Water Policy 17 (2015) 815–830

Impacts on the utilization degree of canal water caused by agricultural water reallocation: a case study from China

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Abstract

Our study area in the People's Victory Canal Irrigation District (PVCID), which is downstream of the Yellow River in China, has been undergoing agricultural water transfer to the city for municipal uses. Water supply condition data from PVCID are used to analyze the impacts of water reallocation on agricultural water supply quality, and field survey data in PVCID are used to examine the impacts of agricultural water supply quality on the utilization degree of canal water. Several issues on the current compensation methods are also discussed. Results show that the amount of irrigation water and the number of days for irrigation are affected by water reallocation, especially when the amount of water diversion significantly decreases. Regression results show that timeliness and adequacy of canal water are important factors affecting the utilization degree of canal water. Several factors reveal significant association with the utilization degree of canal water, such as the water price of canal water, water fee charge methods, soil texture of the largest cropland, precipitation, and age of farm household head. Current compensation methods can hardly compensate for the decrease in canal water reliability. Some recommendations are put forward to compensate for the adverse effects of agricultural water transfer.

Keywords: Canal water; China; Choice; Water reallocation; Water supply quality

1. Introduction

Agriculture with low water use efficiency consumes approximately 70% of the total water resources in Northern China (Tang *et al.*, 2014). A tendency to reallocate water from agriculture to meet industrial and domestic needs can be observed (Zhou *et al.*, 2009), such as in the People's Victory Canal Irrigation District (PVCID), Luhun Irrigation District, Qunku Irrigation District (Zhou, 2007), and Baisha Irrigation District.

doi: 10.2166/wp.2015.162

Moreover, several irrigation districts are in the process of transferring water from the agricultural to the non-agricultural sector in Henan Province. Agricultural water reallocation increases water supply in the city and promotes economic development. The positive effect of agricultural water reallocation has been reported in China and other parts of the world. For example, irrigators use a water market strategy as a common tool to assist their farm management in Australia (Wheeler *et al*., 2014). Zekri & Easter (2005) estimated that the market between farmers and an urban water company helps increase the profitability of farmers in Tunisia.

Agricultural water transfer or agricultural water trade may have adverse effects despite their benefits. For instance, water market forces do not benefit peasants and poor farmers by improving their access to or promoting the ownership of water supply in Chile (Bauer, 2004). Delivery reliability of irrigation water is affected by water trade and agricultural water transfer (Heaney *et al*., 2006; Hu, 2007). Grain yields and crop revenue are affected by agricultural water transfer because of the changes in irrigation water supply (Chen, 2008; Zhou *et al*., 2009; Whited, 2010). Surface water irrigation is important for wetland and groundwater recharge. Jia *et al*. (2013) showed that YinNan Irrigation District in Northwest China has maximal wetland to farmland area during the irrigation season because of the recharges from canal seepage and field percolation (Jia *et al*., 2013). Precipitation and irrigation contribute 50–1,090 mm/year recharge in the north plain of China (Wang *et al*., 2008). Therefore, the reallocation of irrigation water may have an adverse effect on the environment of the irrigation district.

The grain production of Henan Province is vital for China's food security, and the overdraft of groundwater is critical in some places in Henan Province. Roost *et al*. (2008) showed that ponds play a crucial role in adapting agriculture to reduced canal supplies after agricultural water transfer. In case of a worse supply quality of canal water after agricultural water transfer, farmers tend to use well water and pond water rather than canal water for irrigation. Therefore, understanding the change in canal water utilization degree after agricultural water reallocation is important for grain production and management of the irrigation district. However, the factors affecting the utilization degree of the irrigation water source have not been carefully investigated. Furthermore, the impact of agricultural water reallocation on the utilization degree of the irrigation water source is not yet clearly understood.

The objective of this paper is to identify the impact of agricultural water reallocation on water supply quality of the irrigation district and the utilization degree of canal water.

2. Study area

The PVCID is located in the north of Henan Province, China, and covers 99,000 ha, as shown in Figure 1 (Administration Bureau of PVCID, 2002). This area has been irrigated since 1952. Most of the irrigation water comes from the Yellow River and groundwater, and the remaining irrigation water comes from local small rivers.

The PVCID has transferred agricultural water to Xinxiang City for municipal uses since 1970. Farmers are not compensated because they hold water use rights only. Farmers are penalized during drought periods because the highest priority in allocating water is given to the urban water company. This area is dominated by a continental temperate monsoon climate, and precipitation is highly concentrated from June to September. The average rainfall in the area is 620 mm/year (Administration Bureau of PVCID, 2002). The major crop of the area is wheat, which was grown in up to 60% of the irrigated area in 2002 (Wen *et al*., 2002). The efficiency of the water delivery system is assumed to be 0.54. In 2012, the average irrigation water efficiency was 0.44 (Zhu, 2012). The present study also examines the irrigated crops in PVCID, such as winter wheat, rice, and maize. Farmers plant rice or maize after the winter wheat harvest.

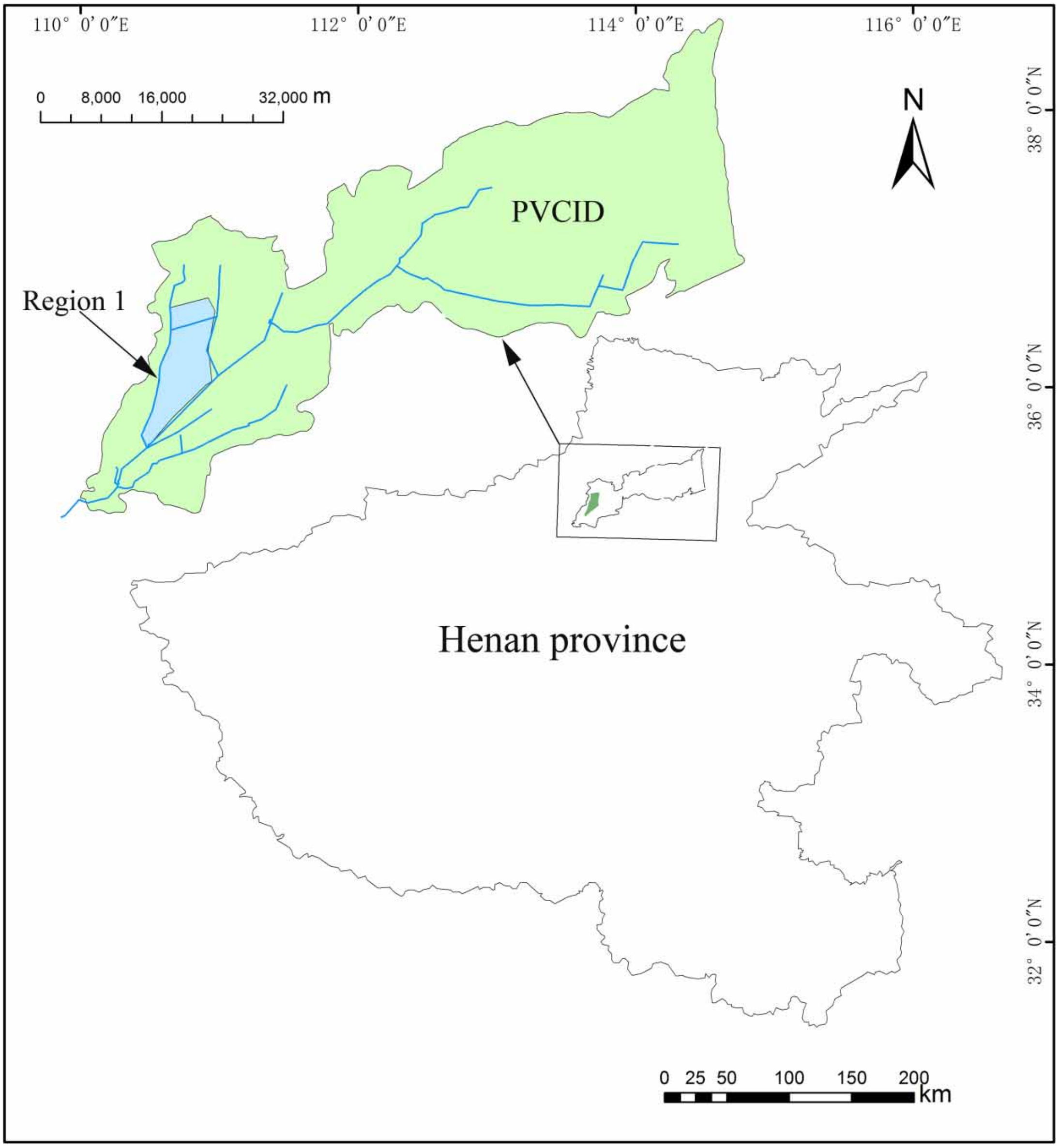

Fig. 1. Location of the study area.

3. Data sources

Data on the water supply condition and on the factors affecting the water supply condition from 1952 to 2010 were obtained from secondary sources (Niu & Liu, 1987; Administration Bureau of PVCID, 1992, 2002; Wen *et al*., 2002; Henan Province Water Conservancy Research Institute, 2012). Water supply condition data include the water diversion amount, irrigation water amount, number of days of water diversion, number of days for irrigation, and irrigated croplands. Data on the influencing factors contain precipitation and agricultural water reallocation amounts.

Household survey data were collected by field research in Region 1 of PVCID (Figure 1) in April 2013. This zone is a relatively separated area in PVCID. The water supply condition in this area varies from upstream to downstream. In addition, canal waters, well waters, and local small river waters can be used in this area, and they are convenient for the analysis of farmers' choice of irrigation water source.

Considering the distribution of the delivery system, we selected one township in the upstream, midstream, and downstream, respectively. Five or six representative villages were randomly selected from each township. In each village, we interviewed about 10 randomly selected households. Overall, the survey covered 17 villages and 182 farm households. Structured interviews were conducted with the head of each household or the person responsible for farming activities.

We developed the questionnaire based on an informal pre-survey conducted in March 2013. Interviewers who assisted the researcher in conducting the survey were trained in administering the questionnaire in a formal interview. Because farmers have minimal education, interviewers asked farmers 56 questions from the questionnaire, and wrote down the farmers' answers in the interviews. Our goal was to obtain information about the farmers' choice of irrigation water source and its influencing factors, such as delivery performance of the irrigation district, cost and risk of irrigation water, resource characteristics of the household, and characteristics of the farm household.

The survey contained a series of crop-specific questions, such as water sources of irrigation, water amount, water timeliness and water quality of different water sources, and cost of using different water sources for planting wheat, rice, and maize for the year 2012. Resource characteristics of the household were evaluated by the soil texture of the largest cropland and farmers' evaluation of precipitation in 2012, which were collected by asking farmers whether they thought the precipitation of 2012 was greater than those of previous years. Data describing household characteristics, such as age and education level of farm household head and the number of household adults at home, were also collected. Table 1 demonstrates the mean values and standard deviations of mean values for the variables used in the analyses.

4. Impacts of agricultural water reallocation on the water supply quality of PVCID

Unal *et al*. (2004) pointed out that water delivery performance in tertiaries is rated worse for adequacy, dependability, and equity than for efficiency. The equity of water delivery in PVCID was good overall according to the household survey. Thus, we evaluated the impact of agricultural water reallocation on the water delivery performance of the irrigation district by water adequacy and water timeliness. Figure 2 illustrates the variation of net irrigation water and precipitation from 1952 to 2000 in PVCID. The net irrigation water per ha per time was calculated by total irrigation water divided by total irrigated croplands in a year.

Figure 2 also shows that the PVCID net irrigation water fluctuated, tending to increase from 1952 to 1977, and tending to decrease from 1978 to 2000. The average PVCID net irrigation water was 2,890.60 m^3/ha/time from 1952 to 1977 and was 2,385.18 m^3/ha/time from 1978 to 2000. Precipitation tended to decrease between 1953 and 2000. The net irrigation water did not decrease with the decrease in precipitation unless the water resource became scarce or the crop planting proportion changed.

Table 1. Summary of the main variables affecting the utilization degree of canal water[a].

Variable description	Canal water		Canal water and well water		Canal water and substitute water	
	Wheat ($n = 53$)	Rice ($n = 38$)	Wheat ($n = 75$)	Rice ($n = 51$)	Wheat ($n = 85$)	Rice ($n = 54$)
Dependent variable						
Irrigation times using canal water	2.42 (0.85)	5.3 (1.78)				
Ratio of irrigated croplands using canal water			0.57 (0.33)	0.72 (0.31)	0.55 (0.34)	0.72 (0.31)
Independent variables						
Water delivery performance of irrigation district						
Adequacy of canal water (0 if insufficient, 2 if sufficient, 1 otherwise)	1.58 (0.72)	1.42 (0.79)	1.61 (0.76)	1.60 (0.76)	1.59 (0.78)	1.60 (0.76)
Timeliness of canal water (0 if not timely, 2 if timely, 1 otherwise)	0.45 (0.72)	0.58 (0.79)	0.55 (0.89)	0.68 (0.95)	0.56 (0.89)	0.68 (0.95)
Cost of canal water						
Water price of canal water (USD/ha/year)	117.59 (21.26)	125.9 (13.97)	131.11 (34.04)	138.19 (9.28)	126.54 (38.19)	138.19 (9.28)
Average time required for irrigation (hours/ha/time)	27.15 (17.49)	NA[b]	32.79 (26.87)	33.10 (15.6)	32.13 (25.91)	33.10 (15.6)
Risk of canal water						
Water fee charge methods (0 if before irrigation, 1 if after irrigation)	0.06 (0.25)	0.00 (0.00)	0.16 (0.37)	0.12 (0.33)	0.21 (0.41)	0.12 (0.33)
Resource characteristics						
Soil texture of the largest cropland (0 if sandy soil, 1 others)	0.94 (0.25)	0.97 (0.17)	0.94 (0.25)	0.96 (0.20)	0.91 (0.29)	0.96 (0.2)
Precipitation (0 if less than usual years, 2 if more than usual years, 1 others)	1.06 (0.63)	1.00 (0.61)	0.87(0.56)	0.92 (0.49)	0.85 (0.56)	0.92 (0.49)
Characteristics of farm household						
Age of farm household head	56.58 (10.63)	54.48 (11.11)	53.39 (11.04)	54.00 (11.02)	53.71 (11.15)	54.00 (11.02)
Educational level of farm household head: 0 if no formal education; 1 if primary school; 2 if middle school; 3 if high school; 4 if university diploma or above	1.61 (0.92)	1.7 (0.92)	1.81(0.65)	1.72 (0.74)	1.79 (0.64)	1.72 (0.74)
Number of household adults at home	2.65 (1.84)	2.73 (1.81)	2.42 (1.34)	2.60 (1.41)	2.38 (1.3)	2.60 (1.41)

Source: Household survey in the PVCID, conducted by North China University of Water Resources and Electric Power in 2013.
[a]The standard deviation (S.D.) is in parentheses.
[b]NA: not analyzed for lack of data.

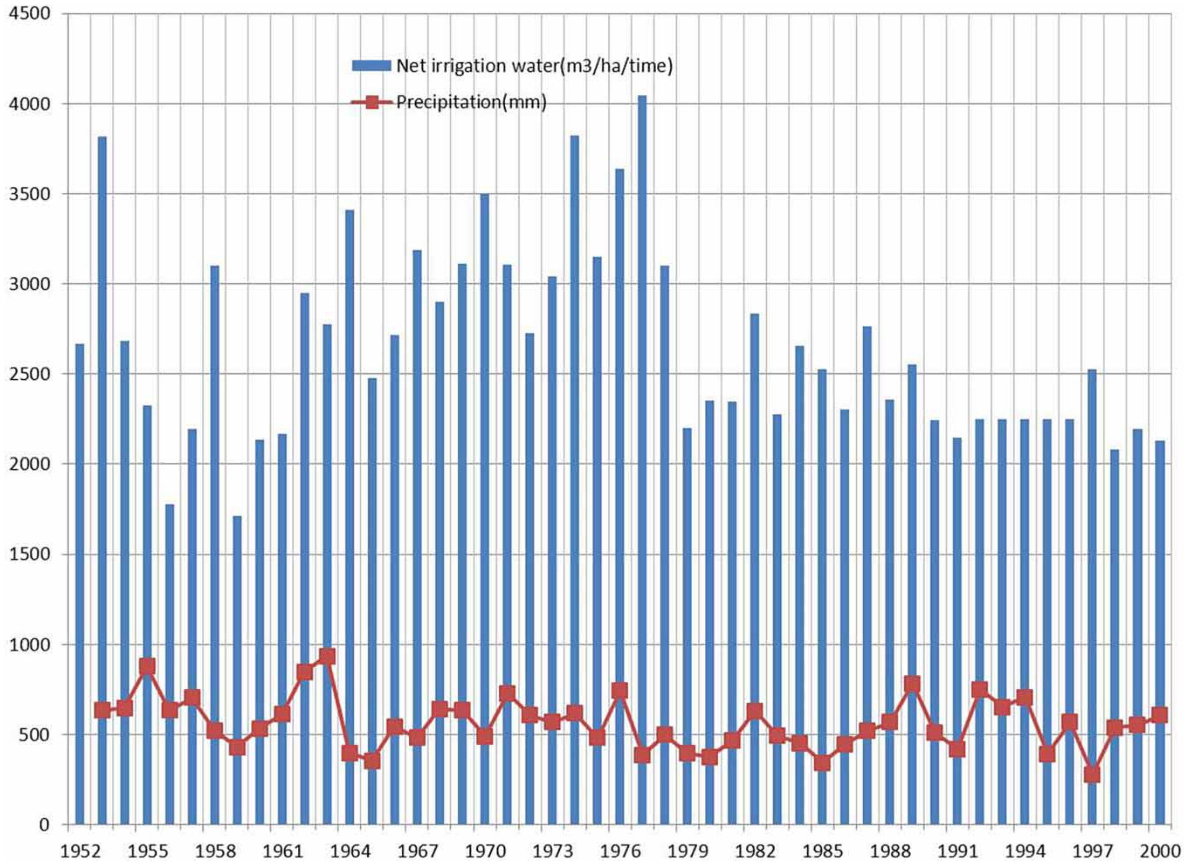

Fig. 2. Variation of net irrigation water and precipitation from 1952 to 2000 in PVCID.

Therefore, the water resource of PVCID was scarcer than before because the crop planting proportion was also affected by the water resource condition.

Figure 3 shows the variation of water diversion amount and irrigation water amount from 1952 to 2010 and the water amount transferred to the city from 1982 to 2010. Although the water was actually transferred beginning 1970, the figure only shows water transferred beginning 1982 because of the lack of water transfer amount data from 1970 to 1981. Figure 3 further shows that water diversion amount and irrigation water amount fluctuated and had a decreasing trend from 1961 to 1964 and from 1977 to 2004. This finding is in accordance with the decrease in average net irrigation water from 1978 to 2000. The water diversion amount and irrigation water amount significantly decreased from 1961 to 1964 because of the large areas of land salinization due to unsuitable irrigation. The water diversion amount and irrigation water amount decreased from 1977 to 2004 because of the cut-off of the Yellow River.

Water transfer to the city did not have a large variation before 2004, and it increased significantly from 2005 to 2010. The average amount of water transferred to the city was 46.78 million m^3 from 1982 to 2004 and was 190.22 million m^3 from 2005 to 2010. This finding indicates that the decrease in net irrigation water per ha was mainly caused by the decrease in water diversion before 2004 and by the decrease in water diversion and increase in water transferred to the city after 2004.

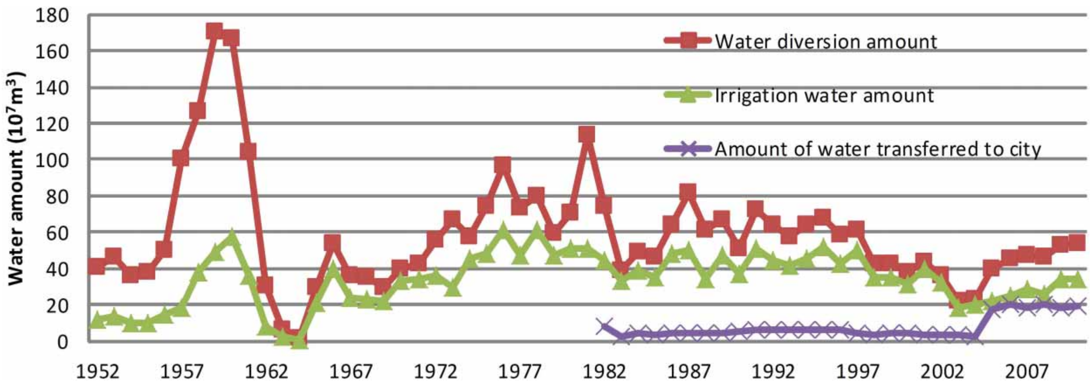

Fig. 3. Variation of the main water uses from 1952 to 2010 in PVCID.

Figure 4 shows that the irrigation water amount changed with the amount of water diversion, but the rate of this change varied in different periods. The irrigation water amount demonstrated a significant change with the amount of water diversion from 2005 to 2010, and it changed the least with the amount of water diversion from 1952 to 1969. Water resource was scarcer than before in PVCID beginning 1977, and the amount of agricultural water transfer significantly increased beginning 2004. This finding explains how irrigation water will be greatly affected by water reallocation if water diversion significantly decreases. Moreover, agricultural water reallocation increases the unreliability of irrigation water in PVCID.

The timeliness of canal water supply through the years is difficult to evaluate. The number of days for irrigation was used to measure the timeliness of canal water supply because the long delay of canal water would result in the cancellation of irrigation. Figure 5 illustrates the variation in the number of days of water diversion and the number of days for irrigation from 1952 to 2010 in PVCID.

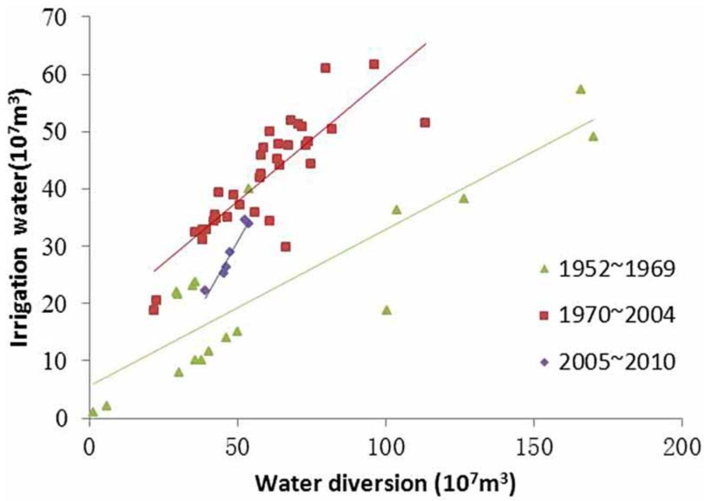

Fig. 4. Relationship between water diversion and irrigation water in different periods from 1952 to 2010 in PVCID.

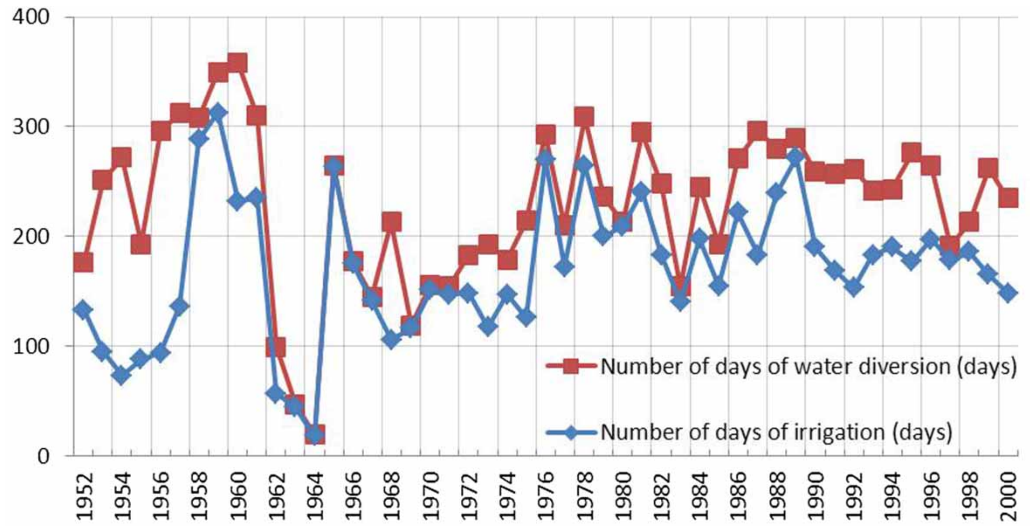

Fig. 5. Variation of the number of days of water diversion and the number of days for irrigation from 1952 to 2010 in PVCID.

Figure 5 also shows that the number of irrigation days fluctuated and tended to decrease from 1960 to 1964, 1965 to 1968, and 1977 to 2000. This result is in accordance with the decrease in water diversion and irrigation water amount from 1961 to 1964 and from 1977 to 2004. These changes could also be explained by land salinization and the cut-off of the Yellow River.

Figure 5 shows that the number of days for irrigation changes with the number of days of water diversion. The difference between the number of days of water diversion and the number of days for irrigation can reflect the surplus of water diversion to irrigation, which varies with time. This difference tended to decrease from 1952 to 1967 and to increase from 1968 to 2000, while the agricultural water was actually transferred beginning 1970 in the PVCID. The difference between the number of days of water diversion and the number of days for irrigation nearly increased at the same time as agricultural water transfer because the water supply duration for the city is longer than for irrigation. Therefore, water transfer to the city affects the timeliness of canal water supply by reducing the number of days for irrigation and the reliability of canal water.

5. Factors affecting the utilization degree of canal water

5.1. Utilization degree model of canal water

The surveyed farmers irrigated their croplands with canal water, well water, or local small river water. Water sources of their croplands are shown in Table 2. About 29% of the surveyed farmers could irrigate their croplands only with canal water, 45% with canal water and well water, and 52% with canal water and substitute water, such as well water and local small river water. We analyzed the impacts of agricultural water supply quality on the utilization degree of canal water if only canal water, canal water and well water, and canal water and substitute water were available.

Table 2. Water sources of croplands of surveyed farmers.

	Only canal water	Canal water and well water	Canal water and local small river water	Canal water , well water, and local small river water	Others	Total
Households	53	81	12	6	30	182
Ratio	29%	45%	7%	3%	16%	100%

Source: Household survey of authors.

The utilization degree model of canal water is specified as follows:

$$Y_i = x_i\beta_i + \varepsilon_i \tag{1}$$

where Y_i is the variable indicating the canal water utilization degree of the i-th farmer. x_i is the vector of explanatory variable, and β_i is the corresponding regression coefficient.

The variables, their sources, and the rationale for inclusion in the models are presented in Table 1. Utilization degree of canal water is defined as irrigation times using canal water if only canal water can be used. Utilization degree of canal water is defined as the ratio of irrigated croplands using canal water if several water sources can be used. Its function is defined in Equation (2):

$$K = \sum_{j=1}^{n} A_{Cj} / \sum_{j=1}^{n} (A_{Cj} + A_{wj} + A_{Rj}) \tag{2}$$

where K is the ratio of irrigated croplands using canal water. A_{Cj}, A_{Wj}, and A_{Rj} are the area of irrigated croplands using canal water, well water, and local small river water in the j-th irrigation, respectively.

Cost of canal water was evaluated by water fee and time required for irrigation using canal water. The water fee is paid to the Administration Bureau of PVCID and is collected by village collectives or contractors depending on the management pattern. The water fee of canal water was calculated using the average conversion rate of US dollar to Renminbi (CNY) in 2012 (1 USD = 6.3 CNY). Risk of canal water was evaluated by water fee charge methods. Farmers may suffer greater risk if they pay the irrigation fee before irrigation because canal water is not timely. Labour resources may constrain the utilization degree of water source, which needs more labour to use. Labour resources are represented by the number of household adults at home. We used the number of household adults at home rather than the number of household adults because some household adults are off-farm workers. Greater levels of water scarcity were expected to increase the uptake of substitute water sources for canal water.

5.2. Regression results

We analyzed the data with linear regression using IBM SPSS Statistics. The linear regression results are shown in Table 3 using the variables for the utilization degree of canal water under different water sources in planting wheat and rice. The utilization degree of canal water in planting maize was not analyzed because of the lack of data.

Timeliness of canal water was slightly significant and positive for the utilization degree of canal water in wheat planting if canal water and well water could be used. However, it was not significantly

Table 3. Estimated linear regression model for the utilization degree of canal water[a].

	Canal water		Canal water and well water		Canal water and substitute water[b]	
	Wheat	Rice	Wheat	Rice	Wheat	Rice
Water delivery performance of irrigation district						
Adequacy of canal water	0.43 (0.36)	0.13 (0.50)	0.09 (1.07)	0.08 (0.84)	0.08 (0.98)	0.08 (0. 91)
Timeliness of canal water	0.28 (0.25)	0.54 (0.42)	0.14* (1.97)	0.03 (0.40)	0.11 (1.41)	0.01 (0.08)
Cost of canal water						
Water price of canal water	−0.008 (0.01)	−0.05** (0.02)	−0.0003 (−1.05)	−0.001 (−0.05)	−0.003 (−1.5)	0.004 (0.86)
Average time required for irrigation	0.01 (0.01)	NA1[c]	0.0009 (0.39)	−0.01 (−1.38)	0.003 (1.06)	−0.008 (−1.28)
Risk of canal water						
Water fee charge methods	−1.97* (1.06)	NA2[d]	0.06 (0.32)	−0.17 (−0.48)	0.13 (0.87)	−0.21 (−0.63)
Resource characteristics						
Soil texture of the largest cropland	−1.1 (0.87)	−1.10 (1.92)	0.44* (1.98)	0.05 (0.13)	0.45* (1.98)	0.15 (0.50)
Precipitation	0.07 (0.34)	1.23* (0.61)	0.17 (1.36)	0.15 (0.88)	0.12 (1.00)	0.20 (1.28)
Characteristics of farm household						
Age of farm household head	−0.01 (0.02)	−0.06* (0.03)	−0.0003 (−0.04)	−0.02 (−1.65)	0.004 (0.6)	−0.02 (−1.62)
Educational level of farm household head	0.38 (0.24)	0.03 (0.4)	−0.01 (−0.14)	−0.04 (−0.30)	−0.01 (−0.06)	−0.01 (−0.08)
Number of household adults at home	−0.06 (0.10)	0.19 (0.19)	0.03 (0.64)	0.06 (0.93)	0.02 (0.42)	0.08 (1.46)
Constant	3.58 (1.90)	13.96 (4.09)	−0.01 (−0.02)	1.90 (0.91)	−0.15 (−0.33)	0.96 (0.78)
Number of households	53	38	71	51	85	54
R^2	0.34	0.41	0.54	0.45	0.45	0.53

[a]The *t* statistics are in parentheses. **significance at 5%, *significance at 10%.
[b]Substitute water includes well water and local small river water.
[c]NA1: not analyzed for lack of data.
[d]NA2: not analyzed as the water fee is charged before irrigation in all samples.

associated with the probability of adopting canal water in other cases. This result implies that timeliness of canal water is an important factor affecting the utilization degree of canal water, especially if alternative water sources can be utilized. Well water can be used any time and local small river water can be used freely unless there is no water. Timeliness of canal water is the worst among the water sources in PVCID. According to the farmers' interviews, the longest delay of PVCID canal water supply was 55 days for wheat and 45 days for rice, which indicates that the delay of canal water is more serious in wheat planting than in rice planting.

Adequacy of canal water was not significant in the choice of canal water in any case. The water amount of well water was almost adequate except in the arid season. The water amount from a local small river was more insufficient and unstable than those of canal water and well water. Farmers may use well water for irrigation if the canal water is insufficient. Based on the farmers' interviews, canal water was usually adequate if it was supplied on time. This finding reveals that the timeliness of canal water is more important than the adequacy of canal water in choosing canal water.

The water price of canal water had a significant and negative association with the utilization degree of canal water in rice planting if only a canal water source was available. This finding indicates that the economic cost of irrigation is an important factor affecting the utilization degree of the water source. The average water price of canal water was 133.21 USD/ha/year or 23.94 USD/ha/time; the average cost of irrigation using well water was 66.75 USD/ha/time; and the average cost of irrigation using a local small river water was 37.89 USD/ha/time. The cost of canal water was the lowest, whereas the cost of well water was the highest because of the lack of electric power lines and high oil price. Therefore, the cost of canal water is not significant for the utilization degree of canal water if several water sources can be used.

Water fee charge methods had a slightly significant and negative relationship with the utilization degree of canal water in wheat planting if only a canal water source was available. The water fee is charged before or after irrigation in PVCID. Farmers are restricted to use more canal water for irrigation if the water fee is charged before irrigation. The water fee is not refunded or discounted even if the water delivery performance is poor in PVCID. Farmers face more risk of losses if the water fee is charged before irrigation if the canal water supply is not timely.

Soil texture of the largest cropland had a slightly significant and a positive association with the utilization degree of canal water in wheat planting if canal water and well water source could be used and if all canal water, well water, and local small river water could be used. Cropland with sandy soil required great irrigation frequency. Farmers had to use well water to irrigate their croplands in the intervals between canal water supply, as canal water was supplied in accordance with a schedule in PVCID.

Precipitation had a slightly significant and positive relationship with the utilization degree of canal water in rice planting if only canal water could be used. Farmers no longer need to irrigate with well water in the intervals between canal water supply if precipitation is sufficient.

Age of farm household head had a slightly significant and negative association with the utilization degree of canal water in rice planting if only canal water could be used. A possible reason for this is that older farmers use more additional water, such as well water, to irrigate because crop income is more important for them as they lack the ability to do off-farm work.

The other explanatory variables lacked statistical significance. This finding may indicate that these variables do not affect the utilization degree of canal water or that they are not good indicators of the factors affecting the utilization degree of canal water.

5.3. Potential factors affecting the utilization degree of canal water

We noted some additional factors affecting the utilization degree of canal water, such as water quality and irrigation flow of water source, labour cost of irrigation using water source, and management pattern of irrigation at the village level according to the household survey.

The water quality of local small rivers was bad, whereas that of other water sources was generally good. Nevertheless, the water quality of the Yellow River water was the best for crops according to the household survey. In places with alkaline soil, farmers had to use canal water for salt leaching. Some of the interviewed farmers used well water to dilute the contaminant in the local small river water to avoid crop failure. Table 1 shows that the ratios of the irrigated croplands using canal water are 0.57 and 0.72 in planting wheat and rice, respectively, if canal water and well water can be used. The ratios change to 0.55 and 0.72 if canal water and well water or local small river water can be used, respectively. The possible reason for this is that wheat is more sensitive to bad water quality and needs less water than rice.

Irrigation flow is important for the utilization degree of canal water. A water source with high irrigation flow can save much irrigation time for the farmers as the price of labour in China is high. Irrigation flow of canal water is the greatest. The irrigation flow of well water and local small river water depends on pumping capacity. Table 4 illustrates the average time needed to irrigate different crops using different water sources and shows that the irrigation time using local small river water is the shortest and that using well water is the longest. Irrigation time using canal water is not the shortest probably because the flow of canal water decreases in the downstream of the canal.

Labour cost of irrigation includes installing and removing the pump and pipelines as well as monitoring irrigation. Installing and removing of equipment are no longer needed to irrigate using canal water. Farmers do not have to monitor irrigation when they use canal water because the water fee is not charged by the amount of water. In PVCID, farmers usually open a hole on the ridge of their farmland to bring canal water in and then go home; they would come back to block the hole hours later. Only one person is needed to irrigate using canal water, and women or old farmers can do this work easily. The labour cost of canal water is the lowest with this water use habit, but the waste of canal water is high.

An average of two persons and 0.95 h are required to install a pump and pipelines, and two persons and 0.87 h are needed to remove the pump and pipelines to irrigate using well water. Women and old farmers lack the physical power to install and remove the pump because of the lack of electric power lines.

Table 4. Irrigation time of crops using different water sources (hours/ha/time).

	Wheat		Maize		Rice	
	Irrigation time	No. respondents	Irrigation time	No. respondents	Irrigation time	No. respondents
Local small river water	21.15	10	18.60	5	15.00	1
Canal water	24.15	124	19.35	36	28.50	79
Well water	35.25	86	28.65	29	30.60	47

Source: Household survey by the authors.

The labour cost of installing and removing equipment when using local small river water is nearly the same as that of using well water. Farmers usually monitor irrigation all the time because the waste of water directly increases the pumping fee if they use well water and local small river water to irrigate. Irrigation using well water or local small river water can save much water, but the labour cost of using these water sources is high.

Canal water is provided by village collectives or contractors in the study area of PVCID. Table 5 shows the ratio of irrigated croplands using canal water under different management patterns in 2012 with water sources of canal water and well water or local small river water. Farmers use more canal water to irrigate all crops if canal water is provided by the contractors. This scenario indicates that the contract management of canal water is more effective than village collective management. Therefore, management pattern is a potential factor affecting the utilization degree of canal water.

Water management of the village collective has several shortcomings compared with that of contractors according to the household survey in PVCID. The contractors are private in canal water supply in the PVCID. Some of the village collectives signed contracts with the contractors to prevent further exploitation and injustice. Most of the water supply under the management of contractors is fair according to the household survey. First, village cadres do not have time to improve canal water supply performance because they are too busy with their heavy government tasks after the merging of small villages into one large village. Contractors have enough time to improve the canal water supply because they have fewer tasks than village cadres.

Second, village cadres do not have incentives to improve canal water supply because they cannot earn profit through canal water management. The contractors do have incentives to improve the canal water supply because they can earn profit through canal water management, and farmers do not pay the water fee if the canal water supply is poor.

Third, many farmers do not pay the water fee because they have conflicts with village cadres or because the village collective owes them money under the management of the village collective. Farmers have no reason to repudiate the water fee even if they have conflicts with village cadres because contractors have no connection with the village collective under the management of contractors.

Fourth, farmers are difficult to organize to maintain the canals because of the lack of labour force and the farmers' tendency to obtain a free ride. Conversely, contractors can employ people to maintain the canals.

Fifth, the management of a village collective is difficult to supervise. Conversely, the contractors of canal water management in some villages are chosen through competitive bidding. Moreover, the contractors can be supervised by the village collective. On the other hand, some contractors are not subcontracted with the village collective, and some contracts are ambiguous and ineffective in the PVCID. Contract management should be improved in the management of canal water.

Table 5. Ratio of irrigated croplands using canal water under different management patterns.

	Wheat	Rice	Maize
Village collective management	0.48	0.62	0.32
Contract management	0.54	0.63	0.73
Total	0.50	0.62	0.49

Source: Household survey by the authors.

6. Compensation methods in agricultural water transfers

The adverse effects of agricultural water transfer to the irrigation district are mainly compensated by projects or funds in China. For instance, compensation projects include water-saving projects (e.g., canal lining), water source projects (e.g., well digging), and crop planting adjustment (e.g., converting rice production areas to dryland farming) (Zhou *et al*., 2009). The compensation fee is mainly calculated on the basis of the construction cost of compensation projects, and the compensation fee in some of the cases is calculated by the substitute cost of the transferred water resource.

The canal lining method only reduces the seepage of canals, but it cannot increase agricultural water if no sufficient agricultural water can be delivered to canals, and it cannot compensate the timeliness of canal water. The well-digging method can partly increase the reduced water sources, but it may have a further adverse impact on groundwater resources, management of canals, and salinization of soil. The method of crop planting adjustment can decrease water demand of the crop, but it may also decrease the income of farmers.

The government invested in canal lining and well digging in PVCID after agricultural water transfer. Some farmers dug new wells by themselves, and some farmers converted rice production areas to maize production areas. These methods did not change the poor water supply performance of PVCID. The maximum groundwater depth of monitoring wells in PVCID increased from 6.75 m in 2000 to 16.18 m in 2008 according to the monitoring data of the Administration Bureau of PVCID. Some croplands with high soil salinity faced the risk of salinization after increasing irrigation with well water. The lined canals were gradually discarded with the decrease in canal water use, which squandered the government investment. According to the household survey, the average yields of wheat, rice, and maize were 3,609, 2,949, and 2,563 kg/ha, respectively, in 2012. Therefore, the conversion of rice to maize affects the grain yield of the irrigation district.

Comprehensive reforms are required to mitigate the potential adverse effects of water transfers (Rosegrant & Ringler, 2000). Suitable compensation methods should consider the decrease in probability of agricultural water source after water transfer, the countermeasures of farmers to agricultural water transfer, and the additional adverse effects of these countermeasures and compensation methods.

The recommendations to compensate for the adverse effects of agricultural water transfer are as follows: (1) invest in water source projects such as wells, ponds, and small pump stations aside from agricultural water-saving projects to compensate for the decrease in probability of agricultural water source; (2) construct more electric power lines in farmlands, especially in the areas with pumping irrigation; (3) organize a suitable rotation irrigation and an efficient exchange of irrigation information between the irrigation district administration and the farmers to improve the canal water supply at the district level; (4) choose a suitable management pattern, such as contract management, to improve the canal water supply at the village level, and improve the contract between the contractors and the village collective; (5) charge the water fee after irrigation and discount the water fee according to the performance of the canal water supply to reduce canal water risk; and (6) charge the water fee based on irrigation time or the amount of water rather than on irrigation areas of croplands to encourage farmers to save water.

7. Conclusions

This study analyzes the impact of agricultural water reallocation on water supply quality of the irrigation district and the utilization degree of canal water. The results show that water amount, water supply timeliness, and reliability of irrigation water in PVCID are affected by agricultural water reallocation, especially when the amount of water diversion significantly decreases. The timeliness of canal water significantly affects the utilization degree of canal water. Water price of canal water, water fee charge methods, soil texture of the largest cropland, precipitation, and age of farm household head are significant factors affecting the utilization degree of canal water. Water quality and irrigation flow of the water source, labour cost of irrigation using the water source, and management pattern of irrigation at the village level are potential factors affecting the utilization degree of canal water. Existing compensation methods hardly compensate for the decrease in reliability of irrigation water, which may affect groundwater resources, management of canals, and soil texture. Better compensation methods are needed to achieve social equity in agricultural water reallocation.

This quantitative analysis on the impact of agricultural water reallocation on the water supply quality in PVCID has limitations because of the lack of data. Further research should include the potential factors in the utilization degree model by enlarging the sample size.

Acknowledgements

This study was supported by the ‘948’ Project of the Ministry of Water Resources of China (Grant No. 201328), the Plan for Scientific Innovation Talent of Henan Province in China, the Major Science and Technology Research Project of the Education Department of Henan Province (Grant No. 14A570003), the Support Plan of the Education Department of Henan Province for Science and Technology Innovation Teams (Grant Nos 141RTSTHN028 and 15IRTSTHN030), the Key Projects in the National Science and Technology Pillar Program during the Twelfth Five-year Plan Period (Grant No. 2012BAC19B00), and the Plan for Introduced High Level Talents of North China University of Water Resources and Electric Power (201066/001337).

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Received 12 August 2014; accepted in revised form 1 February 2015. Available online 24 March 2015