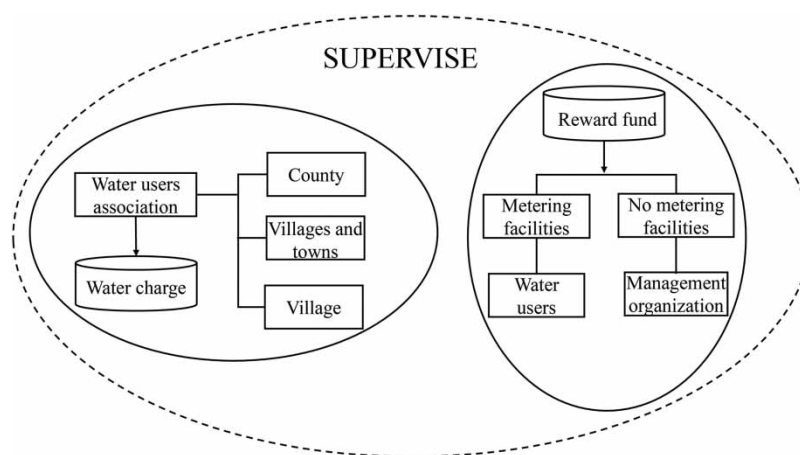


Fig. 2. | The process of water charge collection of 'overuse-charge' policy.

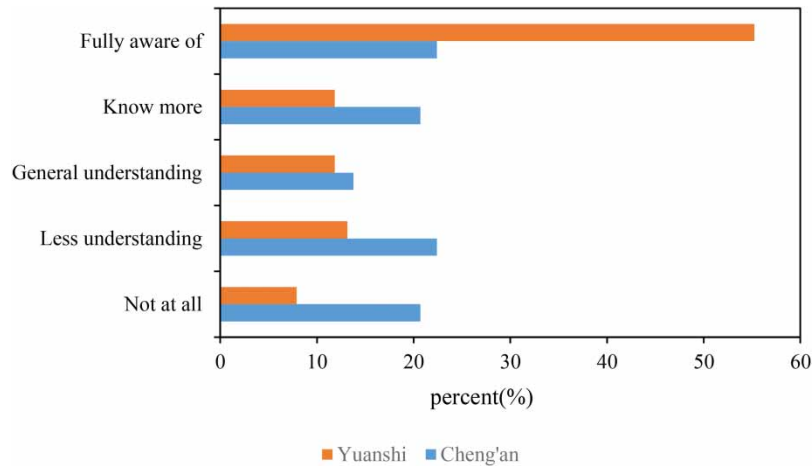
**Table 1.** | Farmers and production characteristics in survey area.

Variables	Options	Regions				
		Nanpi (%)	Xian (%)	Haixing (%)	Cheng'an (%)	Yuanshi (%)
Gender	Male	83.3	91.8	89.1	81.2	95.5
	Female	16.7	8.2	10.9	18.8	4.5
Age (years old)	24–35	3.6	3.5	1.7	0.5	1.8
	36–45	10.8	4.7	9.2	11.4	3.6
	46–55	27.5	27.1	23.5	24.8	23.4
	56–65	27.5	34.1	38.7	35.6	35.1
	>66	30.6	30.6	26.9	27.7	36.1
Education	<Primary school	12.2	4.7	6.7	8.9	2.7
	Primary school	28.8	18.8	11.8	24.2	10.8
	Junior high school	39.2	54.1	54.6	43.6	41.4
	Senior high school	17.5	20.0	26.1	22.8	44.2
	>= Junior college	2.3	2.4	0.8	0.5	0.9
Family population (people)	<2	29.3	33.0	50.4	26.7	32.4
	3–5	42.8	37.6	33.6	35.6	36.9
	>6	27.9	29.4	16.0	37.7	30.7
Area of cultivated land (ha)	<0.20	6.7	7.0	9.2	7.9	6.3
	0.20–0.46	31.1	35.3	46.2	33.2	41.4
	0.46–0.67	33.8	16.5	26.1	30.2	27.0
	>0.67	28.4	41.2	18.5	28.7	25.3
Number of land blocks	1–3	55.9	47.1	35.3	74.8	75.7
	4–6	36.9	27.1	41.2	22.8	22.5
	>6	7.2	25.8	23.5	2.4	1.8
Planting structure	Wheat	97.8	98.8	78.2	96.4	99.1
	Corn	97.8	98.8	100	97.1	99.1
	Fruit tree	3.6	0	0	0	0
	Cotton	1.8	2.3	0	21.6	0
	Soybean	0	0	4.2	0	0
	Hot pepper	0	0	0	12.2	0
Peanut	0	0	0	0	4.5	

## Farmers' cognition

### (1) The 'overuse-charge' policy is not widely promoted

Among the five counties surveyed, only Cheng'an county and Yuanshi county have implemented 'overuse-charge' agricultural water price mechanisms, while the other three counties (Haixing county, Nanpi county, and Xian county) have not. Among the 714 households in the survey, 112 households have implemented overuse price increases, including 42 households in Cheng'an county and 70 households in Yuanshi county, accounting for 15.69% of the total survey. In Yuanshi county, 55.26% of the surveyed farmers fully understood the overuse and price increase, while 22.41% fully understood the overuse and price increase in Cheng'an county. In addition, 20.70% of the farmers in Cheng'an county did not know about the price increase, while only 7.89% of the farmers in Yuanshi county were unaware. This shows that most of the farmers in the areas where the price increase has been implemented know more about the policy. However, few farmers understand the policy. Therefore, it is necessary to further publicize the policy in rural areas (Figure 3).



**Fig. 3.** | The farmers' understanding of the 'overuse-charge' agricultural water price mechanism.

## (2) Farmers' cognition of IAWV

In the questionnaire, the related questions of IAWV included whether the farmers received the IAWV certificate, whether they knew their allocation amount, and whether they had conducted IAWV transactions. According to the survey data, most farmers have obtained the IAWV license, but most farmers do not know the amount of IAWV allocation, even when the amount is clearly written on the IAWV license. The situation of Yuanshi county is better than that of Cheng'an county. Some farmers in Cheng'an county engage in water trading, but those in Yuanshi county do not (Table 2).

The above analysis shows that the proportion of farmers who have conducted IAWV trading is low, and that the impact of the IAWV trading policy is not significant. This is because the price of IAWV trading is relatively

**Table 2.** | Farmers' cognition of IAWV.

Regions	Questions	Options	Samples	Proportion (%)
Cheng'an	Whether the farmers receive the IAWV license	No	86	42.79
		Yes	104	51.74
		Yes, I know.	11	5.47
		But I do not get one		
	Whether the farmers know their allocation amount	No	138	86.79
		Yes	21	13.21
Whether they have conducted IAWV transactions	Yes	6	5.71	
	No	99	94.29	
Yuanshi	Whether the farmers receive the IAWV license	No	21	19.27
		Yes	60	55.05
		Yes, I know.	28	25.69
		But I do not get one		
	Whether the farmers know their allocation amount	No	48	46.15
		Yes	56	53.85
Whether they have conducted IAWV transactions	Yes	-	-	
	No	104	100	

low, and the incentive for farmers to trade in the IAWV market is insufficient. The irrigation water use of crops is high, and situations in which the water use is lower than the IAWV do not occur. Farmers do not consume surplus water for water trading.

According to the survey data, the proportion of farmers in IAWV trading is low. There are two reasons for this: on the one hand, the price of IAWV trading is relatively low, and the incentive for farmers to trade in the water trading market is insufficient; on the other hand, the existing IAWV is extremely low; therefore, in practice IAWV trading is unlikely to be conducted. It is rare that the irrigation water use of farmers is lower than that of the IAWV, and farmers seldom have surplus water to trade the IAWV. According to the irrigation quota management model proposed in this study, the amount of water less than the AIWQ can be applied to government repurchases.

### (3) Farmers' cognition of irrigation quota

The survey of Cheng'an county and Yuanshi county shows that farmers' understanding of the irrigation quota is relatively low. Among them, 93.33% of the farmers in Cheng'an county and 73.47% in Yuanshi county were not aware of the irrigation quota. In addition, among the farmers who were aware that they were entitled to a water quota as mentioned in the questionnaire, the proportion of farmers who knew their specific water quota was almost zero. This result reflects that, although the irrigation quota is determined, farmers are not aware of it. If the farmers' cognition of the irrigation quota is not clear, the limiting effect of the water quota on farmers' irrigation water use will not be obvious.

Comparing different survey areas, Yuanshi county has the highest installation rate of metering facilities and adoption rates of water-saving technology, which are 31.2 and 53.1%, respectively. Farmers in this area have higher cognition of water prices than other areas, and the actual irrigation water use is lower than that in other areas. Farmers in Yuanshi county think that owing to the water prices, 60.3% less water will be used, the water saving being higher than 47.9%, which is the water saving in the survey area. The actual irrigation water use of wheat in Yuanshi county is 2,828.25 m<sup>3</sup>/ha, lower than the average value of 3,315.15 m<sup>3</sup>/ha in the survey area. This indicates that agricultural water price reform must be comprehensive and accompanied by metering facilities and water-saving technology.

According to the above data, the agricultural water price reform in Yuanshi County has been completed better. The cognition of irrigation quota in Yuanshi County is 20% higher than that in Cheng'an county. The reason is that the installation proportion of irrigation metering facilities and the adoption rate of water-saving technology in Yuanshi County are higher than those in other areas. The actual irrigation water consumption in Yuanshi County is closest to the agricultural irrigation quota standard. The survey data show that most of the farmers in Cheng'an county and Yuanshi county think that they use less irrigation water than the quota. But this is not in line with the actual situation, indicating that farmers do not have a clear understanding of the irrigation quota.

According to the actual survey data, most farmers do not know their actual irrigation water amount and irrigation quotas. Only 26.5% of Yuanshi County in the demonstration area of water price reform know their actual irrigation water use and irrigation quotas (Table 3). The main reason for this is the lack of metering facilities. Because of the aforementioned reasons, the agricultural water price reform in groundwater irrigation areas should not only include the reform of water prices, but comprehensive reform including the installation of metering facilities. To summarize, the measurement of IAWV is more difficult than that of the irrigation quota. There were no differences in the division of IAWV. It is obviously wrong not to distinguish whether water-saving facilities are used, regardless of the soil moisture content, whether food crops or cash crops. The determination of IAWV may be based on rainfall in a certain year. It is unreasonable to regulate farmers' by the amount of water owned by the region, and it is not conducive to farmers' water savings. The irrigation quota can be



**Table 3.** | Farmers' cognition of the agricultural irrigation water quotas.

Regions	Questions	Options	Samples	Proportion (%)
Cheng'an	Is there excessive irrigation?	Never	89	57.79
		Occasionally	33	21.43
		Sometimes	16	10.39
		Often	12	7.79
		Frequently	4	2.60
Yuanshi	Is there excessive irrigation?	Never	76	80.85
		Occasionally	9	9.57
		Sometimes	1	1.06
		Often	4	4.26
		Frequently	4	4.26

accurately set. The significance of irrigation quota management is reflected, which overcomes the difficulty of realizing IAWV in reality.

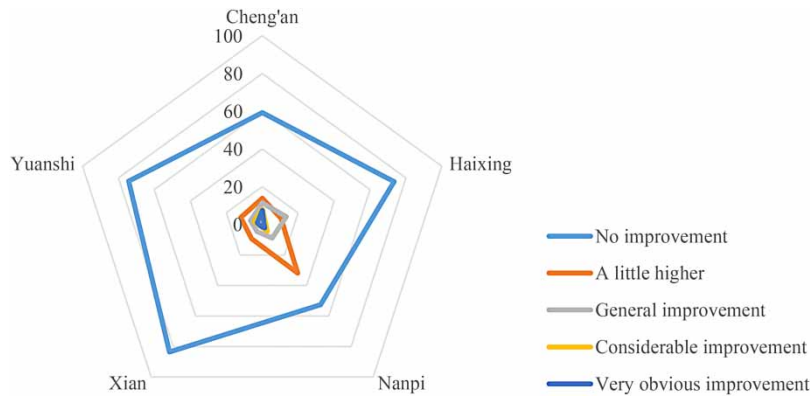
### The challenges in the implementation of 'overuse-charge' policy

#### (1) Low increase in water price and less water savings

The water price of the 'overuse price increase' policy is formulated in stages according to the difference in water use, which makes it difficult for farmers to understand and implement. If the water use is within the IAWV quota, the current agricultural water price shall be applied at 0.5 yuan per cubic meters. At the second stage, when the water use exceeds the IAWV, the water use exceeding the quota will be increased by 20% based on the current agricultural water price – 0.1 yuan per cubic meter. According to the existing research results, the water price (0.1 yuan per cubic meter) increase is insufficient to encourage water saving. In short, the rising range of the water price is small, and the probability of farmers' irrigation behavior change is low.

According to our research, most farmers think that the water price has not increased. In the sample, 65.10% of the farmers thought that the water price had not increased, of which Xianxian county accounted for 83.53%, and Nanpi county accounted for the smallest (52.51%). Conversely, 8.25% of the total sample think that the water price has increased significantly – farmers' perception of the water price increase is relatively low. Most farmers believed that water prices have not increased or have increased only slightly in the past 5 years. According to the relevant principles of the planning behavior theory, the water price increase has been so low that farmers cannot perceive it.

Following the implementation of the 'overuse-charge', there were 25.00 and 53.33% farmers in Cheng'an and Yuanshi, respectively, who believed that the cost of water charges decreased. The proportion of farmers with unchanged water expenditure was 34.42% in Cheng'an county and 38.67% in Yuanshi county. The feedback result is that after the implementation of the policy, the proportion of farmers whose water costs increased is 40.38% in Cheng'an county and 8.00% in Yuanshi county. Notably, the policy itself has little impact on farmers' water expenditure, especially after the implementation of the policy in Yuanshi county, where the proportion of farmers with increased water expenditure is less than 10%. As far as water cost is concerned, the proportion of farmers with rising water costs is small. Therefore, the incentive for farmers to be willing to change their irrigation behavior may be insufficient, which reflects the weak water-saving efforts with the increase in water price policy (Figure 4).



**Fig. 4.** | The farmers' perception of the water price improvement.

(2) The rewards are complex and difficult to implement.

The reward standard of the 'overuse-charge' policy is complex. Only the surplus water (the difference between the irrigation quota and water use) of those whose water use is above the IAWV and less than the irrigation quota will be rewarded, and no reward will be given in other cases. For every cubic meter of water saved, grain water users can be rewarded twice the price increase. For each cubic meter of water saved, other water users can be rewarded according to the amount of the price increase. The reward standard for water saving by grain water users is generally higher than that for other water users.

The water use of farmers was divided into different parts. A is the water use within the IAWV. B is the part where the water use of farmers exceeds the IAWV but is lower than the irrigation quota. C is the difference between the water use quota and the water use of farmers.  $C = \text{water use quota} - B - A$ . D is the part of the actual water use higher than the irrigation quota. Farmers' water charges and rewards are shown in the table below (taking the current water price of 0.5 yuan per cubic meters as an example) (Table 4).

The 'overuse-charge' policy is divided into three levels of water use standards, and the water price standards and reward standards in each stage are inconsistent, which makes it difficult to implement and understand in practice.

Given the fact that the current irrigation water volume is rarely lower than that of the given IAWV, the grading design is conducted based on the quota. The specific content is as follows: a reward will be given if it is lower than the quota, trade will be conducted if it is lower than the quota, and the price will increase if it is higher than the quota. We summarize it as 'one line and two gears' mode (Figure 5). The advantage is that the government can

**Table 4.** | The reward model of the 'overuse-charge' policy.

	Irrigation water use	Total water expenditure	Reward or not	Reward amount
Stage 1	$AIWU < IAWV$	$0.5 \times A$	No	—
Stage 2	$IAWV < AIWU < AIWQ$	$0.5 \times A + 0.6 \times B$	Yes	Grain crops $0.2 \times C$ Non-grain crops $0.1 \times C$
Stage 3	$AIWU > AIWQ$	$0.5 \times A + 0.6 \times B$	No	—

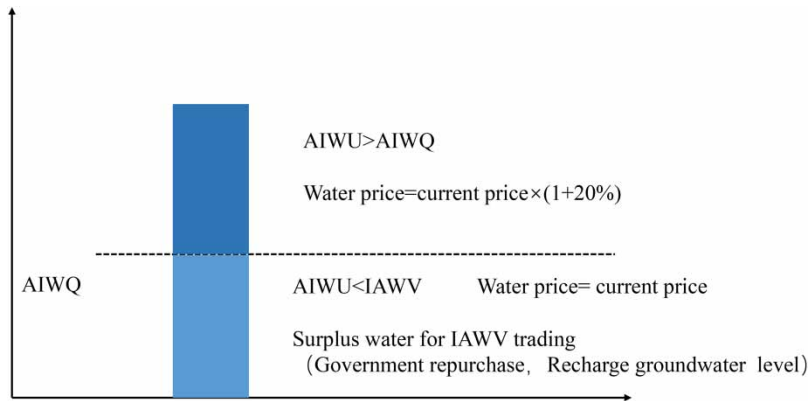


Fig. 5. | The irrigation quota management mode.

reduce the expenditure on water-saving rewards, and the price increase measures make farmers more aware of the increase in water price to increase their motivation for water saving.

(3) Conflict between water saving and water charges

After the reform of the ‘overuse-charge’, the functional form between the actual water fee  $f(x)$  paid by users and the actual irrigation water use of farmers is as follows:

$$f(x) = [ax - 0.2(b - x)]I_{(0,a]}(x) + [a \times b + (1 + n)(x - b) - m \times (c - x)]I_{(b,c]}(x) + [a \times b + (1 + n)(x - a)]I_{(b,\infty)}(x)$$

where  $x$  is the actual irrigation water use (cubic meters per ha),  $a$  is the water price within the IAWV (yuan per cubic meters),  $b$  is the IAWV (cubic meters per ha),  $n$  is the increase rate (%) after the water use exceeds the IAWV,  $m$  is the reward standard (yuan per cubic meters per-ha) when the actual water use is above the IAWV and below the water quota,  $c$  is the irrigation quota (cubic meters per ha), and  $I$  is the transaction price of the IAWV.

According to the IAWV, irrigation quota, and irrigation water price stipulated in the study area, the above formula can calculate the corresponding water charge under different irrigation water quantities. Taking Haixing county as an example, the IAWV is 1,695 cubic meters per ha, and the irrigation quota is cubic meters per ha. When the irrigation water volume was 1,710 cubic meters per ha, the water fee was 35.5 yuan per cubic meters, and when the irrigation water volume was 1,695 cubic meters per ha, the water fee was 56.5 yuan per cubic meters. At the critical point of IAWV, there is a negative relationship between irrigation quantity and water fees. In other words, there exists contradiction if more water is used for irrigation and less water fees are paid. Similarly, the situation can be found in several other areas.

When the water use is within the limit of the IAWV under the policy of ‘overuse-charge’, the water fee that farmers should pay is significantly lower than in the traditional mode. When the water use is higher than the IAWV but lower than the water quota, the reformed water charge will be lower than that in the traditional mode. However, when the water use exceeds a certain amount between the critical point of the IAWV, the water fee expenditure under the mode of ‘overuse-charge’ will be higher than that under the traditional mode. Within the limit of the IAWV, the water fee that farmers should pay under the mode of ‘overuse-charge’ is significantly lower than that under the traditional mode. After a certain amount of water use is exceeded, the water fee expenditure under the mode of ‘overuse-charge’ will be higher than that under the traditional mode. The

contradiction of policy may lead to the adverse selection of farmers with low irrigation quantities because these farmers can spend the same water fee, and they can irrigate more under the mode of 'overuse-charge', but this does not result in water saving.

## CONCLUSION

According to the policy of 'overuse-charge' when the amount of water used by farmers is within the limit of IAWV, there will be a situation where more water is used, the low water fee is paid. To a certain extent, this causes a waste of water resources in the actual irrigation process. This is because the amount of water use is lower than that of IAWV, and water trading occurs. The water-saving reward can be obtained only when the actual water use exceeds the quota of IAWV and is lower than the quota. As the reward amount is higher than the water fee, the relationship between the water fee and water use is reversed.

This study suggests changing the current 'two lines and three grades' model to the 'one line and two grades' model, taking the AIWQ of Hebei Province as the standard, and rewarding lower than the quota, IAWV transaction, and increasing higher than the irrigation quota. The improved agricultural water price policy avoids the need to use more water and pay less water fees. The characteristic of this method is to make full use of the market. A quota management policy mobilizes farmers to participate in water market transactions, fully utilizing market means to allocate water resources. If the water use is lower than the quota, the transaction can be conducted. The surplus water of farmers (the difference between water quota and actual water use) can be traded, which expands the trading scope of water resources. In addition, as farmers can obtain funds through trading in the water resources trading market, there is no need for the government to reward them for water saving.

The water price reform policy proposed in this study is in line with the concept of agricultural 'irrigation quota management'. It is simple and easy to use, and has the value of popularization and application in other groundwater irrigation areas. As mentioned above, the water price reform of groundwater irrigation area includes the installation of metering facilities and the promotion of water-saving technology. The former is beneficial to restricting farmers' water use behavior and to reducing irrigation water. The latter helps to reduce the higher water costs incurred by farmers due to the increase in water prices. Therefore, in order to successfully implement the water price reform policy less than the quota reward proposed in this paper, the funds need to be guaranteed. The funds must be used to improve the installation rate of metering facilities and improve the adoption of farmers' field water-saving technology in the form of subsidies and the promotion and application of water-saving technologies such as surface drip irrigation, and micro spray irrigation are applied.

## DATA AVAILABILITY STATEMENT

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

## ACKNOWLEDGEMENTS

This study was sponsored by the philosophy and social science foundation of China, (project No. 18ZDA074). The authors are grateful to the anonymous reviewers and editors for their valuable comments and suggestions.

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First received 17 August 2021; accepted in revised form 10 November 2021. Available online 29 November 2021