Official Journal of the World Water Council
Water Policy

Water Policy Vol 25 No 3, 253 doi: 10.2166/wp.2023.217

Does agricultural water-saving policy improve food security? Evidence from the Yellow River Basin in China

Rui Yang[a] and Hang Xu[b,*]
[a] College of Humanities and Development Studies, China Agricultural University, Beijing 100193, China
[b] College of Economics and Management, Northwest A&F University, Yangling 712100, China
*Corresponding author. E-mail: xuhang@nwafu.edu.cn

ABSTRACT

For our empirical research, the 2012 implementation of China's National Agricultural Water-Saving Outline serves as a quasi-experiment. In addition, one of the main regions in China for grain production is the Yellow River Basin. Based on this, we utilize a Difference-in-Difference (DID) empirical technique to assess the impact of the agricultural water-saving policy on food security using data from prefectures in China's Yellow River Basin from 2000 to 2020. According to the estimated results, grain production has greatly increased as a result of the agricultural water-saving policy. This conclusion still holds when other water-related policies are considered. The agricultural water-saving policy may enhance other input factors in grain production by assuring water demand, which is one possible mechanism of the influence. The empirical results show that the policy indeed increases the water productivity in agricultural production, which will ensure the effective water utilization in agricultural production, and the grain sown area, which is the most important production factor in agriculture. In heterogeneity analysis, the impact of the policy on food security is the largest in the lower reach, followed by the middle reach and the smallest in the upper reach in the Yellow River Basin.

Key words: Agricultural water-saving policy, China, Difference-in-Differences, Food security, Grain production

HIGHLIGHTS

- A Difference-in-Difference (DID) technique is employed to estimate the impact of the agricultural water-saving policy on grain yield in China.
- The agricultural water-saving policy increases grain yield, thus improving food security in China.
- The possible reason for the increase in grain yield is the increased agricultural water productivity as well as the grain sown area in China.

1. INTRODUCTION

According to Kinda *et al.* (2022), three dimensions of food security can be identified: availability, accessibility and utilization. The availability of food refers to the quantity of food supplied within domestic production and imports from foreign countries. Access to food through trade is vulnerable to international political conditions. Therefore, from the perspective of food availability, the food security of a country depends more on domestic production, which is also the focus of this paper. The past half-century has seen great growth in the amount of food production, but there is still more than one in seven people today who do not have enough food for consumption (Godfray *et al.*, 2010). The threat to food security in developing countries can easily lead to social conflict (Martin-shields & Stojetz, 2019). Therefore, improving food security is still an essential issue over the world.

There are lots of research to identify the impact of various factors on food security, and the factors include agroecology (Bezner Kerr *et al.*, 2021), climate change (Schmidhuber & Tubiello, 2007; Brown & Funk, 2008; Wheeler & von Braun, 2013; Campbell *et al.*, 2016), COVID-19 (Amare *et al.*, 2021; O'Hara & Toussaint, 2021), culture (Briones Alonso *et al.*, 2018), management strategies (Bairagi *et al.*, 2020; Bazzana *et al.*, 2022), land rush (Kinda *et al.*, 2022), trade (Dithmer & Abdulai, 2017), food price (Amolegbe *et al.*, 2021), organic agriculture (Meemken & Qaim, 2018), precision agriculture (Gebbers & Adamchuk, 2010) and agricultural policy (Rosegrant & Cline, 2003; Bureau & Swinnen, 2018; Bizikova *et al.*, 2020; Sibhatu *et al.*, 2022). Besides, Rosegrant & Cline (2003) indicate that the crop yield may fall in many areas because of increasing water scarcity. The competition for water between agriculture and industry will affect the ability to produce food (Godfray *et al.*, 2010). The efficient use of irrigation water may be an essential way to ensure food security (Cole *et al.*, 2018). Among the studies of the impact of agricultural policies on food security, there are still few literatures analysing the impact of agricultural water-saving policies on food security. While water resource is an important factor in food production, the impact of agricultural water-saving policy on food security cannot be ignored. In addition, water-saving agriculture mainly refers to a way to promote agricultural production through the construction of water conservancy facilities and the promotion of water-saving irrigation (Wang *et al.*, 2002).

The significant scarcity of water resources is also a problem in China, and the mismatch between supply and demand is still the fundamental obstacle to sustainable growth. The Chinese government introduced the National Agricultural Water-Saving Outline as a national strategy in 2012 to maintain food security and sustainable economic growth. The construction of water conservation projects and the promotion of modified irrigation technology that uses less water are the primary components of this policy. For water conservancy projects, the policy requires the continued construction of irrigation facilities in major grain-producing areas with severe water shortages and areas with fragile ecological environments and strives to solve the problems of ageing support facilities and large leakage losses. For the promotion of modified irrigation technology, the policy requires local governments to build a number of large-scale promotion projects for high-efficiency irrigation technology in areas with good agricultural production conditions.

The construction of water conservation projects and the promotion of high-efficiency irrigation technology will be beneficial to promote food security (Wang *et al.*, 2002; Yang & Gao, 2021). In order to better understand whether the agricultural water-saving policy affects food security, it is now possible thanks to China's National Agricultural Water-Saving Outline, which was introduced in 2012. The implementation of the policy is mainly aimed at reducing irrigation water, which accounts for the largest agricultural water use and the increase in irrigation water relies on the land area of crop planting. As a result, the amount of exogenous suitable sown area will determine how densely the agricultural water-saving policy is implemented throughout Chinese prefectures (Nunn & Qian, 2011). In order to study the impact of agricultural water-saving policies, Xu & Yang (2022) use the size of suitable arable land to measure the regional differences of the agricultural water-saving policy. This provides the basis for analysis using the empirical strategy of the continuous Difference-in-Differences (DID).

The DID approach reveals that China's agricultural water-saving policy may increase food security. After considering other water-related policies, the above conclusions still hold. When further analysing the potential mechanism of the impact, we find that the policy can promote water productivity in agricultural production and the grain sown area, so we indicate that the policy may increase other input factors to promote food security through improving the effective utilization of water resources and thus ensuring the water demand for agricultural production. From the perspective of heterogeneous impacts, it can be found that, in the upper, middle and lower reaches of the Yellow River Basin in China, there are regional differences in the impact of the agricultural water-saving policy on grain production. In the upper reach of the basin, the impact is relatively small; in the middle reach, the impact is almost equivalent to the overall average impact; and the impact is greatest in the lower reach. The reason may be due to the differences in the geographical characteristics and land potential in the upper, middle and lower reaches of the basin. The slope and elevation of the upper reach are larger than those in the middle and lower reaches of the basin, while the land potential in the middle and lower reaches of the basin is greater than that in the upper basin. This conclusion can be also empirically tested by heterogeneity analysis.

This research adopts an empirical technique of DID to evaluate the impact of the agricultural water-saving policy on food security using data from prefectures in nine provinces of China's Yellow River Basin from 2000 to 2020. The rest is structured as follows: Section 2 describes the methods and data sources. Section 3 contains the key findings of this investigation. Section 4 contains the discussion. Section 5 highlights the study's findings.

2. METHODS AND DATA SOURCES

2.1. Empirical strategy

According to Xu & Yang (2022), in order to elucidate the influence of the agricultural water-saving policy on food security, we chose an empirical technique of DID. Because the agricultural water-saving policy was implemented nationwide in 2012 and the size of suitable arable land can be used to measure the regional differences in agricultural water-saving policies (Xu & Yang, 2022). Therefore, the empirical strategy is the continuous DID specifically. In contrast to the usual DID technique, the treatment variable in this study is the suitable arable land, which is a continuous variable. The basic specification can be seen in the following:

$$\begin{aligned} \mathit{Grain\ Yield}_{it} =& \beta\, \mathit{ln\ Land\ Area}_i \times \mathit{Post}_t + \sum_i \gamma_i \times I_i + \sum_{t=2001}^{2020} \rho_t \times I_t \\ &+ \sum_{t=2001}^{2020} \nu_t X_i^1 \times I_t + \lambda X_{it}^2 + \varepsilon_{it} \end{aligned} \tag{1}$$

where i denotes Chinese prefectures and t denotes years ranging from 2000 to 2020. The $\mathit{Grain\ Yield}_{it}$ denotes the grain yield. The $\mathit{ln\ Land\ Area}_i$ is the natural log of the land area suitable for cultivation. The Post_t is a dummy variable, which indicates whether it is after 2012. The I_i and I_t are region and time fixed effects, in which one prefecture and 1 year will be retained as the reference group in the fixed effects. The X_i^1 is the time-invariant control variables and the X_i^2 is the time-variant variables. The ε_{it} is the error term. The β, γ_i, ρ_t, ν_t and λ are coefficients. The coefficient, β, can be regarded as the impact of the suitable cultivated land on grain yield before and after the policy began in 2012.

To further dynamically examine the impact of the policy on grain production, we further use a dynamic model, which can be expressed in the following form:

$$\begin{aligned} \mathit{Grain\ Yield}_{it} =& \sum_{t=2001}^{2020} \beta_t\, \mathit{ln\ Land\ Area}_i \times I_t + \sum_i \gamma_i \times I_i + \\ & \sum_{t=2001}^{2020} \rho_t \times I_t + \sum_{t=2001}^{2020} \nu_t X_i^1 \times I_t + \lambda X_{it}^2 + \varepsilon_{it} \end{aligned} \tag{2}$$

where the definitions of the above variables are consistent with the previous one. This equation can estimate the dynamic effect over time. Furthermore, according to Nunn & Qian (2011), the initial year will be left as a comparison group. If the parallel trends are satisfied, the estimated coefficients will start to become significant after the policy.

2.2. Study area and data sources

The study area of this paper is the nine provinces through which the Yellow River flows in China, including Shandong, Henan, Shanxi, Shaanxi, Inner Mongolia, Ningxia, Gansu, Sichuan and Qinghai, as shown in Figure 1. The

Fig. 1 | Study area.

Yellow River Basin is located in the north of China where water resources are relatively scarce, in which the per capita water resources in this river basin are just 27% of the national average. Although agricultural water usage is quite broad, the efficiency of agricultural water use is low. The Yellow River Basin is also an essential economic zone in China and a major producing area of agricultural products, in which about one-third of China's food production comes from this region. The samples include the prefectures in the nine provinces, in which 114 prefectures are included. We also use the data from 2000 to 2020 and, therefore, have 2,394 observations.

The dependent variable in this paper is grain yield. The grain crops mainly include wheat, corn, rice, beans and potatoes. Among them, potatoes are calculated by converting 5 kg into 1 kg of grain, and other crops are calculated as raw grain after threshing. The data on grain yield come from the China Statistical Yearbook. The suitable cultivated land is used in this work, according to Nunn & Qian (2011), to index the impact of the policy across prefectures. The quantity of arable land with land potential larger than zero per unit area is the amount of suitable cultivable land, and the data are derived using information from Liu *et al.* (2015). The potential yield of grains per unit area is referred to as the land potential, in which the Global Agro-Ecological Zones (GAEZ) model was used to analyse data on China's agricultural distribution, soil composition and elevation to determine the value. In the process of using the GAEZ model to estimate China's land potential, five crops, including wheat, corn, rice, beans and potatoes are considered. These five crops are the main grain crops in China, accounting for about 70% of the total grain output in China. In the estimation, based on the actual planting system in China, a combination of various cropping methods (including two crops per year, three crops in 2 years and three crops in 1 year) is considered to obtain the greatest potential for land in grain production. The land potential of the study area can be seen in Figure 2 and the unit is kg/ha. It can be found that the areas with high land potential are mainly located in the eastern region, especially Henan and Shandong, while the land potential in the western region is mostly zero.

The selected control variables include geographic, meteorological, agricultural and political variables. The geographic variables are slope and elevation, and the data come from the Resource and Environment Science and Data Center in China. The meteorological variables are precipitation and sunshine, and the data come from the National Meteorological Science Data Center. The agricultural variable is land potential; the data come from Liu *et al.* (2015). The political variable is a dummy variable, which will be equal to 1 if the prefecture is a provincial capital or sub-provincial city and 0 otherwise. In order to further analyse the potential mechanism of the impact of the policy on grain yield, the data in this paper also includes agricultural water productivity and the grain sown area. Agricultural water productivity means the real value added in agricultural production per unit of agricultural water use, in which the real value added in agricultural production is the real value compared to the first year. The data of value added in agricultural production and grain sown area come from the China Statistical Yearbook. The data of agricultural water use are from the China Water Resources Bulletin. The basic information of all the data is shown in Table 1.

3. RESULTS

3.1. Baseline results

Table 2 lists the initial findings from the empirical DID methodology used to calculate the effect of the agricultural water-saving policy on grain yield. The dependent variable is the grain yield, all columns have been added with year and prefecture fixed effects. Column 1 does not include any additional control variables. The estimated results show that the land area suitable for cultivation can increase grain yield at a significance level of 1% after the implementation of the policy, suggesting that the policy may promote grain yield. Columns 2–5 gradually add geographic, meteorological, agricultural and political control variables. The Columns 2 through 5 agree with the actual findings in Column 1 and the estimated coefficients have risen. Based on the selected specification incorporating all control variables, one increase of suitable cultivated land by 1% can lead to an increase of grain yield

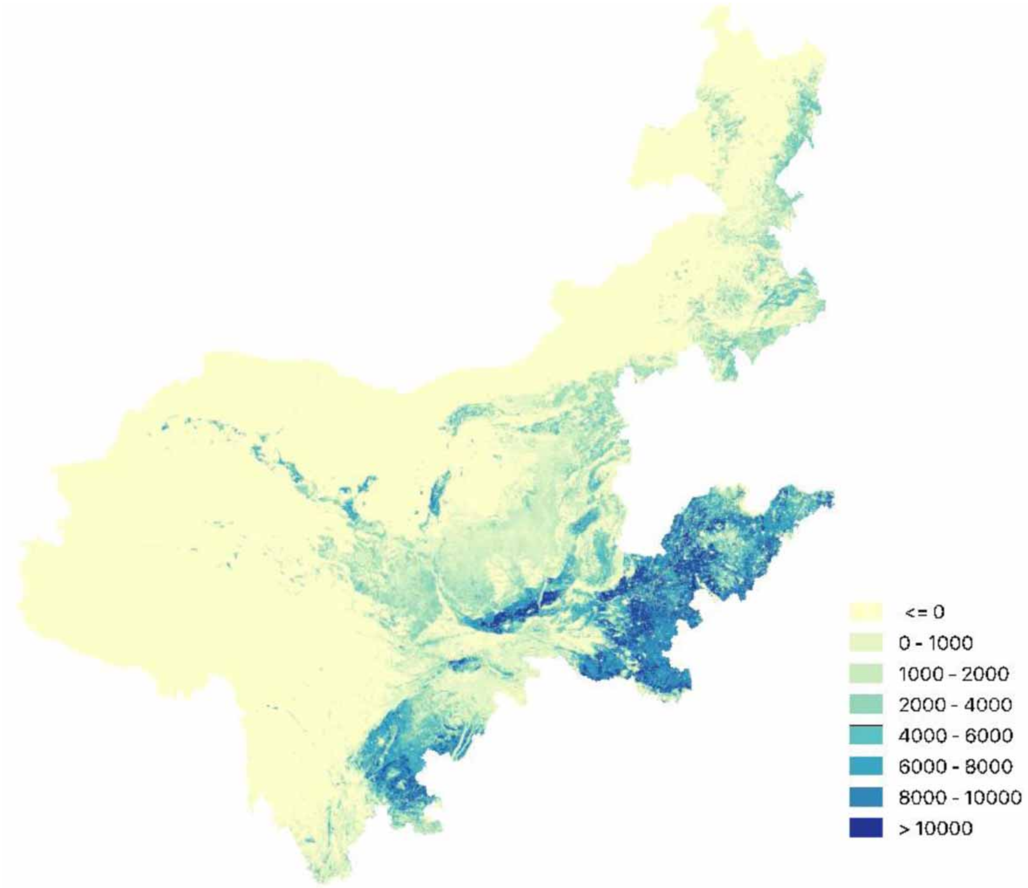

Fig. 2 | The average land potential in the study area.

Table 1 | Summary statistics

Variables	Mean	SD	Min	Max	*N*
Grain yield (10,000 tons)	175.51	206.26	0.06	6,296.50	2,394
Land area (km^2)	10,576.91	8,485.90	0.00	45,722.00	2,394
Slope (°)	11.49	5.95	2.30	27.14	2,394
Elevation (m)	1,154.95	1,067.75	10.03	4,694.95	2,394
Precipitation (mm)	689.33	237.43	169.98	1,475.06	2,394
Sunshine (h)	2,153.98	436.33	985.60	3,102.30	2,394
Land potential (ton/ha)	3,042.95	2,692.54	0.00	8,542.95	2,394
Political (0/1)	0.08	0.27	0.00	1.00	2,394
Water productivity (CNY/m^3)	15.02	46.84	0.02	1,725.00	2,394
Grain sown area (ha)	343.28	276.45	0.37	1,687.02	2,394

Table 2 | Baseline estimation

	Dependent variable: grain yield				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln Land Area × Post	16.87*** (3.72)	20.01*** (4.37)	19.81*** (4.38)	20.20*** (4.42)	20.33*** (4.42)
Constants	59.57* (35.00)	31.93 (40.32)	−69.70 (101.78)	−63.31 (103.23)	−73.92 (103.58)
Prefecture	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	Yes	Yes
Meteorology	No	No	Yes	Yes	Yes
Agriculture	No	No	No	Yes	Yes
Political	No	No	No	No	Yes
Observations	2,394	2,394	2,394	2,394	2,394
R^2	0.06	0.10	0.10	0.12	0.12

Note: Standard errors in parentheses. $^{*}p < 0.1$, $^{***}p < 0.01$.

by 203,300 tonnes after the agricultural water-saving policy. Because the policy still increases grain yield at a significance level of 1% even with the addition of control variables, it may be beneficial for food security.

To ensure the conclusion that the grain yield can be increased due to the agricultural water-saving policy, it is necessary to further test whether it satisfies the parallel trend hypothesis. Therefore, flexible estimation is used for the further analysis below, as shown in Table 3. The fixed effects of year and prefecture are added to all columns. Column 1 just controls the fixed effects and Columns 2–5 gradually add geographic, meteorological, agricultural and political control variables. Different from the baseline estimation, the independent variable becomes the interaction terms between the suitable cultivated land area and year dummy variables, and the estimation results are compared with the first year (Nunn & Qian, 2011). The estimated results in Column 1 show that before 2012, the suitable cultivated land area had no effect on grain yield, and only after 2012 does it have an effect on grain yield at a 10% significance level. This is in accordance with the time node in 2012 when the policy went into effect. When the policy is not implemented, the suitable cultivated land area has no significant impact on grain yield. But only after the policy is implemented, the suitable cultivated land area has a significant impact on grain yield. The estimation results can indicate that the increase in grain yield is indeed due to the policy. Column 2 further adds geographic variables, and the estimated results indicate that there is a significant effect of the policy on grain yield simultaneously in the same year when the policy is put forward, but there is still no significant effect before 2012. Columns 3–5 gradually add meteorological, agricultural and political variables, and the results are in line with the first column. According to the estimated results in the Column 5, the significant impact of the policy on grain yield appears in the first year at a 10% significance level and appears in the third year at a 5% significance level. Therefore, the results of the flexible estimation confirm the parallel trend hypothesis, so the policy can increase grain yield, thereby promoting food security.

3.2. Robustness checks

Other water resource policies, such as the Water Rights Reform (WRR) and the South-to-North Water Diversion Project (SNWDP), were implemented in China around 2012. The reform of the WRR mainly involves some prefectures in Gansu, Henan, Inner Mongolia and Ningxia, which was implemented in 2014. The SNWDP involves

Table 3 | Flexible estimation

	Dependent variable: grain yield				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln Land area × 2001	−1.81	−0.51	−0.78	−0.54	−0.55
	(11.97)	(14.04)	(14.05)	(14.18)	(14.20)
ln Land area × 2002	1.50	4.25	4.20	3.60	3.66
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2003	0.09	3.73	3.70	1.59	1.65
	(11.97)	(14.04)	(14.05)	(14.19)	(14.21)
ln Land area × 2004	4.48	7.06	6.98	6.07	6.11
	(11.97)	(14.04)	(14.05)	(14.18)	(14.20)
ln Land area × 2005	6.22	7.96	7.64	7.21	7.23
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2006	7.68	9.45	9.54	10.25	10.35
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2007	7.25	8.49	8.19	9.20	9.25
	(11.97)	(14.04)	(14.05)	(14.19)	(14.21)
ln Land area × 2008	12.99	15.44	15.33	15.56	15.68
	(11.97)	(14.04)	(14.05)	(14.18)	(14.20)
ln Land area × 2009	12.92	14.77	14.87	15.76	15.88
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2010	15.64	18.64	18.78	18.96	19.12
	(11.97)	(14.04)	(14.05)	(14.18)	(14.20)
ln Land area × 2011	17.55	21.23	21.36	21.45	21.61
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2012	19.48	23.44*	22.96	22.94	23.10
	(11.97)	(14.04)	(14.06)	(14.19)	(14.21)
ln Land area × 2013	21.30*	26.64*	26.59*	25.58*	25.79*
	(11.97)	(14.04)	(14.07)	(14.19)	(14.21)
ln Land area × 2014	21.72*	27.39*	27.05*	25.88*	26.03*
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2015	23.97**	29.93**	30.17**	28.91**	29.14**
	(11.97)	(14.04)	(14.05)	(14.19)	(14.21)
ln Land area × 2016	22.80*	23.05	23.09	34.92**	35.29**
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2017	23.81**	29.46**	29.49**	28.54**	28.75**
	(11.97)	(14.04)	(14.05)	(14.19)	(14.20)
ln Land area × 2018	26.97**	33.78**	33.95**	32.12**	32.38**
	(11.97)	(14.04)	(14.07)	(14.19)	(14.21)
ln Land area × 2019	27.37**	34.68**	34.06**	32.57**	32.73**
	(11.97)	(14.04)	(14.06)	(14.19)	(14.21)
ln Land area × 2020	27.78**	34.63**	33.24**	32.00**	32.08**
	(11.97)	(14.04)	(14.11)	(14.24)	(14.25)

(*Continued.*)

Table 3 | Continued

	Dependent variable: grain yield				
	(1)	(2)	(3)	(4)	(5)
Constant	−36.38 (105.97)	−96.62 (124.11)	−189.55 (150.39)	−172.35 (152.40)	−182.76 (152.70)
Prefecture	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	Yes	Yes
Meteorology	No	No	Yes	Yes	Yes
Agriculture	No	No	No	Yes	Yes
Political	No	No	No	No	Yes
Observations	2,394	2,394	2,394	2,394	2,394
R^2	0.06	0.10	0.10	0.12	0.13

Note: Standard errors in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$.

some prefectures in Henan, Shandong, which were implemented in 2013. The increase in grain yield may be also due to these two water-related policies. Thus, to further examine the effect of the agricultural water-saving policy on grain production, the two policies will also be included in the following analysis listed below. This will help to eliminate estimation bias brought by other water-related policies.

Table 4 presents the estimated results considering other policies. Columns 1–2 are the estimation results considering the WRR. After the WRR is considered, the suitable cultivated land area still significantly affects the grain

Table 4 | Estimation addressing contemporaneous water-related policies

	Dependent variable: grain yield					
	(1)	(2)	(3)	(4)	(5)	(6)
ln Land area × Post	16.87*** (3.72)	20.72*** (4.43)	16.77*** (3.72)	19.88*** (4.42)	16.77*** (3.72)	20.21*** (4.43)
Water right reform	0.64 (17.00)	−26.40 (17.85)			−2.49 (17.31)	−19.81 (18.11)
South-to-north diversion			13.45 (14.21)	−39.87** (17.17)	13.84 (14.47)	−36.56** (17.43)
Constant	59.50* (35.06)	−66.03 (103.69)	57.89* (35.05)	−56.38 (103.75)	58.12* (35.09)	−51.90 (103.82)
Prefecture	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	No	Yes	No	Yes
Meteorology	No	Yes	No	Yes	No	Yes
Agriculture	No	Yes	No	Yes	No	Yes
Political	No	Yes	No	Yes	No	Yes
Observations	2,394	2,394	2,394	2,394	2,394	2,394
R^2	0.06	0.13	0.06	0.13	0.06	0.13

Note: Standard errors in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

yield after the policy, but the WRR has no significant effect on the grain yield. Columns 3–4 are the estimation results considering the SNWDP. After controlling the SNWDP, the suitable cultivated land area still significantly affects grain yield after the agricultural water-saving policy, and the SNWDP significantly negatively affects grain yield after adding all control variables. Columns 4–5 are the estimation results considering both the WRR and the SNWDP. After simultaneously controlling the two water-related policies, the suitable cultivated land area still significantly increases grain yield after the policy. According to the results in Column 6, increasing suitable cultivated land area by 1% increases grain yield by 202,100 tonnes, which just decreases slightly compared to the baseline estimation. Besides, the WRR can reduce the grain yield, but it is not significant, while the SNWDP can significantly reduce grain yield at a 5% significance level. Therefore, the agricultural water-saving policy can still promote grain yield even after addressing the contemporaneous water-related policies.

In order to ensure that the impact of suitable cultivated land area on grain yield comes from the agricultural water-saving policy in 2012 when addressing the contemporaneous water-related policies, the flexible estimation addressing the WRR and the SNWDP as control variables can be presented in Figure 3. It should be noted that all control variables are also included in the flexible estimation. The estimated coefficients and 95% confidence intervals are shown as markers and dashed lines, respectively, based on standard errors. Figure 3 clearly shows that before 2012, after controlling the WRR and the SNWDP, the suitable cultivated land area still had no significant impact on grain yield before 2012, only after 2012 does it start to have a significant impact in the third year at a 5% significance level after the agricultural water-saving policy. These results show that the policy has contributed to the increase in grain yield after controlling the two contemporaneous policies. Therefore, the estimated results

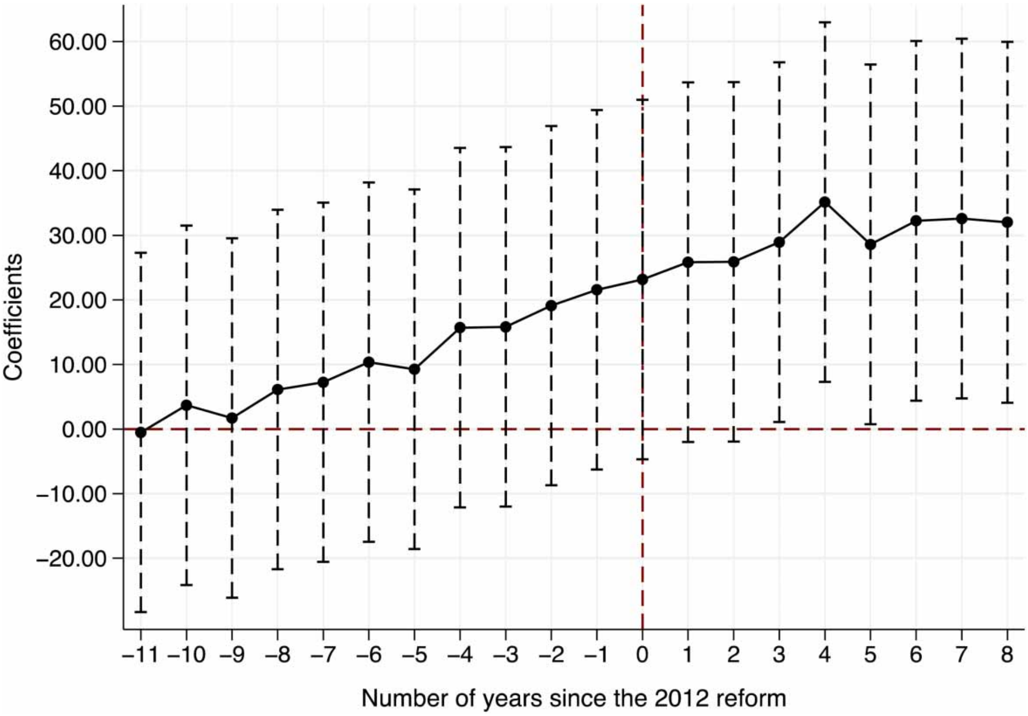

Fig. 3 | Flexible estimation addressing contemporaneous policies.

indicate that the policy indeed causally promotes grain yield when the model is estimated after controlling other contemporaneous water-related policies.

4. DISCUSSION

4.1. Potential mechanism

The findings of this study are in line with the body of previous literature (Wang *et al.*, 2002; Yang & Gao, 2021; Xu & Yang, 2022). According to Wang *et al.* (2002), water-saving irrigation is crucial for ensuring food security. With empirical data, the causal link between water-saving irrigation and agricultural output has been established by Yang & Gao (2021). In addition, according to Xu & Yang (2022), China's agricultural water-saving policy, which promoted water-saving irrigation subsidies, not only did not cut agricultural water extraction but instead enhanced the extraction of agricultural water, which will benefit food production. But, why does the agricultural water-saving policy promote grain yield? The theoretical mechanism is that the agricultural water-saving policy assures grain production water demand through water-saving infrastructure and water-saving irrigation subsidies (Emerick *et al.*, 2016). Subsidies for water-saving irrigation in agriculture will boost agricultural water use and production. In the Yellow River Basin, after ensuring the water need for grain production, other production factors will also increase, thereby promoting grain production. Among the many production factors, the input of land resources is the key production factor. Therefore, the following analysis will first focus on whether the agricultural water-saving policy has enhanced water productivity in agriculture, followed by a discussion of whether the agricultural water-saving policy has expanded grain-planted area.

Table 5 presents the estimated results of the influence of the agricultural water-saving policy on water productivity in agriculture, which is defined as the real value added in agricultural production per unit of water use in agriculture. It should be noticed that year fixed effects and prefecture fixed effects are included in every column. Other control factors are not introduced in Column 1, whereas political, agricultural, meteorological, and geographic control variables were gradually added in Columns 2–5. The results of Columns 1–5 show that

Table 5 | The impact on agricultural water productivity

	Dependent variable: agricultural water productivity				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln Land area × Post	11.41*** (1.19)	11.03*** (1.35)	11.14*** (1.35)	11.13*** (1.37)	11.11*** (1.38)
Constants	−81.21*** (11.23)	−77.81*** (12.48)	−52.79* (31.51)	−48.94 (32.07)	−48.61 (32.26)
Prefecture	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	Yes	Yes
Meteorology	No	No	Yes	Yes	Yes
Agriculture	No	No	No	Yes	Yes
Political	No	No	No	No	Yes
Observations	2,394	2,394	2,394	2,394	2,394
R^2	0.04	0.15	0.15	0.16	0.16

Note: Standard errors in parentheses. $*p < 0.1$, $***p < 0.01$.

the policy can raise water productivity in agriculture at a significant level of 1%. Therefore, the agricultural water-saving policy may ensure that water resources are used effectively in agricultural production. The policy may boost water productivity in both grain crops and cash crops at the same time, but there is no method to discern between grain production and others owing to data-gathering issues.

Table 6 shows the estimated findings of the influence of the agricultural water-saving policy on the area of grain sown, with year fixed effects and prefecture fixed effects included in all columns. Column 1 does not include any additional control variables, and the estimated findings demonstrate that the policy significantly increases the area of grain sown. The geographic, meteorological, agricultural and political control variables are subsequently introduced in Columns 2–5. The estimated findings in Columns 2–5 are consistent with Column 1, even though the estimated coefficients have risen in Columns 2–5. They all continue to demonstrate that the policy can enhance the grain sown area at a significance level of 1%. Therefore, the policy may promote grain yield by increasing the grain sown area. The agricultural water-saving policy may also increase grain production by increasing other production factors, but due to data acquisition problems, there are no other input factor data for grain production to verify.

4.2. Heterogeneity

Because there may be heterogenous in the influence of the agricultural water-saving policy on grain output in the upper, medium and lower reaches of the Yellow River Basin, we separate the samples of the basin into three subsamples of the higher, middle and lower reaches. The upper reach includes the prefectures in Qinghai, Gansu, Ningxia and Sichuan, the middle reach includes the prefectures in Inner Mongolia, Shaanxi and Shanxi, and the lower reach includes the prefectures in Henan and Shandong. Subsample-based estimations can be seen in Table 7, where all columns include various control variables as well as fixed effects for year and region.

The estimated results of the overall sample are presented in Column 1, which can be used as the comparison of the subsample estimation. Column 2 is the estimated result of the subsample in the upper basin. The estimated coefficient is 3.82, which is only 16% of the overall estimated result. Therefore, in the upper reach of the

Table 6 | The impact on grain sown area

	Dependent variable: grain sown area				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln Land area × Post	13.19*** (1.55)	18.68*** (1.70)	18.61*** (1.69)	17.45*** (1.71)	17.59*** (1.68)
Constants	250.95*** (14.56)	202.70*** (15.66)	47.62 (39.33)	51.56 (39.92)	45.67 (39.31)
Prefecture	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	Yes	Yes
Meteorology	No	No	Yes	Yes	Yes
Agriculture	No	No	No	Yes	Yes
Political	No	No	No	No	Yes
Observations	2,394	2,394	2,394	2,394	2,394
R^2	0.15	0.29	0.30	0.31	0.34

Note: Standard errors in parentheses. ***$p < 0.01$.

Table 7 | Heterogeneity analysis: along the Yellow River

	Dependent variable: grain sown area				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln Land area × Post	20.33*** (4.42)	3.82*** (0.65)	22.07*** (2.16)	78.17** (33.83)	33.33*** (8.56)
Constants	−73.92 (103.58)	100.52*** (21.28)	−346.99*** (64.10)	−771.59 (535.52)	−269.78 (200.29)
Prefecture	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Meteorology	Yes	Yes	Yes	Yes	Yes
Agriculture	Yes	Yes	Yes	Yes	Yes
Political	Yes	Yes	Yes	Yes	Yes
Subsample	Whole	Upper	Middle	Lower	M & L
Observations	2,394	1,008	693	693	1,386
R^2	0.12	0.40	0.77	0.21	0.16

Note: Standard errors in parentheses. $^{**}p < 0.05$, $^{***}p < 0.01$. Whole indicates the whole sample of the basin; Upper indicates the upper reach of the basin; Middle indicates the middle reach of the basin; Lower indicates the lower reach of the basin; M & L indicates the middle and lower reaches of the basin.

basin, although the policy can increase grain yield, the impact is relatively small. Column 3 shows the estimated results of the subsample in the middle reach of the basin. The estimated coefficient is almost equivalent to the average estimated coefficient in the overall sample of the basin. Column 4 is the estimated result of the subsample in the lower basin. The estimated coefficient is 78.17, which is 3.8 times the average estimated coefficient in the overall sample of the basin. Therefore, the agricultural water-saving policy can better promote grain production in the lower basin to ensure food security. Column 5 shows the estimated results of the subsamples in the middle and lower reaches of the basin, and the estimated coefficient is also more than 1.5 times the average estimated coefficient in the overall sample of the basin. Therefore, in the middle and lower reaches of the basin, the agricultural water-saving policy has a better effect on promoting grain yield.

The following is a further analysis of the heterogeneity of each characteristic variable, which can further verify the reasons for the regional heterogeneity, as shown in Table 8. All columns are added with year fixed effects, prefecture fixed effects and all control variables. To test the heterogeneity of characteristic variables, the independent variables are the interactions between the ln Land Area × Post and the slope, elevation, precipitation, sunshine, land potential and whether it is a provincial capital or a sub-provincial city. Column 1 shows that in prefectures with a higher slope, the impact of the policy on grain yield is relatively small. Column 2 shows that the higher the elevation, the smaller the impact of the policy on grain yield. Column 3 shows that the difference in precipitation does not affect the impact of the policy on grain yield. The possible reason is that the differences in water supply between prefectures caused by differences in precipitation are alleviated due to the policy. Column 4 shows that the longer the sunshine, the greater the impact of the policy on grain yield. Column 5 shows that prefectures with greater land potential have a greater impact on grain yields from the policy. Column 6 shows that the impact of the policy on grain yield is not significantly different between provincial capitals or sub-provincial regions and other prefectures. Therefore, the differences between the upper, middle and lower reaches of the Yellow River Basin may be due to geographical features and land potential. The slope

Table 8 | Heterogeneity analysis: characteristic variables

	Dependent variable: grain yield					
	(1)	(2)	(3)	(4)	(5)	(6)
ln Land area × Post	38.25*** (9.77)	44.56*** (7.39)	22.11*** (4.78)	6.21 (8.24)	15.97*** (4.66)	20.46*** (4.42)
ln Land area × Post × Slope	−189.86** (92.33)					
ln Land area × Post × Elevation		−1.09*** (0.27)				
ln Land area × Post × Precipitation			−0.42 (0.43)			
ln Land area × Post × Sunshine				0.50** (0.25)		
ln Land area × Post × Land Potential					0.77*** (0.26)	
ln Land area × Post × Land Political						−3,902.81 (4,122.58)
Constant	−32.52 (105.44)	−179.71* (106.41)	−87.44 (104.49)	−4.11 (109.08)	−242.36** (118.22)	−48.08 (107.12)
Prefecture	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes	Yes
Meteorology	Yes	Yes	Yes	Yes	Yes	Yes
Agriculture	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,394	2,394	2,394	2,394	2,394	2,394
R^2	0.13	0.13	0.13	0.13	0.13	0.13

Note: Standard errors in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

and elevation of the upper basin are higher than those in the middle and lower reaches, and the land potential of the middle and lower reaches of the basin is higher than that of the upper basin.

5. CONCLUSION

This paper provides empirical evidence for studying the impact of the agricultural water-saving policy on food security. The implementation of the National Agricultural Water-Saving Outline of China in 2012 provides a quasi-experiment for our empirical analysis. Besides, the Yellow River Basin is one of the major areas of grain production in China. Based on this, we use the data of prefectures in nine provinces in the basin from 2000 to 2020 and employ a continuous DID to estimate the impact of the agricultural water-saving policy on food security as indexed by grain yield. In the model estimation, the treatment variable is the suitable cultivated land area, and its calculation process mainly considers major food crops such as wheat, corn, rice, bean and potato. According to Nunn & Qian (2011), the density in the policy will be consistent with regional differences in exogenous suitable cultivated land area. The estimated results show that the suitable cultivated land can significantly increase the grain yield only after 2012, so it can be considered that the policy can promote food security. After considering other contemporaneous water-related policies, the above conclusions still hold.

Although there is insufficient information to prove the potential mechanism of the impact of the policy on grain yield, we first clarify the impact of the policy on water productivity in agriculture and then examine the impact of the policy on the grain sown area, which is the most important input factor of grain production. The empirical results show that the policy also promotes agricultural water productivity and grain sown area, so we indicate that the policy may promote grain yield by increasing other input factors after improving the effective utilization of water resources and thus ensuring the water demand for grain production. This conclusion is consistent with Emerick *et al.* (2016), who believe that the improvement of agricultural technology will reduce agricultural risks, thereby increasing the input of production factors and thus increasing agricultural production. The agricultural water-saving policy can promote the construction of water conservancy facilities and the adoption of water-saving irrigation technologies, thereby reducing the risk of drought, thereby increasing the factors of grain production and thus ensuring food security. The potential mechanism can be further studied from the perspective of farmers' behaviour. Therefore, future research can focus on the impact of agricultural water-saving policies on farmers' behaviour in agricultural production.

From the perspective of heterogeneity analysis, in the upper, middle and lower reaches of the Yellow River Basin, there are regional differences in the impact of the agricultural water-saving policy on grain production. In the upper reach of the basin, the impact of the policy on grain yield is relatively small; in the middle reach of the basin, the impact is almost equivalent to the overall average impact in the basin; the impact is greatest in the lower basin. The reason may be due to the differences in geographical characteristics and land potential in the upper, middle and lower reaches of the basin. The slope and elevation of the upper basin are larger than those in the middle and lower reaches of the basin, while the land potential in the middle and lower reaches of the basin is greater than that in the upper basin. Therefore, strengthening the agricultural water-saving policy in the lower Yellow River Basin is more conducive to food security in China.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Amare, M., Abay, K. A., Tiberti, L. & Chamberlin, J. (2021). COVID-19 and food security: panel data evidence from Nigeria. *Food Policy 101*, 102099.

Amolegbe, K. B., Upton, J., Bageant, E. & Blom, S. (2021). Food price volatility and household food security: evidence from Nigeria. *Food Policy 102*, 102061.

Bairagi, S., Mishra, A. K. & Durand-Morat, A. (2020). Climate risk management strategies and food security: evidence from Cambodian rice farmers. *Food Policy 95*, 101935.

Bazzana, D., Foltz, J. & Zhang, Y. (2022). Impact of climate smart agriculture on food security: an agent-based analysis. *Food Policy 111*, 102304.

Bezner Kerr, R., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., Parros, P., Mutyambai, D. M., Prudhon, M. & Wezel, A. (2021). Can agroecology improve food security and nutrition? A review. *Global Food Security 29*, 100540.

Bizikova, L., Jungcurt, S., McDougal, K. & Tyler, S. (2020). How can agricultural interventions enhance contribution to food security and SDG 2.1? *Global Food Security 26*, 100450.

Briones Alonso, E., Cockx, L. & Swinnen, J. (2018). Culture and food security. *Global Food Security 17*, 113–127.

Brown, M. E. & Funk, C. C. (2008). Food security under climate change. *Science 319*, 580–581.

Bureau, J. -C. & Swinnen, J. (2018). EU policies and global food security. *Global Food Security 16*, 106–115.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., Thornton, P. K. & Wollenberg, E. (2016). Reducing risks to food security from climate change. *Global Food Security 11*, 34–43.

Cole, M. B., Augustin, M. A., Robertson, M. J. & Manners, J. M. (2018). The science of food security. *npj Science of Food 2*, 14.

Dithmer, J. & Abdulai, A. (2017). Does trade openness contribute to food security? A dynamic panel analysis. *Food Policy 69*, 218–230.

Emerick, K., de Janvry, A., Sadoulet, E. & Dar, M. H. (2016). Technological innovations, downside risk, and the modernization of agriculture. *American Economic Review 106*, 1537–1561.

Gebbers, R. & Adamchuk, V. I. (2010). Precision agriculture and food security. *Science 327*, 828–831.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science 327*, 812–818.

Kinda, S. R., Kere, N. E., Yogo, T. U. & Simpasa, M. A. (2022). Do land rushes really improve food security in Sub-Saharan Africa? *Food Policy 113*, 102285.

Liu, L., Xu, X. & Chen, X. (2015). Assessing the impact of urban expansion on potential crop yield in China during 1990–2010. *Food Security 7*, 33–43.

Martin-Shields, C. P. & Stojetz, W. (2019). Food security and conflict: empirical challenges and future opportunities for research and policy making on food security and conflict. *World Development 119*, 150–164.

Meemken, E. -M. & Qaim, M. (2018). Organic agriculture, food security, and the environment. *Annual Review of Resource Economics 10*, 39–63.

Nunn, N. & Qian, N. (2011). The potato's contribution to population and urbanization: evidence from a historical experiment. *The Quarterly Journal of Economics 126*, 593–650.

O'Hara, S. & Toussaint, E. C. (2021). Food access in crisis: food security and COVID-19. *Ecological Economics 180*, 106859.

Rosegrant, M. W. & Cline, S. A. (2003). Global food security: challenges and policies. *Science 302*, 1917–1919.

Schmidhuber, J. & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences 104*, 19703–19708.

Sibhatu, K. T., Arslan, A. & Zucchini, E. (2022). The effect of agricultural programs on dietary diversity and food security: insights from the smallholder productivity promotion program in Zambia. *Food Policy 113*, 102268.

Wang, H., Liu, C. & Zhang, L. (2002). Water-saving agriculture in China: an overview. *Advances in Agronomy 75*, 135–171.

Wheeler, T. & von Braun, J. (2013). Climate change impacts on global food security. *Science 341*, 508–513.

Xu, H. & Yang, R. (2022). Does agricultural water conservation policy necessarily reduce agricultural water extraction? Evidence from China. *Agricultural Water Management 274*, 107987.

Yang, R. & Gao, Q. (2021). Water-saving irrigation promotion and food security: a study for China. *Sustainability 13*, 12212.

First received 12 October 2022; accepted in revised form 24 February 2023. Available online 13 March 2023