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TECHNICAL REPORT

R. Loeve · L. Hong · B. Dong · Guo Mao · C. D. Chen ·
D. Dawe · R. Barker

Long-term trends in intersectoral water allocation and crop water productivity in Zhanghe and Kaifeng, China

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Abstract This paper examines the trends in water allocation among sectors, water use by source, cropped area, crop production and water productivity. The study was undertaken at two sites in China: the Zhanghe Irrigation District in the Yangtze River Basin approximately 200 km west of Wuhan and Kaifeng City Prefecture located just south of the Yellow River in Henan Province. In both areas, water demand for purposes other than irrigation has grown. In the Zhanghe Irrigation District this resulted in a sharp reduction of water availability for irrigation. The decline of water availability for irrigation resulted in adoption of water saving practices and policies that led to a significant gain in water productivity per unit of irrigation water. In the Kaifeng City Prefecture the increased demand from other uses was met by an increase in groundwater extraction without the dramatic cuts in supplies for agriculture as in the Zhanghe Irrigation District. Gains in water productivity were due almost exclusively to higher crop yields. There will be continuing pressure to further reduce diversions to agriculture from the Zhanghe main reservoir in the Zhanghe Irrigation District and from the Yellow River in Kaifeng. Research continues on testing practices that have the potential for further increasing water productivity, some of the results of which are reported in other papers in this volume.

Keywords Trend analysis · Crop production · Water saving · Irrigation · Water allocation · Water productivity · Hubei · Henan

R. Loeve (✉)
Future Water,
Eksterstaat 7, 6823, DH Arnhem, The Netherlands
e-mail: r.loeve@futurewater.nl

R. Barker
International Water Management Institute (IWMI),
P.O. Box 2075, Colombo, Sri Lanka

L. Hong · B. Dong
Department of Irrigation and Drainage Engineering,
Wuhan University,
430072 Wuhan, China

G. Mao
Kaifeng Yellow River Diversion Management Section (YRDMD),
Kaifeng, Henan, China

C. D. Chen
Zhanghe Administrative Bureau,
448156 Jingmen, China

D. Dawe
International Rice Research Institute (IRRI),
DAPO Box 7777, Metro Manila, Philippines

Introduction

Major efforts have already been made to save water in irrigated rice areas and there is much to learn from previous efforts, particularly in China, where researchers and practitioners have pioneered and developed many practices for farmers to deliver less water to their fields. These methods are collectively known as water-saving irrigation (WSI) practices and many success stories are reported (Wang 1992; Mao 1993; Li and Cui 1996; Peng et al. 1997; Li et al. 1998; Wu 1998; Li 1999; Belder et al. 2004), such as alternate wet and dry irrigation (AWD), which has spread in South China (Li et al. 1999). Li et al. (2003) give an extensive overview of the developments in WSI research in China.

This paper describes the changes in water allocation, crop production, and water productivity over a period of three decades in the Zhanghe Irrigation District (ZID) in the Yangtze River Basin, Hubei Province and in Kaifeng City Prefecture, along the Yellow River in Henan Province (Fig. 1).

First the research locations are described in more detail, after which the sources of data and the rationale for dividing and averaging the data across three separate time periods are discussed. The changes over time in water allocation among alternative uses are described followed by a description of the changes in area irrigated, crop production, and crop productivity. Finally, the factors that may have contributed to temporal increases in crop production and water productivity will be discussed.

Study site and methodology

This section describes briefly the two study site locations in the Yangtze and Yellow River Basins and the procedures for analysis of data by trend and time period.

The Zhanghe Irrigation District

The Zhanghe Irrigation District is situated in Hubei Province in central China, north of the Yangtze river about 200 km west of Wuhan (Fig. 1). The area of the Zhanghe basin is 7,740 km^2 including a catchment area of 2,200 km^2. Until recently, the Zhanghe irrigation system (ZIS) accounted for most of the irrigated area within the irrigation district, with an irrigated area of 160,000 hectares. Traditionally, the Zhanghe reservoir supplies most of the ZIS irrigation water, however there are tens of thousands of medium or small reservoirs, small basins and pump stations in the area partly incorporated into the system but sometimes operating independently. The main grain crops are rice and winter wheat. The upland crops are beans, sesame oil and sweet potatoes. Paddy cultivation accounts for about 80% of the total irrigated area. Loeve et al. (2001) describe in detail the layout and operation of ZIS.

Kaifeng City Prefecture

Kaifeng City Prefecture is located on the south bank of the Yellow River, 70 km east of Zhengzhou the capital of Henan Province (Fig. 1). It has a total area of 6,644 km^2 of which 363,300 ha are cultivated. There are four irrigation districts located within Kaifeng City Prefecture, of which Liuyuankou Irrigation System is studied in more detail. Loeve et al. (2003) give an overview of the history and physical characteristics of Kaifeng City Prefecture, Liuyuankou irrigation district and System. By the end of 2000, the actual irrigated area of Kaifeng City Prefecture was 327,000 ha, accounting for 90% of the cultivated land in Kaifeng City Prefecture. About 133,000 ha (40% of the actual irrigated area) is directly irrigated by Yellow River water. The main crops are corn, soybean, cotton and peanuts, with some rice in surface irrigated areas. In the winter season wheat is the most important crop. To place Kaifeng and its irrigation districts in context Dong et al. (2003) give an overview of the history and current issues of the irrigation districts in Henan Province along the Yellow River.

Fig. 1 Location of Zhanghe Irrigation District and Kaifeng City Prefecture in China

Analysis of data by trend and time period

The time series on which this paper is based were compiled by ZID for the period 1966 to 2002 and by Kaifeng City Prefecture for the period 1968 to 2000. The figures in the text show the trends over time. In the tables, however, mean values are shown for three separate time periods, 1966 (or 1968)–78, 1979–88 and 1989–98 (or 2002). This division was made to reflect the very sharp changes that occurred at the end of the first and second time periods (according to Hong et al. 2001).

Following the end of the Cultural Revolution in the late 1970s, significant reforms took place that affected both irrigation and agricultural production. Introduction of improved varieties and increased use of chemical fertilizers led to a sharp increase in rice yields. In ZID, volumetric pricing of irrigation water was introduced. New pumping stations were built. Medium- and small-size reservoirs were restored or expanded. In Kaifeng Prefecture, the Yellow River diversions dropped dramatically.

The end of the 1980s saw further changes. Industrial and municipal demand rose, resulting in an increased competition between water for agriculture and other uses. The introduction of hybrid rice in ZID gave a further boost to rice yields. In ZID the installation of two new hydropower plants greatly increased the hydropower capacity. The pressure to save water led to an expansion of alternate wetting and drying irrigation (AWD) practices at the farm level and to other water-saving practices.

Recent reports from ZID indicate dramatic changes from 2002 onwards which might justify the start of a new period. In 2002, ten provinces, including Hubei, implemented a new policy regulation described as *fee gai shui* or literally changing from a water fee to a tax. Farmers have to pay (part) of their water tax in advance. In 2002 reservoir releases dropped dramatically but rice production remained fairly stable. Time will tell how much of this water saving can be attributed to the new policy or to favorable weather conditions in 2002. In this paper the year 2002 is included in the third period (1989–2002).

Long-term trends in the Zhanghe Irrigation District (ZID) and system (ZIS)

This section presents the analysis of long-term trends in water use, crop production, and irrigation water productivity for the Zhanghe Irrigation District and system and concludes with a discussion of the factors contributing to the increase in crop production and water productivity.

Water allocation among alternative uses

Over the past three decades, with the increase in population and industry, the water demand from municipal, industry, and power generation has increased (Fig. 2). Jinmen city, a few kilometers from the Zhanghe main reservoir, is a new industrial city and has developed quickly in recent years. Figure 2 also shows the 5-year moving average for both irrigation and other uses to reduce the major fluctuations over the years and to better visualize the trend.

In ZIS most of the irrigation water supply comes from the Zhanghe Reservoir supported by medium and small size reservoirs and supplemented by pumping stations. A large (partly) interconnected irrigation network including storing, diverting, and withdrawing water has been established.

In the 1960s the main reservoir supplied three quarters of the irrigation water, but in the last decade it supplied only half of the total water for irrigation (Table 1). The water supply for irrigation from the main reservoir has dropped sharply since the mid-1980s. Despite the sharp drop in the water supply from the reservoir during 1979–88, the total water supply for irrigation declined only slightly. In the 1980s a number of medium size reservoirs and ponds were restored or constructed to increase water-storing capacity, which evened out farm-level water availability from year to year and provided greater water control during the cropping season, facilitating water saving through alternate wetting and drying irrigation techniques on field level. However from the mid-1980s onward the water supply from small reservoirs and other sources declined. This seems to be due to the fact that many of the medium and small sized reservoirs became physical and financial independent from the main reservoir and its organization and were technically no longer a part of ZIS.

The water supply for other uses (Fig. 2) has increased rapidly especially during the 1990s. The largest increase in water allocation was for hydropower, followed by industry and municipal water (Table 2). In contrast to most

Fig. 2 The Zhanghe Reservoir, Hubei, China. Allocation for irrigation and other uses (municipal, industry, hydropower and flood releases), 1966–2002, (adjusted from Hong et al. 2001)

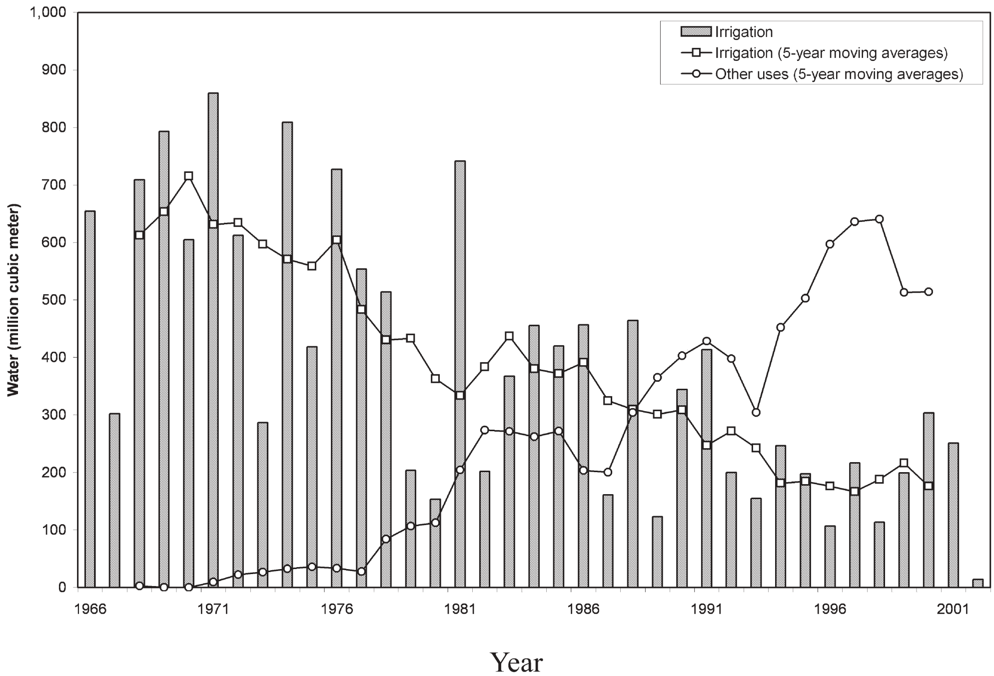

Table 1 Water supplied for irrigation in ZIS, by source

	Million cubic meters×100			
Period	Main reservoir	Small reservoirs	Other sources	Total
1966–1978	6.03	1.50	0.96	8.50
1979–1988	3.62	2.47	1.65	7.74
1989–2002	2.06	1.07	0.65	3.78

Table 2 Water releases Zhanghe reservoir

Period	Average water use in million cubic meter×100					Rainfall
	Irrigation	Industry	Municipal	Hydropower	Flood control	(mm)
1966–1978	6.03	0.17		0.25	0.15	952
1979–1988	3.62	0.37	0.09	0.53	2.27	968
1989–2002	2.06	0.47	0.17	2.88	1.83	945

Table 3 Command area and area irrigated in ZID and ZIS

Period	Area in 1000 ha					
	ZID command area		ZID irrigated area		ZIS irrigated area (directly by reservoir)	
	Total	Rice	Total	Rice	Total	Rice
1966–1978	150	138	143	138	134	130
1979–1988	156	142	140	134	105	100
1989–2002	142	124	125	112	82	76

Table 4 Changes in rice planted area, production, yield and water productivity in ZID

Period	Rice			Water supplied	$WP_{irrigation}$	$WP_{irrigation}$ [1]
	Planted area	Production	Yield			
	ha×1,000	t×1,000	t ha^{-1}	100×MCM	kg m^{-3}	kg m^{-3}
1966–1978	173	698	4.04	8.50	0.87	1.11
1979–1988	149	1,001	6.72	7.74	1.44	1.10
1989–2002	117	933	8.03	3.78	3.50[2]	2.17[3]

[1] To eliminate the influence of yield increases on the water productivity the yield of 1978 (5.1 t ha^{-1}) is taken to calculate production in all years

[2] In 2002 the water diversion was extremely low, but yield and production decreased only slightly resulting in a very high $WP_{irrigation}$. If the year 2002 was not taken into account the $WP_{irrigation}$ would be 2.55 kg m^{-3}

[3] See note 2. If the year 2002 was not taken into account the $WP_{irrigation}$ would be 1.63 kg m^{-3}

irrigation systems, the water flowing through the generators cannot be diverted back to irrigation.

The water allocated to hydropower during 1989–2002 exceeded the water allocated to irrigation. As a result of the growth in demand by hydropower and other sectors, the amount of water from the Zhanghe main reservoir allocated to irrigation in the past decade declined to one third of its 1966–78 level (603 to 206 million m^3).

Changes in cropped area

Table 3 shows the crop area irrigated in ZID and by ZIS for three time periods. Most of the irrigation is for rice. During 1966–78, the area irrigated in ZID and by ZIS approximated the command area. However, at the beginning of the 21st century, the irrigated rice area declined substantially compared to the 1979–88 period.

During 1999–2002, the irrigated rice area declined by 29% in ZIS and by 30% in ZID compared to 1985–88. While this decline is large, it is much less than the 63% decline in total irrigation water supplied over the same period. Hong et al. (2001) describe in more detail the development over time of the irrigated rice area in ZIS and ZID up to 1998.

Changes in crop production

Table 4 presents rice production, planted area, yield and water productivity for ZID. Rice production rose sharply during 1979–88 compared to the previous period despite a decline of 14% in the planted area. This can be attributed to the rapid increase in rice yields due to the spread of modern varieties and increased use of chemical fertilizers following the change in agricultural policies at the end of the Cultural Revolution. Over the three time periods the rice yield doubled. When the rice area began to decline substantially by the second half of the 1990s, rice production followed suit as yield growth had slowed to almost nothing. Comparing 1999–2002 with 1985–88, the rice area declined by 29% while average yields rose by 11%. The net effect was a 21% fall in rice production. To some extent, this was compensated for by increased production of (non-irrigated) upland crops.

The total water supply for irrigation in ZID is unknown, except for the water supply in ZIS. However, it can be assumed that the main supply of water to areas in ZID not served by ZIS is the ZIS drainage water, and using this information it is possible to estimate the change in water productivity over time. This assumption seems reasonable as in 1966–78 the area irrigated by ZIS and ZID was almost identical (Table 3). However, to the degree that this assumption does not hold, the water productivity values shown in Table 4 represent an overestimate (Hong et al. 2001). If gains in production per unit area were not due to improved water management, then it is interesting to remove the influence of these yield increases by assuming that yields throughout the period 1968 to 2002 were constant at the levels prevailing in 1978, just before the reforms began (holding yields constant at the level of any specific year will give similar results). After making these adjustments, we then calculated an alternative measure of water productivity over time, changes in which are due primarily to improved water management that reduces the amount applied per unit area and shifts in cropping patterns. Table 4 shows that even after removing the influence of yield increases substantial gains in water productivity are observed that can be attributed to improved water management techniques.

Factors contributing to the increase in crop production and water productivity

In the Zhanghe Irrigation District long-term trends in water allocation across sectors and in production per hectare and per cubic meter of irrigation water show that there have been water savings and a considerable increase in irrigation water productivity water over time (Hong et al. 2001). Despite the decline in water for irrigation from the reservoir and in the area irrigated in ZID, rice production has declined only slightly over the averaged periods but has declined by about 25% from the peak reached in the mid to late 1980s. Hong et al. (2001) describe several factors that may have contributed to sustained rice production including:

– economic and institutional reforms initiated in 1978,
– -a shift in cropping pattern from two to one crop of rice,
– -on-farm and system WSI practices, such as AWD,
– -volumetric pricing of water,
– -development of alternate sources of water such as small reservoirs and groundwater,
– -recapture and reuse of return flows through the network of reservoirs.

The various changes that occurred are not independent of each other, and more research is needed to identify more precisely the contribution of each of these factors. According to Hong et al. (2001) more than half of the increase in water productivity in ZID can be explained by the increase in yield. But a substantial amount of the gain in water productivity remains to be explained by other factors. AWD practices may be one of the reasons behind the increase in water productivity in ZIS over time. Many farmers have adopted some form of AWD in ZIS (Moya et al. 2001) and the adoption of AWD practices had no effect on yields and reduced the water use at least at the farm scale (Cabangon et al. 2001; Moya et al. 2001; Belder et al. 2004).

Long-term trends in Kaifeng City Prefecture

This section presents the analysis of long-term trends in water use, crop production, and irrigation water produc-

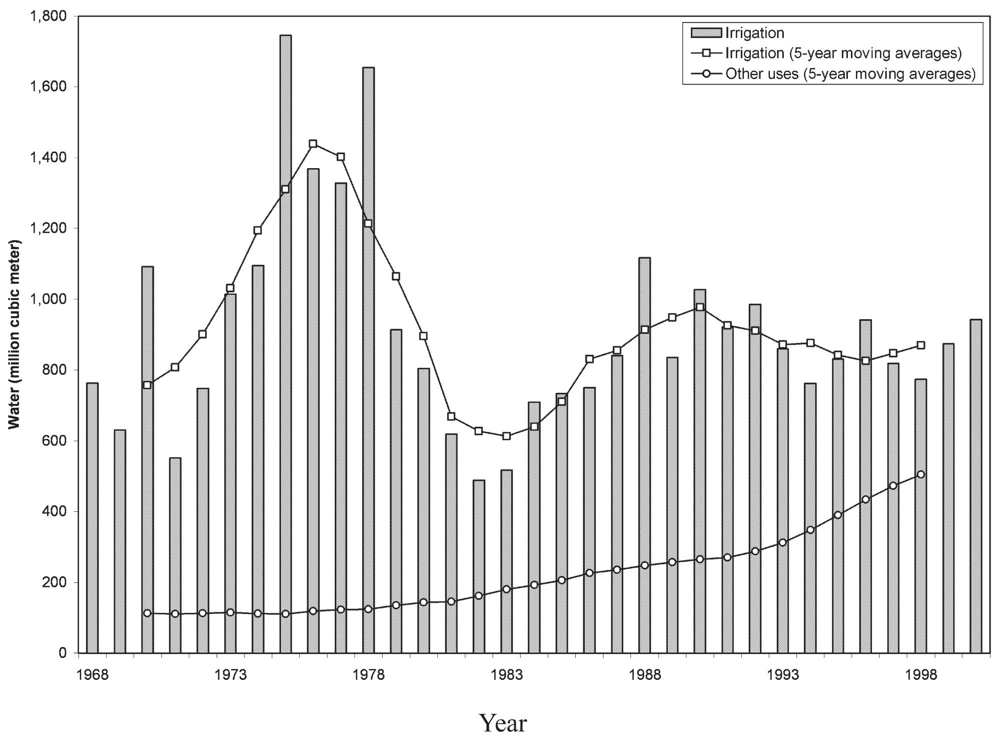

Fig. 3 Water allocation for irrigation and other uses (municipal, industry and livestock) in Kaifeng City Prefecture, Henan, China, 1968–2000

tivity for the Kaifeng City Prefecture and concludes with a discussion of the factors contributing to the increase in crop production and water productivity.

Water allocation among alternative uses

During the past 30 years, industrial, municipal, and livestock sectors have captured a larger share of the total water use in Kaifeng City Prefecture (Fig. 3), with their share rising from 13% in 1968 to 37% in 2000 (Table 5). The biggest increase came from industries, which in 1968 only used about 6% of the total water, but in 2000 had increased their share to 27%. The percentage of water use for agriculture correspondingly decreased from 87% in 1968 to 63% in 2000.

In the late 1970s there was a sharp decline in agricultural water use (Fig. 3), due mainly to a reduction in Yellow River diversions. A similar trend, although less obvious can be seen for the Yellow River diversion for Henan Province as presented by Dong et al. (2003) and in Liuyuankou Irrigation System (Loeve et al. 2003).

Groundwater extraction by all sectors increased from 151 million m^3 in 1968 to 1,153 million m^3 in 2000 (Table 6). In the last 5 years, more than 75% of the total water use in Kaifeng City Prefecture came from groundwater. This increase in groundwater use has allowed municipal and industrial demand to be met without cuts in supplies for agriculture. The share of total groundwater extraction used for the municipal and industrial sector increased from less than 5% in the first two periods to 35% in 2000 and increased rapidly in the 1990s (Table 6). It is not clear for how much longer this trend is sustainable. Current research shows already a deep cone of depression in groundwater levels under Kaifeng city urban area, which might affect groundwater levels in rural areas.

Average total water use in the last decade is at the same level as in the period 1968–78. However the Yellow River diversions dropped from 943 million m^3 in 1968–1978 to 392 million m^3 in the last decade, with a continuing downward trend. Whereas in the 1968–1978 period 77% of the total water use came directly from the Yellow River, in 1989–2000 this was reduced to less than one-third.

Changes in cropped area

Table 7 shows the planted area of major crops on Kaifeng City Prefecture and average annual growth rates (3-year moving average). The average annual growth rates were calculated with the 3-year moving average data series to eliminate major fluctuations per year, which are not representative for the period concerned.

Among the summer crops corn was historically the most important. Since the economic reforms, however, the area planted to cotton and peanut has expanded at the

Table 5 Water use by sector Kaifeng City Prefecture (1968–2000)

	Average water use in million cubic meters				
	Irrigation	Municipal	Industry	Livestock	Total non-irrigation
1968–1978	1,090	44	52	18	114
1979–1988	749	54	109	22	186
1989–2000	881	68	273	44	384

Table 6 Water use by source Kaifeng City Prefecture (1968–2000)

	Average water use in million cubic meters					
	Total	Total YRWD	Total groundwater	Groundwater for industry	Total for M&I	YRWD for M&I
1968–1978	1,205	943	262	10	96	42
1979–1988	935	505	430	31	164	79
1989–2000	1,265	392	873	208	341	64

YRWD: Yellow River water diversion

Table 7 Area of major crops, 1968–98, Kaifeng City Prefecture, with annual average growth rates in selected periods

	Area in 1000 ha					
	Wheat	Corn	Soybean	Cotton	Peanut	Rice
1968–1978	193	54	41	26	20	7
1979–1988	240	82	55	70	47	6
1989–1998	289	75	30	97	78	7
Annual growth 1968–78 (%)[1]	1.3	21.0	–5.0	3.8	–3.5	0.8
Annual growth 1979–88 (%)[1]	3.7	–3.1	0.4	13.0	10.7	–7.5
Annual growth 1989–98 (%)[1]	0.6	–0.7	–4.6	0.0	1.4	9.1

[1] Annual average growth rates (3-year moving average)

expense of food crops like corn and soybean. The wheat area in Kaifeng City Prefecture increased rapidly after the reforms, and most of the expansion had occurred by 1985. The reduction in rice area during 1979–88 coincides with the reduced Yellow River water diversions in this period. The same trend was observed in Liuyuankou Irrigation System and is explained by deteriorated structures and lack of canal maintenance which forced the system management to reduce diversions to avoid further damage to canals and reduce danger of breaches (Loeve et al. 2003). Heavy investment in infrastructure improved the water availability and around 1988 the trend reversed and the rice area increased.

Changes in crop production

Table 8 shows the production of major crops in Kaifeng City Prefecture and average annual growth rates (3-year moving average). As in China in general, yields increased rapidly in the past 20 years. Most of the yield growth occurred in the first few years after the reforms, but yields continued to increase after 1985.

The increase in production of wheat, corn and soybean in the period 1989–98 can be attributed to the increase in yield. For peanuts both the increase in planted area and higher yields resulted in a tremendous increase in crop production. The increase in production of all crops, except rice, in the period 1989–98 can be attributed to the increase in yield. For rice the increase in planted area was the main factor for higher production.

Without detailed information about water use per crop in Kaifeng City Prefecture, it is impossible to calculate the water productivity per crop. However a more general idea about the water productivity trend over time can be established.

At the end of the 1970s agricultural water use declined sharply, primarily due to reduced diversions from the Yellow River. One major reason for this decline in water use was that large amounts of Yellow River water (and its associated sediment) were diverted for land reclamation from 1973–1978. Once this strategy ended, water use declined sharply. This suggests that there were improvements in water productivity (in terms of planted area per unit water utilized) in the first few years after reforms. During 1989–1998 agricultural water use was essentially constant in Kaifeng City Prefecture, as was crop area. Crop production has increased, but can be attributed entirely to increased yields per unit area. Thus, any gains in water productivity in this period are most likely due to improved varieties and increased use of inputs such as fertilizer, not improved water management techniques.

Table 9 shows the agricultural production value of the main crops in Chinese Yuan or Renminbi (RMB) in Kaifeng City Prefecture. Because many different crops are grown in Kaifeng, production must be converted to value before adding. However, because the data cover a long period of time, the value of production would have increased substantially due only to general inflation in the economy, and this clearly is not a "real" increase in water productivity. To correct for this problem, we valued production for each year at the same set of prices, the prices prevailing in 2001, which thus eliminates gains due

Table 8 Production, 1968–98, Kaifeng City Prefecture, with annual average growth rates in selected periods

	Production in 1,000 tons					
	Wheat	Corn	Soybean	Cotton	Peanut	Rice
1968–1978	233	86	34	8	11	21
1979–1988	754	241	65	51	67	21
1989–1998	1,139	386	55	87	208	42
Annual growth 1968–78 (%)[1]	10.7	21.8	–3.2	1.5	–0.8	6.0
Annual growth 1979–88 (%)[1]	10.2	3.3	2.8	21.2	19.4	–3.4
Annual growth 1989–98 (%)[1]	4.8	3.9	1.8	4.2	6.8	11.6

[1] Annual average growth rates (3-year moving average)

Table 9 Agricultural production value in Chinese Renminbi (RMB) and water productivity, 1968–98, Kaifeng City Prefecture, with annual average growth rates in selected periods

	Agricultural production value (main crops)[2]		$WP_{irrigation}$[2]	Agricultural production value (main crops)[3]		$WP_{irrigation}$[3]
	Million RMB[4]	RMB ha^{-1}	RMB m^{-3}	Million RMB[4]	RMB ha^{-1}	RMB m^{-3}
1968–1978	450	784	0.83	536	937	0.56
1979–1988	1,444	2,302	1.89	750	1207	1.05
1989–1998	2,386	3,554	2.74	869	1297	1.00
Annual growth 1968–78 (%)[1]	8.0	7.8	5.6	2.2	2.0	–2.7
Annual growth 1979–88 (%)[1]	10.1	8.5	6.6	3.4	1.9	4.5
Annual growth 1989–98 (%)[1]	4.9	4.3	4.4	0.5	0.0	2.5

[1] Annual average growth rates (3-year moving average)
[2] Prices of 2001
[3] Prices of 2001 and yield of 1978
[4] RMB100 equals about US$12

to inflation. If gains in production per unit area were not due to improved water management, the influence of these yield increases should be removed by assuming that yields throughout the period 1968 to 1998 were constant at the levels prevailing in 1978, just before the reforms began. After making both of these adjustments, an alternative measure of irrigation water productivity over time was calculated, changes in which are due primarily to improved water management that reduces the amount applied per unit area and shifts in cropping patterns (Table 9). Of course, it would better to gauge long-term trends in water productivity by using data on net returns after subtracting production costs, but no such data are available in this instance.

Table 9 clearly confirms that the agricultural production value increased tremendously over time and most of the gains came from the increased value per hectare. When corrected for yield increases the water productivity value remains fairly constant after the initial increase after the reforms. The increase in water productivity per unit of irrigation water is, however, impressive, although most of it cannot be attributed to improved water management techniques.

Factors contributing to the increase in crop production and water productivity

In Kaifeng City Prefecture long-term trends in water allocation across sectors and in production per hectare and per cubic meter of irrigation water supplied show a considerable increase in water productivity over time. However the data indicate that these gains have come from increased yields per unit area, not from reductions in water use due to water saving irrigation techniques. The reduction in Yellow River diversions over time is compensated for by an increase in groundwater extraction in Kaifeng City Prefecture. It is not clear how much longer this trend is sustainable.

A further reduction in Yellow River diversions to the different irrigation districts in Kaifeng City Prefecture will most likely affect the cropping pattern and might have a negative impact on the agricultural output. Different actions are already undertaken at irrigation district level to make the best possible use of the currently available water. In Liuyuankou Irrigation System drainage water flowing out of the rice growing areas is redirected to so called "recharge ditches", where it is used either to recharge the groundwater or pumped to the fields directly for irrigation. These kinds of practices will have a positive impact on the water productivity in the system and will influence the total water productivity in Kaifeng City Prefecture as a whole.

Conclusions

This paper examined the trends in water allocation among sectors, water use by source, cropped area and crop production and water productivity per unit irrigation water. In both study areas the water demand for purposes other than irrigation has grown. In the Zhanghe Irrigation District this resulted in a sharp reduction of the water availability for irrigation. In Kaifeng City Prefecture the increased demand from other uses were met by an increase in groundwater extraction without the dramatic cuts in supplies for agriculture as in ZID. However, it is not clear for how much longer this trend is sustainable.

In the Zhanghe Irrigation District several water saving practices have been adopted to maintain crop production. The yield per unit area doubled, but production per unit irrigation water supplied almost tripled between the periods 1966–78 and 1989–2001. There are many different factors that may have contributed to the increase in water productivity, including AWD practices, a changing cropping pattern, development of alternate water sources, volumetric pricing of water and the recapture and reuse of return flows through the network of reservoirs. The relative importance of the different factors contributing to increasing water productivity has yet to be determined and is a major scope for future research. A major objective of this research will be to identify those practices that could be successfully extended to other regions, both inside and outside China.

In Kaifeng City Prefecture agricultural production increased substantially following the economic reforms. At the end of the 1970s agricultural water use declined sharply, primarily due to reduced diversions from the Yellow River, which indicates increased water productivity per unit of land. In the last decade agricultural water use has been essentially constant as has agricultural crop area, but agricultural production has increased substantially. Data indicate that these gains have come from increased yields. Gains in irrigation water productivity in this period are most likely due to improved varieties and increased use of inputs such as fertilizer, not improved water management techniques. The increase in water productivity is, however, impressive, although most of it does not result from reductions in water use due to water saving irrigation techniques.

When interpreting water productivity per unit of irrigation, some caution is warranted, since it is highly dependent on rain. If a lot of rain occurs in one year, less irrigation water is required to achieve the same yield and irrigation water productivity increases. Although there is variability in the amount of rainfall per year, long-term climate data do not indicate a change in rainfall patterns in both study areas.

This study illustrates the different stages a basin will experience under pressure of increased competition of water. In the Zhanghe Irrigation District new fresh water sources, i.e. small reservoirs were already exploited and the scope for developing new water sources was limited, resulting in the introduction of water saving policies and practices. But there appears to be little scope for additional water savings and hence any further increase in allocation to non-agricultural uses is likely to result in further reduction in crop production. In Kaifeng City

Prefecture there was still an opportunity to exploit new water sources, i.e. groundwater, and up to now most of the water productivity increase has come from increased yields. However with an ever increasing competition for water and a limit to the exploitation of groundwater, water saving policies and practices will be needed in the future.

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